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Article

A Smart City Economy Supported by Service Level Agreements: A Conceptual Study into the Waste Management Domain

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Abstract: The full potential of smart cities is not yet realized, and opportunities continue to exist in relation to the business models which govern service provision in cities. In saying this, we make reference to the waste services made available by councils across cities in the United Kingdom (UK). In the UK, smart waste management (SWM) continues to exist as a service trialed across designated cities, and schemes are not yet universally deployed. This therefore exists as a business model which might be improved so that wider roll-out and uptake may be encouraged. In this paper, we present a proposal of how to revise SWM services through integrating the Internet service provider (ISP) into the relationship alongside home and business customers and the city council. The goal of this model is to give customers the opportunity for a more dynamic and flexible service. Furthermore, it will introduce benefits for all parties, in the sense of more satisfied home and business owners, ISPs with a larger customer base and greater profits, and city councils with optimized expenses. We propose that this is achieved using personalized and flexible SLAs. A proof-of-concept model is presented in this paper, through which we demonstrate that the cost to customers can be optimized when they interact with the SWM scheme in the recommended ways.

Keywords: service level agreement (SLA); smart waste management (SWM)

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1. Introduction

A smart city is comprised of smart people, a smart economy, smart mobility, smart environments, smart living, and smart governance [1]. Within the context of the work presented in this paper, we consider these aspects of "smartness" to refer to people or processes that are components of the smart city infrastructure. While primary attention is often given to the technical resources and services within a smart city, there is an opportunity to realize that smart people are also critical components [1]. In the context of our definition, a smart person is someone who engages with and potentially contributes to smart city processes. We consider smart people to be resources which can be exploited for the benefit of all and, equally, which need to be managed. As an example, consider a citizen in an autonomous vehicle driving around a city—in the future, it may be possible that memory resources onboard the car can be pooled for short-term dynamic use by others in the local area. This is therefore a citizen-centric resource which can be both exploited and which needs to be managed. Citizens, and their devices, in smart cities therefore have the potential to be useful resources, and harnessing their capabilities can encourage participation in services so that the city can grow as a business entity. A business entity in this context refers to one which stakeholders can benefit from due to the way that the city is operated, and primarily with a focus on the financial implications of operating the city in this way.

Taking this notion of citizens as resources of smart cities further, we can distinguish between the citizens who are more likely and less likely to participate in the technology to understand how they might be harnessed for use, in addition to their need to be managed. To do so, we might characterize a city's citizens from a number of perspectives, which can include their location in relation to a city center, the number of people they live with, and their level of education—this type of information builds a profile surrounding citizens, and are details which can indicate their likelihood of participating in smart city technology. Assumptions which we make in this respect are based on research published by Caci in The Acorn Guide [2]. Pooling this detail can also help to understand the effectiveness and indeed desirability of a business model. A positive cost–benefit balance is clearly an essential attribute of an effective business model.

In realizing that there are indicators which can influence the ways in which smart city services are embraced, and therefore the success of smart city business models, we are able to conclude that if online services are less accessible to some members of society, perhaps due to the financial or technical abilities needed to establish a service, this business model does not promote accessibility to and subsequent use of the services by all members of society. By profiling the characteristics of citizens, however, we can use this detail to influence the way that smart city business models are defined. The Office for National Statistics identified in August 2020 that 18% of adults in Great Britain used internet-connected energy or lighting controls [3]. A business model which therefore recognizes that there is an aspect which is preventing the majority from participating can therefore help to improve the rate of uptake of this application.

We therefore argue that this awareness drives a need for services to be offered in new ways, and that service provision should take into account considerations for both the physical service accessibility in addition to their economic accessibility. Online services which are currently made available by ISPs on a free basis do not offer guarantees with regard to their quality, and are therefore unable to be entirely relied upon. Paid services, on the other hand, offer a relatively inflexible level of service through a contract to which a customer is committed for a defined period of time. In revisiting the ways that services are made available in smart cities, we believe there is an opportunity to similarly recommend new business models for smart cities.

New business models might be considered to be financial opportunities in smart cities which have not been tapped into so far. Economies in the smart city from the perspective of waste management can be considered from multiple angles:

- *Home and business citizens* can benefit from more effective waste collection schedules, with the consequence of reduced visits to waste collection sites outside scheduled collection times.
- The finances available to *city councils* can benefit from the use of more cost-effective routes for waste collection around cities, and subsequent positive environmental impacts from CO_2 emission reduction. The city council may also benefit financially from reduction in fly tipping, both in terms of the collection vehicle cost to collect the waste and the human cost of both physically collecting the waste and monitoring and responding to reports of fly tipping.
- From the perspective of *ISPs*, they can benefit from the integration of customers who would not otherwise be internet users, or who were previously with other ISPs who are not providing the service(s) desired. Supporting smart waste management (SWM) services also opens the opportunity of gathering waste data, which may be attractive to other citizens and councils to become familiar with the ways in which smart waste management may be offered and the effectiveness of these contrasting approaches.
- Transparency and standardization of the smart city ecosystem is essential for the two-way information exchange among the business, city council and customers. Transparency can be introduced by using technologies such as distributed ledger technology (DLT) which will expand the horizon and enhance the efficiency of the city council by keeping all assets traceable in a tamper-proof information system. This

will also add a level of security by giving specific actors in the waste management system access levels to various data shared across the waste management domain. For example, actor A in a waste management scenario cannot access a section of the data posted by actor B and C in the waste management system but actor B can access all sections of data of actor A completely, but not actor C. DLT solutions like IOTA can provide such functionality as demonstrated by the authors of [4]. This upholds and enforces the General Data protection Law (GDPR) within the waste management ecosystem. Standardization can be introduced by having an agreement for knowledge and process sharing among all smart waste management participating partners as well as other city councils for best practices. This way one standard can be practiced throughout the ecosystem rather than other city councils working in silos without any well-defined benchmark. This will keep the entire business management layer of the smart city waste management consistent throughout the ecosystem as well as result in a well-structured business model development for the future. The overarching idea being to utilize the best business model practices from all the smart cities all over the world and combine them to form the foundation or the base standard for everyone.

The work presented in this paper is therefore driven by a realization of the beneficiaries and diverse relationships between entities existing in smart cities. Such a scenario realizes the perspective of Ruhlandt (2018) [5] regarding the multifaceted IoT ecosystem complexity, with each player in the ecosystem having their own objective. Specific to SWM, a homeowner might only be concerned about needing to know if their bin needs to be placed in a location for emptying, and not the fact of the waste in their bin being able to be merged with a neighbor's bin for a more efficient collection process. A city council might only care about ensuring that all bins in a region are collected according to the weekly schedule, regardless of the impact on the environment of doing so. Assuming a potential situation of big data and a cloud management strategy to optimize its organization, an ISP might prioritize the availability of SWM data in their cloud repository by not archiving or deleting, which other customers can use to optimize the service provision in another part of the city, without caring about the efficiencies with which the bins were collected. From this perspective, there are few overlaps between the goals of each entity.

However, there is an opportunity to merge the goals so that the competing requirements are achieved in a way which recognizes and accommodates the needs of other stakeholders to achieve a service which is optimized for the needs of all in parallel. By taking a holistic view, opportunities for joint optimization exist which could lead not only to new services but also potentially greater efficiencies. Consider a scenario where we have a smart city offering SWM. An ISP will offer a service level agreement (SLA) to a homeowner for an online connection. It may be the case in the future that the SLA will be more personalized to the user, however, at present, the basic service which offers 99.9% uptime may not meet a customer's needs, in that they may not need this level of service and might appreciate the cost–benefits of a revised, less comprehensive, service. However, ISPs do not offer the option of such services.

We therefore recommend a revision to the way in which the ISP business model operates in this paper, with a focus on the SWM domain. A home or business owner might wish to avail of a SWM service in the smart city. Making reference to Figure 1, this service could be facilitated by the city council (A), yet the homeowner is dependent on a service with the ISP to support it (B). For participating in SWM, a home may be rewarded by the city council (C), yet the homeowner will be relying on the ISP to ensure a connected service is available to them so that these benefits may be achieved (D). In this model, there is an opportunity for revised business models from ISPs to support such an operational scenario between both the city council and the home/business owner with the objective of maximizing the benefits for all stakeholders involved.

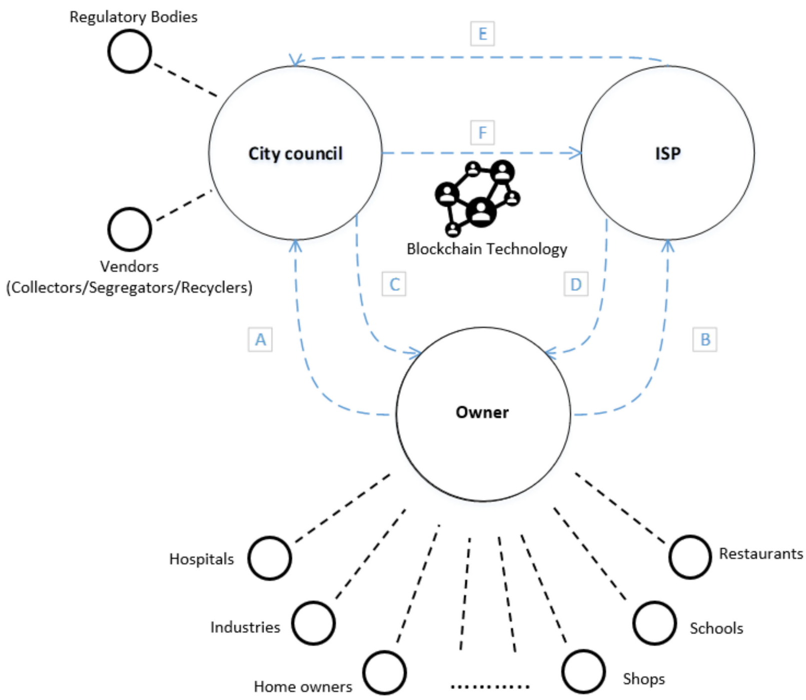

Figure 1. Relationship between entities in proposed business model.

We propose that this model can accommodate the requirements of a range of users, which may include homeowners, or private or semi-private or government institutions such as schools. A homeowner, for example, will be able to use the SWM service which the city council is facilitating even if they do not have a relationship with an ISP. This is important—some citizens are not technically capable of setting up and maintaining a service. Others may be financially unable to do so based on the service offerings which are available to date.

There is therefore an opportunity that the roles and relationships are modified to exploit the benefits for all. The relationship between the ISP and the council can instead be considered from the perspective that the ISP could be reimbursed by the council for the service that they are providing to the council (F) and citizen involvement in it. For example, the service offered by the ISP to the city council could be influenced by the number of customers participating in the SWM program who were not customers originally, and the number of customers making their datasets which comprise their SWM sensor readings publicly available. The ISP will make available to the city council a certain amount of storage space, number of messages which can be sent to the storage space daily, and the number of rules which might be applied on the data storage. The city council will pay the ISP for this service. Home and business owners could be rewarded in their use of the SWM service made available by the council through a tax reduction for their participation. We propose that this service is supported by the SLA made available by the ISP. This will explicitly communicate the nature of the service to all parties involved. The relationships between stakeholders and the role played by each are considered in more detail later in the paper. We argue in our proposal that a council will be associated with a specific SP, as a relationship in our business model proposal; however, we will examine the possibility of a business model that is not restricted to a specific SP as part of our future work. Supporting the model proposed is the collection of context information from customers who are benefiting from the SWM service. One role which is played by the SP in support of the process is in the retention of this context within their cloud capacity. Furthermore, the council will negotiate the price with the SP in an attempt to provision a business model which is effective in the service it provides and in the financial business model for all parties involved. While we appreciate the value of not restricting the SP used in the model, we posit in this work that the business model is positively influenced through the interactions possible between the council and a specific SP. It is the goal that the cost of paying for the cloud service, in addition to the reductions in council tax, exceed the costs which are incurred as a result of not applying the scheme. We believe that we contribute a new and innovative service level agreement provisioning process for SWM homeowner customers in smart cities. In [6], it is identified that there is a lack of stakeholder cooperation to encourage SWM. Our previous research indicates that there is citizen interest in this capability, but that there is a general lack of awareness and understanding about what it involves and what capability it can provide homeowners with. We have therefore focused our work with this understanding in mind.

Given the variety of actors involved in the provision of smart city solutions, it is important to ensure that a clear vision of what is being attempted is agreed in an investment agenda [7]. The "*Economic Basis for Functioning of a Smart City*" [8] considers that smart cities demand new business models, new services to serve households, and the offer of new products. It is their opinion that smart cities continue to exist as an idea, a concept which is not yet fully realized. They observe that the social intelligence of the city is gradually enabling a new economic perspective in smart cities, which can drive changes in the city's economy. They also identify that there are opportunities for citizens to be involved in community activity. Their work relates closely to our proposal in this paper, in that we agree with the notion that community activity can be encouraged through the new services rolled out, and we agree that human intelligence can facilitate the new economic perspectives. Furthermore, community efforts in association with the service can lead to further positive impact for individual citizens. We might consider these to evolve through new approaches to the SLA provisioning process, with the SLA facilitating a customer's use of the new product/service. The benefits achieved from doing so can be further evidenced if the citizens work together in a collaborative effort with one another.

In a "*Smart Waste Management Solution Geared Towards Citizens*" [9], the authors propose an approach to capture context data from citizens' bins so that they may provide an optimized waste management solution by acting on the real-time waste management situation across a city. This is somewhat similar to our work in this paper, with our work differing in that we collect citizen context with the objective of provisioning the SLA and after that, to manage the network such that the SLA continues to be fulfilled. Optimization of the waste management process to a certain extent will influence our SLA; however, our proposal does not involve the design of efficient waste collection routes, for example, as in [6].

Few studies have been identified as addressing the associated business model to support a smart city ecosystem [10]. In "*Business Models for Developing Smart Cities*" [11], the authors consider the challenge of creating new business models from technology. They examine the extent to which multiple business models can co-exist within technology platforms. This takes into account how generic the business model is so that it may be applied to different domains. We recognize and identify with this challenge in the smart city IoT, given the range of applications found here, in addition to the ones which might evolve in the future. In our approach to defining a new business model, we focus primarily on the smart waste management domain, without attempt to make it generic to meet the needs of other domains. However, one of the features of our SLA provisioning mechanism is that it is generic and can be applied across domains—this work is presented in more detail in [12].

It is the intention that the SLA provisioning and management process presented in this paper will contribute to the smart city economy: through expanding the ways in which services are made available and the types of services that are provisioned, the aim is to open the accessibility of smart city services to groups who might otherwise be marginalized from participating, with a longer-term benefit to all stakeholders involved in this process. The revised business model is presented in Section 3, alongside a proof-of-concept of its benefits to home and business owners.

The remainder of the paper is organized as follows: In Section 2, we present a materials and methods section, which includes a literature review of the state-of-the-art contributions made to smart waste management. Our proposed business model for the smart city domain is also presented in Section 2, in which the revised relationships between bodies operating in smart cities are outlined. This includes a consideration of the decision-making process using which entities interact with one another to achieve the SWM function, in addition to a proof-of-concept which verifies the positive impact that can be achieved through the relationships proposed. The proposed improved scenario is considered in Section 3, and finally, the paper concludes and considers further work in Section 4.

2. Materials and Methods

In this paper, we examine the costs and benefits to customers who have opted in to the SWM scheme in a conceptual and theoretical way. As opposed to selecting specific case studies of SWM deployments, we instead profile the maximum and minimum cost-benefit impacts when homeowners participate with the SWM schemes using the variety of configurations available. We focus on SWM schemes which we have defined and consider to be applicable to homeowners in this paper, as opposed to additionally examining the needs of business owners. We appreciate that waste management for businesses is more likely to operate on a larger scale, and that a contrasting set of parameters will be applicable for business customers. We therefore do not accommodate this aspect of the investigation here. When a homeowner customer participates in the SWM scheme, a cost–benefit impact is realized through a reduction in the amount of council tax which a homeowner is liable to pay—a customer in this market will therefore either pay 100% of their council tax (not participating in SWM), or they will receive a % of a rebate (participating in SWM). The extent to which a customer is rewarded for participating in SWM depends on the specific configuration of their service and their activity within the scheme.

The research makes an assumption that smart bin technology will be available for all who wish to participate in the scheme. We do not anticipate that bin sensors need to be deployed on all homeowner bins, and only on the bins of homes which wish to participate in the scheme. Route optimization is not a component of our current work—in this paper, our focus is the definition of a service level agreement and the supporting process, for customers participating in SWM in a smart city. We recognize, however, that an efficient waste collection strategy is an important component of recovering the costs involved in deploying a SWM scheme, and to respond to this, we plan to explore an intelligent route optimization process as part of the next phase of our SWM research program.

2.1. Proposed Business Model

We encourage that the service offered to a citizen prioritizes people in the decisions made, in comparison to offering a more basic type of tiered service which might be assumed to respond to the needs of all citizens in a more generic way. This takes into account citizen desire for flexibility in their SLA in the sense of not being tied into a fixed-duration contract and consideration of the personal characteristics of people within households, which can impact service usage. In Section 2, Figure 2 is discussed in more detail, with consideration of the relationships between players in the SWM business model.

2.2. Relationships and Interactions between Participants in the SWM Business Model

The proposed SWM business model is based on the principle of a multi-way relationship between the:

(1) homeowner/business and service provider,
(2) homeowner/business and city council, and
(3) council and service provider (Figure 1).

A relationship will initially be established between a city council and an ISP, and support of the SWM process will first be negotiated between these parties. The SLA which supports SWM will be provided to the homeowner/business by the ISP on behalf of the council. The council will pay for the SP's services to the homeowner/business, in the sense of connecting the bin sensor to the cloud repository, where the collected sensor data will be retained, processed, and managed.

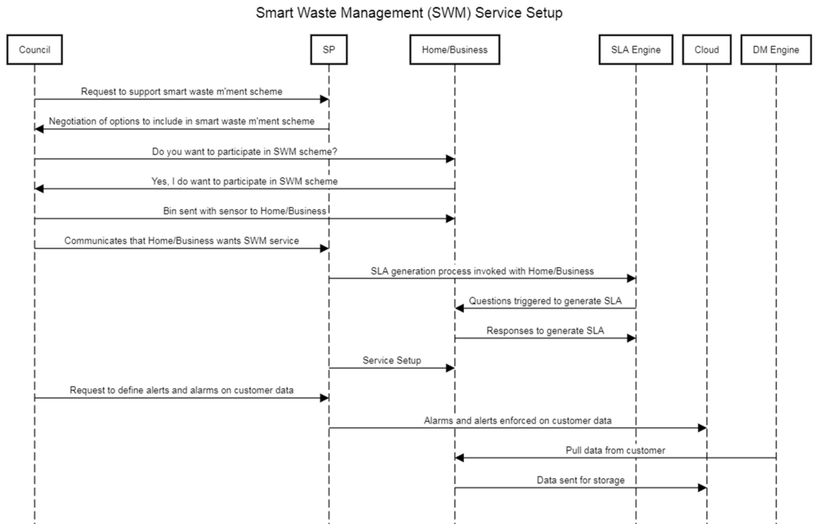

Figure 2. Smart waste management service setup process.

In this model, as is common practice in the United Kingdom, we make an assumption that a home/business owner has a contract with the council and pays a tax in response for services received. We extend this relationship such that the council will also have a contract with an ISP. The council offers home/business owners service credits for participating in SWM. The SLA exists between the council and home/business owner from the perspective of the SWM offered. In this model, we assume a connection between the bin sensor and the home/business WiFi over WiFi.

Interactions between the entities participating in this model are considered in Figure 2, in relation to the time that will be accrued in this process. To explain these in more detail: The council will request that a service provider (SP) supports operation of this scheme. The options involved in the scheme will subsequently be negotiated between the council and ISP. These include the amount of storage space which will potentially be required, and the amount of processing which this data will be exposed to (for example, number of rules run against it and duration of data retention). The level of service being delivered will subsequently be communicated from the ISP to the city council for a specified charge. Once negotiated, the city council will begin their interaction with a home or business owner to inquire if they wish to participate in the SWM scheme. If they decide that they wish to join the scheme, action will be taken to ensure that a bin with a sensor is available at the home, and that it is compatible with the wider smart waste management technology being used. An individual SLA will then be established between the home and the ISP from the perspective of the resources needed but not any costs; the steps executed to assign the SLA for a homeowner are presented in more detail in Section 3.1. The SLA assignment will be determined based on aspects such as a customer's desire to schedule their bin collection frequency, which may be more or less frequent than the scheduled collection, or the public availability of the sensor data that has been collected from their bin. Each of these configurations will have an impact on the resource assignments allocated for a customer and subsequently the city council, in addition to a homeowner's council tax reduction. The homeowner's needs will then next be communicated from the ISP to the city council. The charge for the service will be agreed between the city council and the ISP, and paid for by the council; the council will recover their costs through the improved efficiency of the smart waste management scheme on offer.

To support the running of this mechanism, we make an assumption that a service provider's cloud will be responsible for running a SLA engine and providing data management (DM) capability through a DM engine. When a smart bin is available at the home or business site, the council will communicate with the service provider that the SLA generation process can be initiated. At this point, the SP initiates that the SLA engine begins its interactions with the home/business so that the SWM SLA may be defined for the customer. Responses will be returned to the SLA engine, and the SLA recommendation will be made. The service will then be set up between a SP and a home/business. Implementation costs will involve the cost of a sensor, one or more bins for each type of waste being collected, technology on waste collectors to guide the collection route, and cloud space to retain context collected which will influence the waste collection process.

As this study is currently in its research phase, the actual product and implementation cost is beyond the scope of this paper at this stage. However, after initial investigation, we found that the proposed system can be implemented in two ways: (a) use existing over-the-shelf waste sensors for data collection and (b) develop and implement an indigenous product. Many companies working in the waste-management domain have developed waste sensors and they are available on the market; a few examples can be found in [13–16]. The sensor per unit cost is in the range of GBP 150 to 300, and some provide their products on lease i.e., per sensor per month rent basis. Exploring the latter option, we can develop and implement an indigenous product in a cost-effective manner using ultrasonic sensor and IoT development boards. Our pilot analysis indicates that the actual product and implementation cost of the proposed system is in the range of GBP 9550 to 13,055, considering only the capital cost (operational cost is ignored at the moment), which may vary slightly, subject to availability and procurement of the system's components or design changes during implementation. Brief details of the various components of the proposed system, including hardware and software costs, are given in Table 1.

Once customers have subscribed to the service, the council is in a position to define, with the ISP, the rules which should be applied to the collected data, and alarms so that the council gets maximum utility from it. The system finally moves into a state of being operational and monitoring will be initiated to ensure that the service being delivered is fulfilling the customer's agreed service level.

To explain the impact of the scoring mechanism on the council tax charged to a customer: Customers who are not participating in this scheme will be charged the full council tax, while customers who are participating in SWM will benefit from a cost deduction. The extent of the deduction will depend on the way which the customer chooses to interact with the service. The reduction is greatest for those who are most flexible in how their waste collection service is provided and who exploit all opportunities for its optimization. The scoring mechanism is contextualized in more detail in Figure 3 (first phase) and Figure 4 (second phase), with the process finalizing in Figure 5, specific for homeowners—the questions used to generate the scores and SLAs for businesses will vary from those applicable to homeowners. We see the homeowner service setup as being the option with greatest opportunity for personalized configurations, and therefore focus on this scenario here for that reason. Once a customer indicates that they wish to participate in the smart waste management scheme, they are asked if their SWM will involve changing their bin collection frequency on demand. This is asked on the basis that those who are more flexible in the frequency of collection will be rewarded more highly. We believe that on demand scheduling can contribute to the efficiency of bin collection processes—there is a body of research on efficient techniques to design a bin collection route based on need for collection, as opposed to a weekly scheduling approach e.g., [17,18]. This can be based on the sensed fill level of bins. However, customers may also explicitly decide that, based on what they know their waste activities will be in the coming weeks, whether they need their bin to be emptied or not. A customer will subsequently be assigned a score depending on whether they wish their bin to be collected more or less frequently on demand than the default rate of scheduling.

Table 1. Estimated costs of proposed system components—hardware and software.

System Component		**Particulars**	**Costs**		**Remarks**
			Capital	**Operational** -	
Hardware	Sensors	Sensoneo Single Sensor [13] Enevo-bin-sensor [14] SAYME Dumpster RCZ1 [15] IoTsens waste sensor [16] Ultrasonic Sensor HC-SR04	£150–£300 per unit £10 per 5 units		Operational costs include regular testing and replacements
	IoT Device	Arduino UNO ATmega328 Microcontroller	£23–£30	-	Operational costs include regular testing and replacements
	Server	Machine: Dell PowerEdge T640 Processor Intel®Xeon® OS: Windows Server®2019 SSD: 600GB-1TB RAM: 16GB-128GB	£1500–£2700	-	Operational costs include period server maintenance and upgradation
	Networks	Tenda F9 Wi-Fi router TP-Link TL-W8961N Wi-Fi router Linksys E5400 Wi-Fi router	£20–£45 per unit	£20–£30 per month	Operational costs include fee to the service provider
Software	Installation	Sensor installation in bins	£5–£10 per unit	-	-
	Sensing App	Development of app for sensing module	£500–£1000	-	-
	Web Server	Development of server for data analysis	£5000–£6000	-	-
	Mobile App	Development of mobile app for waste collection staff	£1500–£2000	-	-
	Configuration	System installation, configuration and setup	£500–£1000	-	-
	Training	Training for council staff	£500–£1000	-	Ten hours training program to learn how to use system

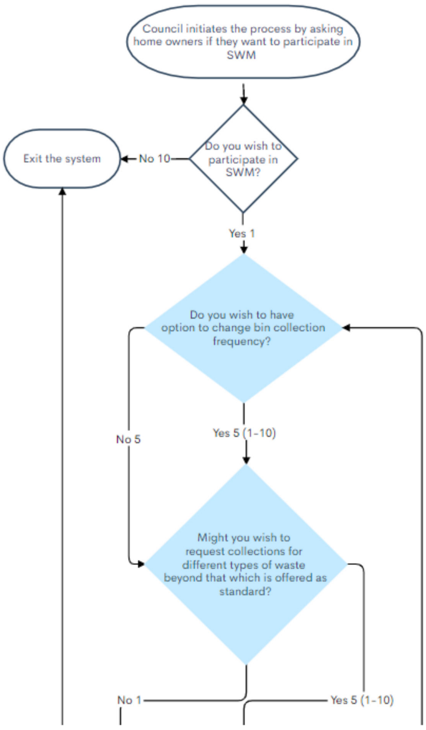

Figure 3. First phase of scoring a customer for SWM.

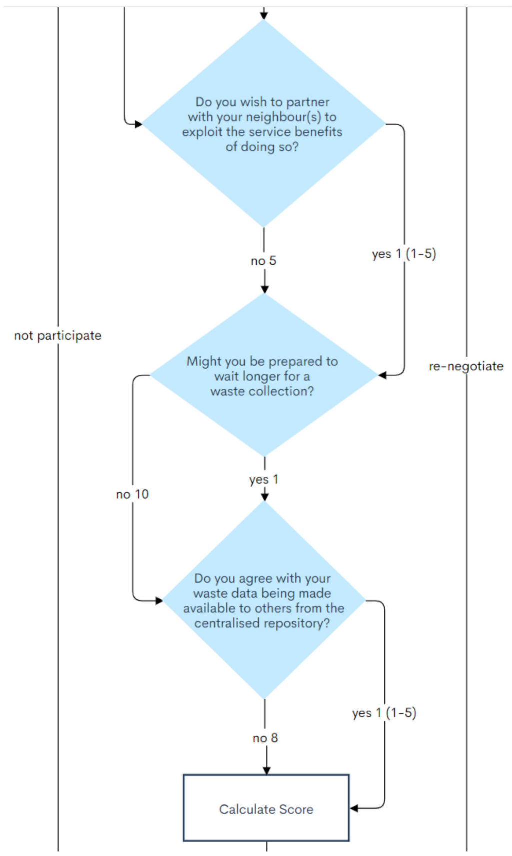

Figure 4. Second phase of scoring a customer for SWM.

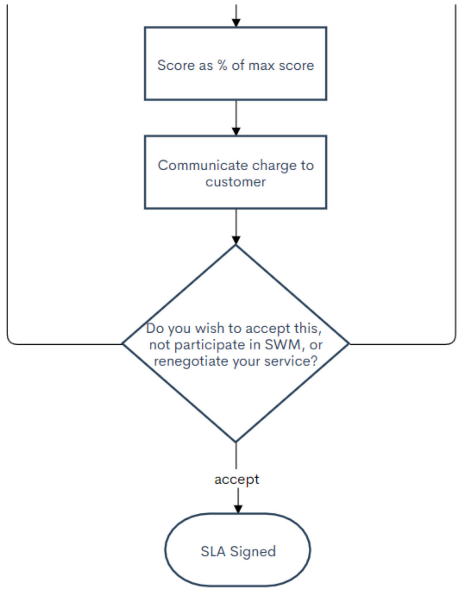

Figure 5. Third phase of assigning a customer SLA.

3. Results

3.1. Establishing the Conditions of the Customer's SLA

The first part of the SLA assignment process is presented in Figure 3.

If a customer indicates that they wish to participate in SWM and they do not wish to adapt their bin collection frequency, they will receive a score of 5. The customer is not assigned the lowest possible score of 1 as they are not indicating that a reduced collection frequency will be acceptable to them, and they are not assigned the highest possible score of 10 as they are not requesting that their waste is collected more frequently. A customer who wants to participate in adapting their collection frequency will initially be assigned a score of 5, with the option of being assigned a score of 1 to 10, depending on how they apply this option. In reality, it is possible they will request a more frequent collection, in which case they will receive a score of 10—their more intensive collection request will be reflected in the extent of the reduction in their council tax. On the other hand, they may request a less frequent service and will be rewarded with a score of 1—these customers will receive a greater reduction in their tax.

A customer is then asked about their desire for possible scheduled collection of different types of waste. This refers to being able to schedule the collection of different types of waste. A higher score is given for those who are opting for the collection of different types of waste: As there is a higher cost to the council of provisioning this service, so we expect that this must be compensated for in the cost which is recompensed by a customer. A customer who wishes to participate in SWM but does not wish to use this service will receive the lowest score of 1, as they are not making any additional demands on their service. A customer who indicates that they do wish to participate in this service will be assigned a score of 5 initially, and once their pattern of collections can be observed, this will either be increased to 10, if they are scheduling different types of collections, or reduced to 1 if they do not request different collection types in practice. While a customer is scored more highly for having more types of waste, we agree that citizens should be encouraged to use selective waste collection, which is the reason that we advocate this aspect of the service. To protect the interests of all parties, customers need to pay for the service they are receiving. This selective waste collection is intended to go beyond the waste collection services that are typically offered—for those who indicate "No" in response to this question, their service will run as it normally would, which may still involve more than one bin depending on the current practices of their local council, and having paper, glass, and plastic being separated.

The second phase of this scoring process is defined in Figure 4.

A customer is next asked if they want to work with their neighbor(s) to organize their waste management; this could involve, for example, neighbors sharing a bin. A customer who does not want to participate in this will be scored 5. A customer who chooses to participate in this, on the other hand, will receive a score of 1 initially, which may be raised to 5 after a period of monitoring if they do not, in practice, work with their neighbor. A customer will be asked if they are prepared to wait longer for a waste collection. In the event that they are, they are scored 1, otherwise are scored 10. Finally, a customer is asked if they agree to their data being made publicly available through the centralized repository in anonymized form. In agreeing to this, the customer effectively becomes a data producer and is rewarded for operating in this role with a score of 1; otherwise they are assigned a score of 5. If they do not agree to this, they will receive a score of 8. The scores have been selected so that they are proportionate with one another. A score of 8 has therefore been chosen in line with the other scores awarded, as will be described in the following sections.

At the end of this process, an overall score is calculated for a customer, which is applied against the annual council tax and communicated to the customer (Figure 5). If a customer agrees to this score, the SLA will be signed; otherwise the customer will have the option of renegotiating their score. As part of this process, customers will be presented with the configurable SLA options again, and informed of the impact of the different options on their overall score and subsequent tax.

Once the SLA moves into a state of being active, context data will be collected from bin sensors. The rate at which this is performed is dependent on the personal characteristics of the customer, such as the frequency with which their bin lid is opened and the rate at which the bin is filled. The definition of this aspect is beyond the scope of this paper and will be examined as part of our future work.

We have considered possible factors which may prevent this model from being successfully deployed in any city, the UK or beyond. The approach defined operates on an assumption that the actors who are involved in supporting this model (see Figure 2) are present in all smart cities where the scheme is used—council, service provider, home, and cloud. We recognize that the technical ability of homeowners may limit their ability to participate in the range of services available in smart cities and, for this reason, our prior work has focused on making the service setup process as autonomous as possible [12,19]. The scheme presented in this paper is therefore similarly written with an understanding of these principles in mind. Operation of the scheme is dependent on a homeowner's bin having a sensor which, we can assume, might be potentially vulnerable to theft. Ensuring a homeowner has a bin sensor will be the responsibility of the council and a need to replace the technology will have a detrimental impact on the cost effectiveness of the scheme. The ability for a homeowner to protect their bin sensor might therefore be a further aspect accommodated within the design of the model presented in this paper, however, the specific details will be considered as part of our future work and not here. Where the bin collection strategy is dynamic, in the sense that the days of collection each week are flexible, there is a need either for the homeowner to be informed that the bin should be placed in the correct position for collection, or that the waste collectors have permission to enter the property to retrieve the bin. Taking this work to the next stage may therefore involve consideration of how the service collection detail is communicated to a homeowner. Support of this model requires the bin collection strategy to be deployed in a manner which will allow the costs incurred to be recompensed. This will take into account the bin collection strategy, as one example, with a need to ensure that it is efficient to support both the customer and council needs. Definition of a supporting bin collection strategy is beyond the scope of the work presented in this paper, and will be examined as part of our future work.

3.2. SLA Scoring

To contextualize how the scoring mechanism is applied when determining a customer's SLA and their council tax bill (Table 2): A customer who is a non-participant of

SWM will pay 100% of their council tax, with a score of 39—this translates to receiving a 0% rebate. Specific to the investigation in this paper, we consider a customer's tax bill in relation to the various city services that it is responsible for contributing to i.e., fire service, police service, waste service; the discount which we propose in this work is specific to the charges for waste. This score is calculated by adding the scores that are awarded through the flow chart in Figures 3–5 when a customer does not agree to participate in any of the SWM options (10 + 5 + 1 + 5 + 10 + 8). An initial score of 10 is awarded for citizens who are not participating, while customers who indicate that they wish to participate are awarded a score of 1. For a citizen who is a full participant of SWM with a score of 14 (1 + 5 + 5 + 1 + 1 + 1), on the other hand, they will receive 100% of the rebate available. Achieving this score will mean that they have agreed to apply all aspects of the SWM scheme and can tolerate a fully flexible service. A customer who wants to participate in the scheme, by way of comparison, but who rejects, at least initially, all options for SWM will achieve a 23% rebate, with a score of 30 (1 + 5 + 1 + 5 + 10 + 8). In this model, we make an assumption that a council will set a maximum rebate available, in line with their costs and savings incurred, and participants of the SWM will earn a proportion of this depending on their activities.

Table 2. Default customer scoring.

SLA Options	Yes (Default)	Yes (Rejecting All Options)	No (Default)
	1	1	10
Change collection frequency	5	5	5
Request different collection types	5	1	1
Partner with neighbor(s)	1	5	5
Wait longer for collection	1	10	10
Make data available	1	8	8
Score	14	30	39
% of rebate earned	64.1	23.1	0

To explain how a score of 14 maps to 35.9 and a score of 30 to 76.9, this relates to an understanding that the maximum score that can be awarded in this scenario is 39. If 39 equates to 100%, then 14 maps to 35.9—100/39 = 2.56, and 14 × 2.56 = 14. Similarly, 30 × 2.56 = 76.9.

Citizens may also have scores between these maximum and minimum bands, depending on their configuration of the SWM options. The scores can also evolve over time. A customer might indicate that they wish to change the collection frequency, however, in practice they do not, or they change it in a way which is either more or less frequent than the default. Both of these situations need to be incorporated into the score, updated over time, and reflected in the service charge. The range of configurations possible are examined in more detail in Tables 3–7.

Table 3. Impact of adapting the bin collection frequency.

	Yes (Less Frequent)	Yes (More Frequent)
	1	1
Change collection frequency	1	10
Request different collection types	5	5
Partner with neighbor(s)	1	1
Wait longer for collection	1	1
Make data available	1	1
Score	10	19
% of rebate earned	74.4	51.3

Table 4. Impact of scheduling the collection of different types of waste.

	Yes (Different Waste)	No (No Different Waste)
	1	1
Change collection frequency	5	5
Request different collection types	10	1
Partner with neighbor(s)	1	1
Wait longer for collection	1	1
Make data available	1	1
Score	19	10
% of rebate earned	51.3	74.4

Table 5. Impact of organizing the waste collection with one or more neighbors.

	Yes (Partnered)	No (Not Partnered)
	1	1
Change collection frequency	5	5
Request different collection types	5	5
Partner with neighbor(s)	1	5
Wait longer for collection	1	1
Make data available	1	1
Score	14	18
% of rebate earned	64.1	53.8

Table 6. Impact of waiting longer for waste collection.

	Yes (Wait Longer)	No (Don't Wait Longer)
	1	1
Change collection frequency	5	5
Request different collection types	5	5
Partner with neighbor(s)	1	1
Wait longer for collection	1	5
Make data available	1	1
Score	14	18
% of rebate earned	64.1	53.8

Table 7. Impact of customer making collected waste data available.

	Yes (Make Data Available)	No (Don't Make Data Available)
	1	1
Change collection frequency	5	5
Request different collection types	5	5
Partner with neighbor(s)	1	1
Wait longer for collection	1	1
Make data available	1	8
Score	14	21
% of rebate earned	64.1	46.2

When a customer uses a less frequent bin collection rate, they will be scored 1, and if they request a more frequent collection rate, they will be scored 10. A customer is permitted to have their bin collected more frequently than the default rate, however, they will pay a price for doing so.

In having their bin collected at a less frequent rate, a customer's score is reduced from 14 to 10. If a customer requests that their bin is collected at a more frequent rate, their score will increase from 14 to 19.

A customer has the option of requesting that different types of waste are collected as part of their scheduled service, in a way which extends upon the services currently offered to deal with different types of waste. A customer will be scored more highly in the event that they wish to use this option, and will pay a price for using this extended service (Table 4).

A customer can partner with their neighbor(s) to optimize their waste collection process (Table 5).

In the event that a customer partners with a neighbor, they may share a bin, thereby helping to optimize the collection process. A citizen will receive a score of 1 for adopting this approach, or otherwise, receive a score of 5 for this category.

A customer may also be rewarded for waiting longer for a scheduled bin collection (Table 6).

Finally, a customer has the option of making their waste data available for public use in an anonymized form (Table 7).

The maximum and minimum scores which can be awarded when participating in SWM and either not embracing all options and being inflexible in the way they are applied (resulting in a maximum cost), or embracing all of the options and being fully flexible in the service (resulting in the minimum rebate) are considered in Table 8.

Table 8. Maximum and minimum possible scores when participating in SWM.

	Yes (Maximum)	Yes (Minimum)
	1	1
Change collection frequency	10	1
Request different collection types	10	1
Partner with neighbor(s)	5	1
Wait longer for collection	5	1
Make data available	5	1
Score	36	6
% of rebate earned	92.3	15.4

When participating in SWM according to the proposed business model, the maximum rebate that a customer will receive is 92.3% of the total available. With minimal participation, the customer can receive a rebate of up to 15.4%.

3.3. Cost Impact on System Stakeholders

To explore in more detail the notion of customers earning a percentage of a partial rebate on the waste management element of their council tax, we use the UK as a case study:

The average council tax bill per household in the UK is GBP 1818 [20]. Councils spend, on average, 25% of their tax revenues on waste collection and management [21]. We therefore claim that the average "Waste tax" paid per household is GBP 455. If we say that the maximum level of rebate that can be achieved is 20% of this (so up to GBP 91 rebate per household), we can determine the maximum cost to the council according to the percentage uptake of the SWM scheme. For a "standard" city size of 100,000 properties, a 0% update would result in no rebates, hence zero cost. On the other hand, if 100% of households engage, then the maximum cost to the council (in rebates) is GBP 9.1 m. This process is contextualized in Figure 6 and Table 9.

3.4. Examining the Cost–Benefit Impact on SWM Collection Services

On the basis of the defined model, we expand upon the evaluation to consider the impacts of the costs incurred, and the subsequent deficit that will need to be recovered in a profitable business model. In terms of the service set up between the council and ISP, this takes into account the number of customers participating in the SWM scheme. The number of participants in the program influences the number of alerts which need to be set on the sensor readings stored in the centralized repository, in addition to the amount of storage space needed. The city council will be charged by the ISP for the total storage space allocated, the maximum number of rules which can be run per customer on collected data, and the number of messages which can be transmitted by a customer per month. In our calculations, we make an assumption of 10 GB of storage space per customer, and 12 sensor readings and 5 rules per customer per day. On this basis, we assume a cost of GBP 5 per customer per month to the council. This results in a total monthly charge paid to the ISP by the council of GBP 500, assuming 100 customers. We also make an assumption of a council tax per household of GBP 1818 per year. As the basis of this model is that anyone participating in SWM receives a discount on their tax charge, a cost is incurred by the council if any citizens are involved in the program.

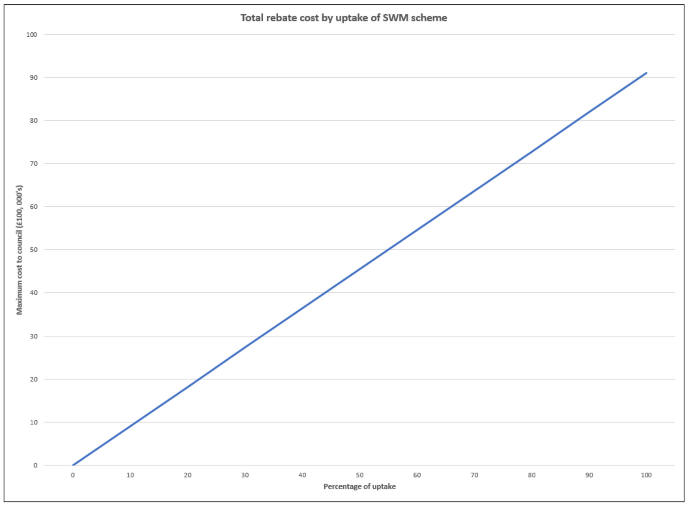

Figure 6. Total rebate cost by uptake of SWM scheme.

Table 9. Example scenarios capturing costs-benefits of SWM proposal.

Participating in SWM (%)	0	10	20	30	40	50	60	70	80	90	100
Not participating in SWM (%)	100	90	80	70	60	50	40	30	20	10	0
Avg. rebate per household (assuming max. engagement) (GBP)	0	9.1	18.2	27.3	36.4	45.5	54.6	63.7	72.8	81.9	91
Total rebate cost (GBP)	0	910 K	1820 K	2730 K	3640 K	4550 K	5460 K	6370 K	7280 K	8190 K	9100 K

Three exemplar scenarios are presented in Table 10 to contextualize the SWM costing process.

Table 10. Example scenarios capturing financial cost–benefits of SWM.

ID		Example Scenario 1	Example Scenario 2	Example Scenario 3
A	Number of customers participating in SWM	50	20	5000
B	Number of customers not participating in SWM	100	100	1000
C	ISP cost per customer (per month) (GBP)	5	5	5
D	Assumed tax bill per customer (per year) (GBP)	1818	1818	1818
E	Total possible council tax (per year) (GBP)	272,700	218,160	10,908,000
F	Max. possible council tax revenue per year (GBP)	262,707	214.163	9,908,769
G	Min. possible council tax revenue per year (GBP)	192,784	186,193	2,916,461
H	Best-case deficit (per year) (GBP)	9992	3996	999,230
I	Worst-case deficit (per year) (GBP)	79,915	31,966	7,991,538

The council tax revenue generated per year when SWM is applied is calculated according to the maximum and minimum costs of applying SWM, which are defined in Table 10. To recap, the maximum cost is incurred when a customer participates in SWM and either does not embrace all options and is inflexible in the way they are applied, or the minimum cost is incurred when the customer embraces all of the options and is fully flexible in the SWM service. With all costs of SWM, a customer will receive a rebate for 92.3% of the total tax charge; with least costs, a customer will receive a rebate of 15.4%. The deficit is therefore calculated by comparing the total possible council tax (E in Table 10) with the maximum (Table 10 row ID F) and minimum (Table 10 row ID G) possible council tax revenues per year when SWM is being applied.

In Scenario 2, when 20 customers participate and 100 customers do not, there is a cost to the council of approximately GBP 3996 per year. When the number of customers participating increases to 50 in Scenario 1, there is an annual cost to the council of approximately GBP 9992. When the scenario is scaled up to 5000 customers participating in comparison to 1000 customers not participating, there is a best-case deficit of GBP 999,230, and a worst-case deficit of GBP 7,991,538. The worst-case deficit is an increase of the best-case deficit by a factor of 7.99 in all scenarios when this business model is applied. It is our intention that this cost to the council will be offset by the benefits of SWM. These benefits, however, are more difficult to quantify precisely. Within this context, we consider the efficiencies that are achieved as a result of dynamically selected bin collection routes, reduced need of the council to respond to fly tipping, and fewer staff needed to support the collection process with fewer bins to collect through customers pairing up. In addition to this, we consider the cost of reduced carbon emissions through an optimized collection and waste management process.

4. Conclusions and Further Work

Smart cities which exploit IoT technology continue to exist as an ideology, as one that could bring great benefits but remaining as one that has not yet been thoroughly explored or deployed in any consistent way across cities. Roll-outs continue to take place in an ad hoc approach, plugging gaps in the technical landscape by the entities who are working most closely with them. The range and diversity of applications and their approach to provision makes it difficult to plug solutions in, in addition to it being difficult to roll technology out in a uniform way across different environments. There is a significant design challenge to provision technology for smart cities.

Coupled with this is the challenge of designing a profitable business model. We generally like our online activity to be free from additional cost, making it more difficult to encourage society to sign up where payment is required, and to achieve a positive return. We make an attempt at defining a business model for smart waste management in this paper, such that all parties who are involved in the process benefit.

The inclusion of the ISP in this business model, which involves the city council and homeowners, is unique—we have not observed a similar approach in the related literature. We wish to firmly position a case in this paper that the involvement of the ISP introduces a new relationship and a new business model to respond to smart city needs. We believe that the ISP should be involved because there is an opportunity for them to benefit from the proposed relationship—internet uptake is not universal and cannot be assumed. Therefore, by offering such a service where internet service is essential has the potential to widen the customer base. Furthermore, the relationship between the city council and the ISP is a new relationship that we posit can prove to be fruitful in particular for the ISP, with the city council depending on the availability of cloud resource space to retain customer sensor data which will influence the smart waste management decisions being made—again, without the proposal of our business model, this relationship may not exist and the ISP and council may not be in a position to benefit.

From our prior research [22], we recognize that there is a general lack of understanding and awareness across society with regard to the concept of smart waste management: In our previous work [22], we have collected questionnaires to capture the general understanding of and potential uptake of SWM schemes. Given the interest in smart waste management, we have continued to pursue research in this field, with this paper being an example of this. However, we recognize that there is a general lack of understanding as to what smart waste management involves across society. The full potential of SWM can only be fulfilled if a variety of aspects are in place, which include a new business model and new relationships between key players, the city council and an internet service provider, in the case of a SWM service. In this paper, we make a proposal of an approach to establishing a service between the SWM players, together with an analysis of the costs–benefits which will be incurred when operating under the proposed system. We articulate the costs to parties providing the service, and the benefits to a customer. The specific benefits to the service providers are not fully understood, however, given that it is necessary to understand the service cost once a customer's SLA becomes active—the phases defined in this paper are representative of costs incurred prior to the service becoming active. Future plans therefore involve making a contribution to this aspect of the business model.

Taking this further, in our future work, we hope to continue to investigate this aspect of business model costs with a view to provisioning an approach which is explicitly beneficial for all involved. This will involve the proposal of an intelligent route optimization algorithm. In addition to this, we will begin work on the next phase of the business model, which becomes necessary once the SLA has been signed and the service becomes operational. This recognizes that the behaviors of the customers may change over time, and therefore, similarly, the characteristics of the SLA can also change over time. We therefore seek to examine, for example, the most effective rate at which to monitor the real-time context data which are collected regarding customer behavior, in addition to the decisions that are applied in response to a citizen's change in behavior. As one example, we seek to define the actions that are taken if a citizen initially chooses to participate in the SWM program, but in practice, they continue to reject all SWM service options. In our model, we will determine the stage at which a decision is made to transfer their status to being a customer who is in fact not participating in SWM. Finally, we will disseminate surveys in an attempt to check if citizens are willing to participate in such a scheme, and to get an understanding of their perception of the model.

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smart cities

Article

Technological Developments of Mobility in Smart Cities. An Economic Approach

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Abstract: This article introduces the concern that exists in the wider economic world concerning the developments carried out in Smart Cities. The various studies that have been developed capture the economic approach by focusing on specific economic development theories. This article initially provides a theoretical response to the need for a joint approach to the different economic theories relating to Smart Cities, placing the bases of their development in the circular economy. Subsequently, the paper presents a device-based proposal to validate the sustainability principles indicated in the Smart Economy, focusing exclusively on the areas of health and mobility. As a whole, the work concludes with the need to incorporate sustainability criteria into economic ambition so that technological developments have a place in future Smart Cities.

Keywords: mobility; smart economy; smart services

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1. Introduction

The development of wireless communication technologies that we have been witnessing in recent years has lead to the development of a multitude of interconnected devices capable of providing relevant information about the environment and the users of these devices. This is known as the Internet of Things [1].

One of the fields in which this type of device is being applied largely is in Body Area Network solutions. Due to the conditions of this type of device, the design tends to be miniaturised and, therefore, does not usually have a high-capacity battery. Protocols such as Bluetooth Low Energy, a low-energy extension of the Bluetooth protocol [2], provide wireless connectivity and long battery life for these devices.

The ease of data acquisition and the flexibility of new electronic circuit manufacturing techniques allow us to design devices that can provide users with a better quality of life without being uncomfortable to use [3].

One of the sectors in which this type of device has not yet been widely used is in physiotherapy and rehabilitation treatments [4]. This sector is essential in our society. It helps a person who has suffered some injury return to their normal life, providing them with enhanced quality of life and the ability to return to work at an early stage [5].

This type of treatment traditionally depends on the professional who carries it out. In this way, the patient is monitored according to his or her sensations and the evolution of the process [6]. However, on many occasions, there are periods of unexplainable deterioration. Given the lack of data on the patient's external life, the professional may doubt the efficacy of certain rehabilitation techniques in certain patients.

From an economic point of view, the approach of different technologies has to follow the precepts of participation in the Smart Economy, from the point of view of Smart Services, in such a way that it can be sustainable and thus help to maintain the idea of the Smart City over time.

It is also important to highlight that the development of Smart Cities is based on the contribution made by the theory of the circular economy, since it is undoubtedly based on sustainable developments that we can find sustainability. As can be seen in the previous literature, the circular economy has mainly focused on the study of waste [7–9]. The link between the circular economy and Smart Cities is still under development and a novelty in health and mobility. However, there are certainly studies that have worked on it recently [10].

After this introduction, the article presents in its second section the concept of the Smart Economy, where it also incorporates the necessary connection between Smart Cities and the development of the circular economy. The third section includes a specific case of the application of technological developments to mobility. The fourth and fifth sections correspond to the discussion and conclusions, respectively.

2. Smart Economy

The economic development of cities has always stood out for being studied from the perspective of efficiency and effectiveness [11]. One of the most widely studied services in cities is the efficiency of law enforcement agencies [12].

2.1. Smart Economy and Smart Cities

The emergence of the concept of the Smart Economy arises from going one step further within the scope of the study of sustainable city development [13]. The move towards cities being and becoming smart is an additional step that is also economically studied by trying to answer questions, such as: does traditional urban economic theory apply to Smart Cities; what do new transport, commerce and communication services consist of, and how do they impact the Smart City economy; or can Smart Cities be inclusive? [14,15].

In the current article, we will focus on the question of new transport and communication services and the ability of new cities to be inclusive.

A key element in the development of Smart Cities is Smart Services. Without Smart Services, it would not be possible to respond to the need to incorporate adequate transport, communication and inclusion [16]. By Smart Services, we mean services that serve the citizens of Smart Cities and their individual needs. These are constantly changing in terms of information and communications technology. In the joint creation of value, the interactions between citizens and service providers take on their full immensity [17].

An essential aspect to highlight concerning the development of mobility solutions relates to the development of the circular economy, which is the basis for the development of Smart Cities [18]. One of the proven connections between the circular economy and the development of Smart Cities through Smart Services is the recycling of urban waste [19,20].

The continuous improvement of the smart service is the basis of the functioning of Smart Services and is the point of connection with the principles of the circular economy. In addition to continuous improvement, Smart Services incorporate the strategic, operational, design and transition cycle [21].

2.2. Circular Economy and Smart Cities

The circular economy is the basis of this article, understanding its development as necessary so that these precepts can be incorporated into the different devices and thus contribute to the sustainable development of Smart Cities [22].

An important idea that stands out in the circular economy is the cycle of materials, which is closely related to the concept of industrialisation [23]. We have to start from the idea that the circular economy aims to reduce negative environmental impacts and stimulate new business opportunities within industrialisation, even though the linear flow has dominated overall development causing severe environmental damage, as the diagram could be seen in Figure 1 [24].

The circular economy concept is not entirely new; it has gained a lot of momentum among both scholars and practitioners. Nowadays the concept has become popular, especially due to its promotion by the world's leading powers. It is at this point where this concept becomes essential in this article, due to its necessary repercussions on the Smart Cities concept, so that all the developments carried out in them are by the sustainability of Smart Cities and Smart Services.

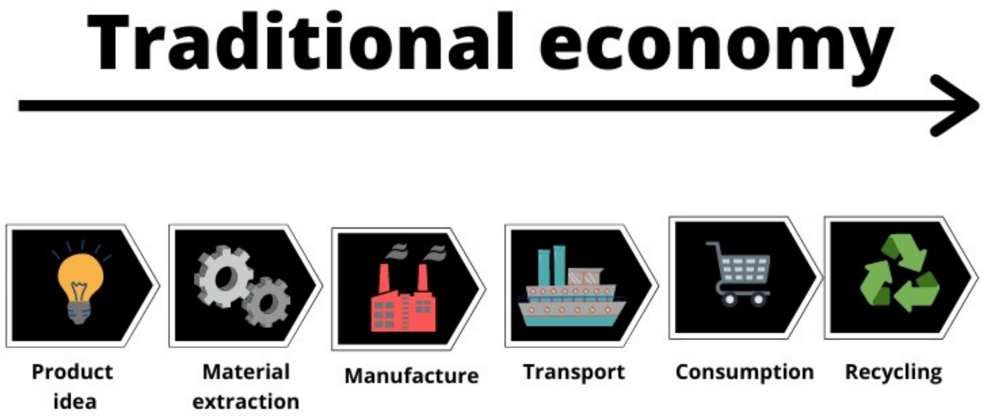

Figure 1. Linear economy.

The real importance of the smart urbanism, which is ultimately given by the arrangement of Smart Cities around new technologies, has been implied in several studies, among which it is worth mentioning [25–27]. Adaptation to the new urbanism has been studied before and it is now the different verticals exposed in the current research that we have to deepen, i.e., those related to health and mobility.

What is new and particularly interesting about the circular economy is that it provides an economic system with an alternative flow model to the traditional linear model of extraction, use and disposal of materials, as well as to the energy flow of the modern economic system, which over time has become unsustainable, and has a major impact on the development of Smart Cities [28].

Circular economy as a concept emerged in the late 1970s, attributed to Pearce and Turner [29], who described how natural resources influence the economy by providing inputs for production and consumption. Added to this is the work of Boulding [30], who describes the earth as a circular place with a limited assimilative capacity, so it is not illogical to think that it is necessary and vital that both economy and environment coexist in equilibrium, and in our case at the city level, as the diagram could be seen in Figure 2.

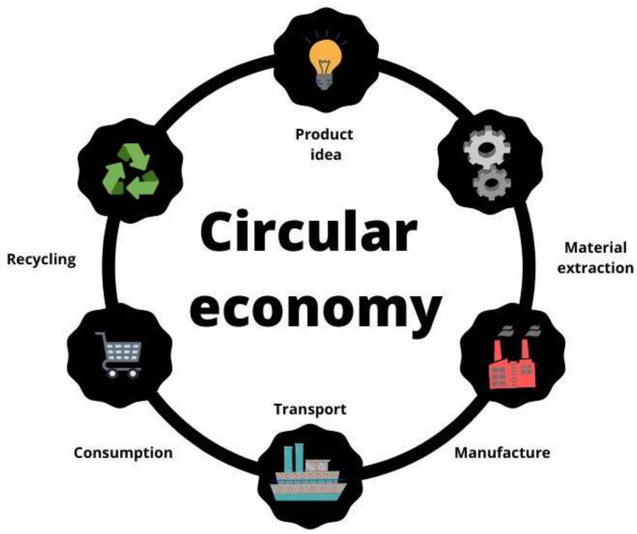

Figure 2. Circular economy.

It should be noted that the coupling between the circular economy and Smart Cities is based on the definition of the process as thinking about all aspects of the economy of cities as a whole, as something circular, instead of thinking about it as something linear in such a way that in each phase the following premises are taken into account:

- Continuous thinking about better production, leading to maximum savings in materials.
- Making waste generated in the manufacturing process profitable.
- Minimisation of the extraction of raw materials, saving the high costs faced by organisations.
- Continuous and targeted thinking towards the creation of recycled materials. Plan for the renovation of waste for its reuse and profitability.

In addition to the above, there are necessary approaches to address from the perspective of Smart Cities governance. The application of business in Smart Cities [31] should be focused on reusing products, materials and components, remanufacturing, repair, renovation and improvement. This needs to incorporate solar, wind, biomass and the reuse of energy derived from the waste throughout the product value and life cycle [32].

Another approach necessary for developing the total Smart City concept from an economic point of view is the industrial approach. Appropriate industrial strategies for waste prevention, job creation in the city, efficiency and dematerialisation of the industrial economy have to be described [33]. It is important to incorporate the idea of using rental as a sustainable business model instead of asset ownership for a loop economy, allowing industries and developers to benefit without externalising the costs and risks associated with, for example, waste [34].

Understanding how the circular economy works and its application within Smart Cities as economic systems and industrial processes will allow us to evolve towards Smart Services from the point of view of mobility as well as timely and sustainable technological developments, the bases of the development outlined here.

3. Integration of the Circular Economy in the Mobility Aspects of the Smart City

As we anticipated, several studies approximate the importance of sustainability in the development of the Smart Economy, which is key to the development of Smart Cities. Below, within the possible verticals that favour the development of Smart Cities based on sustainability, we have those based on health and mobility as a developed use case.

The device mentioned in this article aims to provide real-time data on the support utilised by patients undergoing mobility enhancement, to be analysed by mobility support staff [35,36].

To this end, this development has been patented under utility model ES1249804U [37]. Concerning the state of the art, the invention incorporates specific improvements, such as a measurement system contained in the rubber tip of the crutch, unlike others where it is located inside the cane to be used in any crutch. In addition, thanks to the functionality of the mobile application, it assists the monitoring of patients with different bone injuries by the specialist, as could be seen in Figure 3. Employing a series of sensors and electronic devices that provide wireless connectivity makes it possible to control, know and correct in real-time the percentage of load carried by a patient undergoing rehabilitation in each support during ambulation.

Thanks to the measurement of anthropometric parameters, we are able to establish estimates of the user's state in real-time, understanding by their state the situation in which a set of determined biometric measurements is within pre-set thresholds [38]. Through the development of a prototype such as the one described, the aim is to improve and speed up the physical and motor recovery of the patient, offering support ranges and generating beneficial feedback for the rehabilitator who, by accessing the data generated by the device and stored in the user's mobile phone, can propose corrections on how to support weight when walking and guide the rehabilitation sessions according to the specific case.

During the design of the device, research was carried out into techniques for integrating a load cell into the tip of the crutch or cane (in the area in contact with the ground), which transforms the pressure variation data into an electrical potential variation capable of being read from an Analog–Digital Converter HX711. This 24-bit converter is responsible for transforming the analog voltage signal from the load cell into a digital signal and communicating it to the ESP32 control and communications module.

Thus, after processing the data, and thanks to a wireless communications module included in the ESP32 (low-power SoC chips with integrated Wi-Fi and dual-mode Bluetooth technology), it transmits the information to a smartphone via radio, using the Bluetooth Low Energy (BLE) protocol [38]. Once the mobile device obtains the data, either by a mechanical stimulus (vibration) or by an acoustic stimulus (beep), it indicates to the patient if he/she is outside the support range indicated by his/her doctor and/or physiotherapist, thus allowing him/her to self-correct.

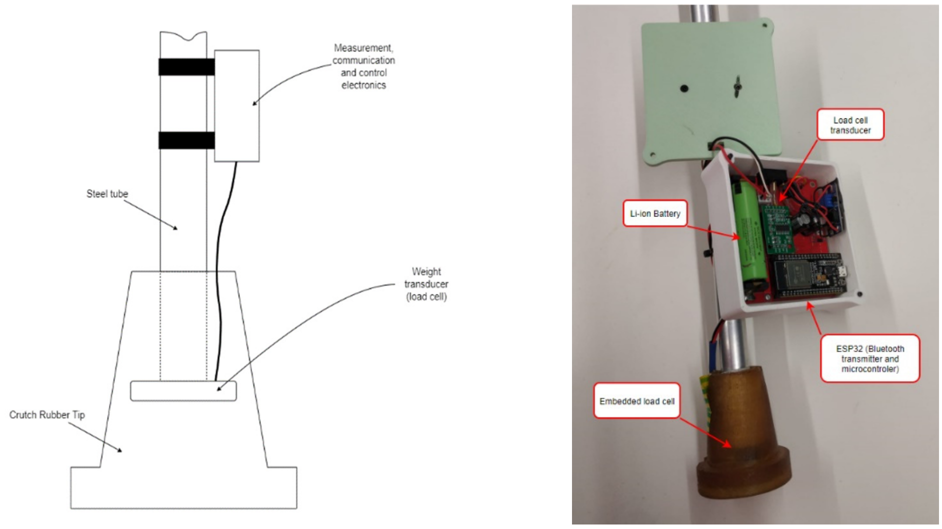

Figure 3. Diagram of the device (**left**) and device developed (**right**).

To achieve this purpose, a mobile application has been designed to control, store and visualise the data transmitted by the device. The mobile phone reads the patient's battery percentage and weight data thanks to the connection from the unique UUID. The integrated software sends an average of 30 data in 300 milliseconds. This provides a tool with which both the patient and the rehabilitator can access the history of data collected during the programmed recovery phases. Additionally, the rehabilitator is able to configure the rehabilitation phases and establish the correct support ranges for each of these phases.

To monitor the recovery process, the concept of a phase is used. A phase comprises, in a given period of time, the optimal conditions for the healing process to take place: the number of crutches the user needs to use and the weight to be supported on them. The main screen of the mobile application shows the previous day's activity, as could be seen in Figure 4: the steps recorded, the battery status of the device, the patient's recovery phase and an analysis of the steps recorded. From this screen it is possible to customise the notifications for exceeding the support limits set by the therapist, connect the crutches and consult the application's records.

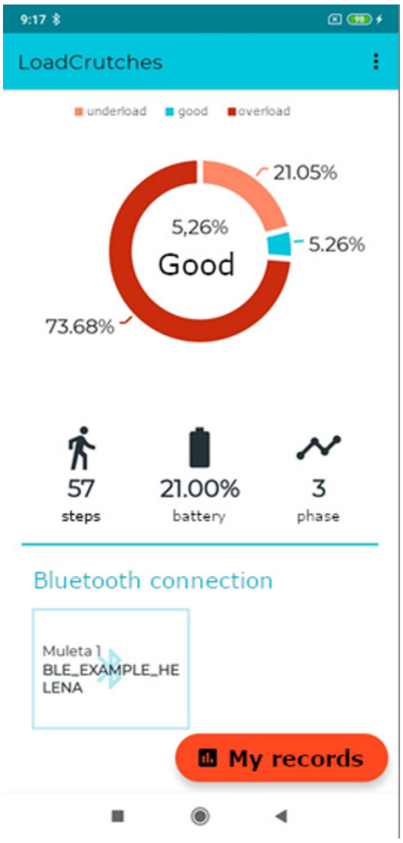

Figure 4. Mobile application overview.

4. Discussion

The technological development of Smart Cities is widely studied from a technological point of view. From the economic point of view, there are various approaches to the concept of Smart Cities. The economic approaches arise in one direction or another, i.e., on the one hand, we have those who approach the concept of the Smart Economy from the point of view of the incorporation of Smart Services. At the same time, other authors link it to the circular economy.

In the current article, we link a use case based on mobility solutions to the economic sphere of Smart Cities. At the same time, it meets the sustainability criteria of the circular economy, which motivates the so-called Smart Economy.

In the current article, the chosen solution is based on Smart City communication solutions and, more specifically, on mobility-related solutions. In the future, different studies can focus on the globality of the Smart Economy, applying not only to mobility criteria but also to other types of criteria related to other services.

At the same time, the economic verticals presented here are developed on the idea of sustainability linked to the circular economy. However, other ways of coupling to economic theory can be explored.

5. Conclusions

This article presents the relationship between technological developments framed within the improvement of Smart Cities and their development within a sustainable framework such as the Smart Economy.

Within the Smart Economy, a link also exists with Smart Services, the latter being those that have to be developed following the precepts of the circular economy and, therefore, those of sustainability. The developments being worked on are those related to mobility, which is the main communication axis of any Smart City. Based on co-communication and mobility as the driving forces of the Smart City philosophy, we advance the relationship they must have with the so-called Smart Economy and, more specifically, with the circular economy.

This article lays the foundations for the necessary work on sustainability from the point of view of the main precepts of the circular economy and the so-called Smart Economy, to make progress in linking them with sustainable technological developments over time.

Theoretically, the link between developments integrated into the Smart Economy and the circular economy idea is presented and conceptualised to succeed over time. As a motivating factor for the need to incorporate the economic reality of Smart Cities into technological developments, new developments must contain the following bases:

Product idea
Material extraction
Manufacture
Transport
Consumption
Recycling
And product idea again

It is important to conclude that if the current scheme is the one followed by any technological development, whether or not it is linked to the idea of mobility, it is theoretically approximated by the current article that its future link with the Smart City ecosystem will have a place within the premises of mobility and sustainability.

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smart cities

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Article

IoT-Based Sanitizer Station Network: A Facilities Management Case Study on Monitoring Hand Sanitizer Dispenser Usage

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Abstract: Maintaining hand hygiene has been an essential preventive measure for reducing disease transmission in public facilities, particularly during the COVID-19 pandemic. The large number of sanitizer stations deployed within public facilities, such as on university campuses, brings challenges for effective facility management. This paper proposes an IoT sensor network for tracking sanitizer usage in public facilities and supporting facility management using a data-driven approach. Specifically, the system integrates low-cost wireless sensors, LoRaWAN, and cloud-based computing techniques to realize data capture, communication, and analysis. The proposed approach was validated through field experiments in a large building on a university campus to assess the network signal coverage and effectiveness of sensor operation for facility monitoring. The results show that a LoRaWAN created from a single gateway can successfully connect to sensors distributed throughout the entire building, with the sensor nodes recording and transmitting events across the network for further analysis. Overall, this paper demonstrates the potential of leveraging the IoT-based Sanitizer Station Network to track public health mitigation methods in a large facility, which ultimately contributes to reducing the burden of maintaining public health during and post-pandemic.

Keywords: Internet-of-Things; LoRaWAN; facility management; public health; COVID-19

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1. Introduction

Preventive measures are among the critical strategies for reducing the burden of the COVID-19 pandemic. Following the guidance of the Centers for Disease Control and Prevention (CDC) [1] within the U.S. and that of other health agencies around the world, these prevention measures include mask wearing, maintaining physical distance from others (i.e., "social distancing"), hand hygiene, deep cleaning, and disinfection. Recent studies suggest that preventive measures will continue to be important, particularly in the current context of vaccination efforts [2–4]. As one of the essential preventive measures performed at an individual level, maintaining good hand hygiene using alcohol-based sanitizers can effectively reduce the spread of the virus, which warrants the scalable deployment of sanitizer stations in public spaces such as hospitals, shopping malls, office buildings, and university campuses. However, deploying a large number of sanitizer stations throughout a large area and in multiple buildings creates challenges for effective facility management. In particular, sanitizer dispensers should be refilled as soon as they empty so that they are available when needed. In this sense, the facilities operations team should be able to (i) monitor the usage of sanitizer stations; (ii) readily identify the locations and number of sanitizer stations that need refilling; and (iii) generate the schedule and route for maintaining the sanitizer stations accordingly. These requirements demonstrate the need for automated usage tracking of sanitizer stations distributed throughout a large area.

Internet-of-Things (IoT)-based monitoring applications have quickly become an important part of our daily lives, and their importance and ubiquity will continue to grow, particularly as they enable large-scale deployments and "smart city" applications [5] such as parking [6] and waste management [7]. Several researchers have described a design framework for these applications (e.g., Fahmideh, et al. [8]) and challenges to implementation (e.g., Syed, et al. [9] and Belli, et al. [10]). IoT devices equipped with Long-Range Wide-Area Network (LoRaWAN) transceivers are now also feasible for monitoring systems to support smart cities, i.e., usage at the city, urban, or rural scale [11–13]. Example applications that have demonstrated the use of LoRaWAN in smart city applications include those monitoring traffic systems (car parking [14] and traffic lights [15]), infrastructure (e.g., lighting control [16]), urban environment (e.g., air quality [17,18]), and utility metering [19]. In addition to the monitoring and control of assets, LoRaWAN is also widely used for large-scale human health monitoring as a component of e-health solutions [11]. These include monitoring of both human physical status (such as blood pressure, glucose, and temperature on an urban scale [20]) and location [21,22]. In sum, LoRaWAN-based IoT systems enable solutions for large-scale monitoring for both assets and humans in dense urban areas.

Applications of LoRaWAN-based IoT systems also provide an opportunity for improving public health during the current pandemic. Particularly, IoT techniques can facilitate sanitizer usage tracking within facilities throughout a large area. Recent advances in IoT technologies enable an integrated approach for wireless sensorized infrastructure to monitor public hygiene in real time or near real time. Applying ubiquitous computing, wireless communication, and smart-and-connected devices allows the transfer of data and information rapidly and reliably [23]. A review of recent studies deploying IoT-based sanitizer stations is provided in Table 1.

Applications of IoT-based sanitizer stations have been set up in health facilities [23–25] such as hospitals, clinics, and nursing homes. The early-stage adoption of sensorized sanitizer stations aims at ensuring compliance with hand hygiene among the medical staff, which is vital in controlling the spread of disease in medical facilities. Such IoT-based systems typically rely on installing sensors (e.g., infrared sensors [23]) on sanitizer stations and RFID tags on each medical staff, which allows the monitoring of hand hygiene activities of each identifiable staff. Therefore, such systems are more appropriate for deployment in private spaces where regular users of the sanitizer stations can be equipped with ID tags.

In the wake of the COVID-19 pandemic, recent studies have started to apply IoT-based sanitizers for improving public hygiene. Herbert, et al. [26] developed sanitizer stations with UV light and cameras, which provide real-time feedback of hand cleaning performance to users to improve their hand hygiene practices. A study by Sumbawati, et al. [27] also deployed a smart control mechanism on the sanitizer station to reduce sanitizer waste. Despite the importance of enhancing hand hygiene via IoT-based sensors, there is also a need for effective management of sanitizer stations at scale during the pandemic—a scale that is often 10 to 100 times the number compared to pre-pandemic numbers. In this sense, recent works have also explored leveraging sensors for monitoring usage and levels of sanitizer in stations in real time [28,29]. However, such works focus mainly on the design of sensorized sanitizer stations to measure the sanitizer usage. The detected usage data should be converted into actionable information for facility management personnel. However, there has been limited reporting on investigations into the design and development of IoT systems to support facility management of sanitizer stations at scale. Hence, there is a need for a proof-of-concept demonstration of sensorized sanitizer stations for scalable deployment in real-world application scenarios, which is not implemented in related studies [28,29]. Given the vital role of individual-level preventive measures, a scalable IoT-based public sanitizer station network to assess usage at the facility level can benefit broader stakeholders, including the facilities managers, field operators (e.g., janitors), public health professionals, and building occupants.

Table 1. Review of related studies.

Studies	Application Scenario	Deployed Techniques
Herbert, Horsham, Ford, Wall and Hacker [26]	Applying a smart handwashing station to improve hand hygiene compliance with real-time feedback (regarding the effectiveness of handwashing).	Camera, UV light, and tablet installed on handwashing station for detecting and displaying unwashed areas of hands.
Chowdhury and De [29]	Sensorized sanitizer station to monitor the sanitizer usage and remaining level.	Liquid stage sensor installed on sanitizer station, with WiFi for data communication.
Bal and Abrishambaf [23]	Sensorized sanitizer station to monitor the compliance with hand hygiene of medical staff.	RFID tag and an infrared sensor for monitoring the hand hygiene compliance of each staff; ZigBee and WiFi for data communication.
Meydanci, Adali, Ertas, Dizbay, and Akan [25]	Sensorized sanitizer station for monitoring the compliance with hand hygiene of medical staff.	RFID tags for monitoring hand cleaning behaviors; ZigBee for data communication.
Tadikonda [28]	Sensorized sanitizer station for monitoring the level of sanitizer.	Ultrasonic sensor for monitoring the level of sanitizer bottle; WiFi for data communication.
Sumbawati, Chandra, Wrahatnolo, Ningrum, Khotimah, and Fathoni [27]	Sensorized dispenser with smart control for automated serving of sanitizer and reducing waste.	Ultrasonic sensor for detecting presence of human hands.

In summary, the motivation for the proposed approach is outlined in Figure 1. The need for scalable deployment of sanitizer stations brings challenges for facility management. IoT-based systems can help to overcome the challenge of large-scale facility management for facility managers, operators, and occupants. However, the review of related studies in Table 1 shows a lack of design, development, and field tests of IoT-based sanitizer station systems for supporting effective public facility management. Therefore, as an initial stage of ongoing research, this study developed a proof-of-concept IoT sensor network to track sanitizer usage in a public space and support facility management using a data-driven approach. A case study was conducted in a large building on The Pennsylvania State University's University Park campus. Specifically, we developed a wireless monitoring unit comprising a commercial-off-the-shelf (COTS) wireless sensor unit and a 3D-printed holder with compliant mechanism to register dispenser interactions. This allows these units to be quickly and easily installed via a "plug-and-play" approach on existing sanitizer dispensers located on campus. We deployed a LoRaWAN gateway for delivering the wireless sensor network (WSN) data to the cloud. A cloud-based platform was developed for data management, analysis, and reporting, with an aim to support the decision-making of the facility management team via an evidence-based approach. In addition to the system design and development, we also tested the system's operation in a large building on campus.

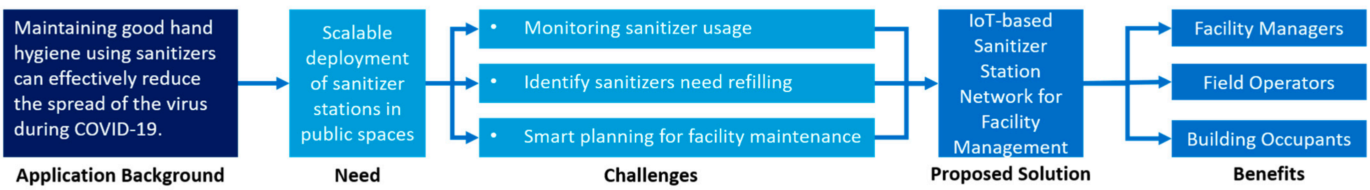


Figure 1. Motivation for the proposed approach.

This paper is organized as follows: Section 2 describes the design, development, and testing of our IoT system. The results of the system test are discussed in Section 3. Finally, conclusions and potential further development paths are described in Section 4.

2. Materials and Methods

Here we describe the design, development, and implementation of the IoT-based Sanitizer Dispenser Network. The overview of the design effort is introduced first, followed by a description of each subsystem. Finally, we discuss the implementation and testing of the prototype system we developed.

2.1. Concept Development

The system we developed (i) tracks usage of sanitizer dispensers in (near) real time on campus; (ii) saves the historical data of sanitizer interactions, and (iii) reports the sanitizer operational status and usage patterns to support facility management (data that can also be assessed by public health professionals). Figure 2 provides a block diagram as an overview of the proposed system. Instead of developing a new IoT-based sanitizer station prototype as in related studies, the existing sanitizer stations on campus are upgraded by installing a sensor module and 3D-printed sensor holder with compliant mechanism, which aims at monitoring dispenser interactions in (near) real time (data are collected and sent every 10 min, which can be set shorter or longer). The captured data from the sensor units are communicated to the cloud-based network server over LoRaWAN. The cloud network server sends the collected data to the application server. The data analysis programs running on the application server transform data from sensors into estimates of sanitizer usage. Such information is presented in real time via dashboards and triggers automated notification (e.g., identified sanitizer dispensers requiring bottle replacement) to the facility management team.

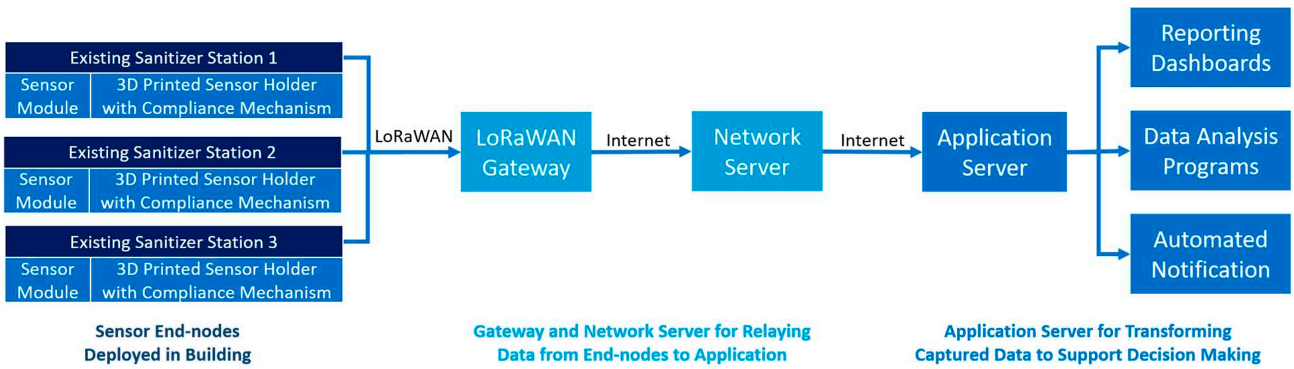


Figure 2. Block diagram of Sanitizer Dispenser Network system design.

2.2. Sensor Module Selection

The Radio Bridge Dry Contact Sensor (Type: RBS301-CON LoRa [30]) was selected for this study due to the following features.

- Low-cost: each sensor costs USD 40–45, which is affordable for deployment scale up.
- Wire-free power supply: the sensors are powered by batteries with a lifetime of up to 5–10 years. The sensors are, therefore, easy to deploy and have no requirement of being near a power source.
- Wireless data communication: the sensors use LoRaWAN for data communication, which is a low-power solution for long-range communication.
- Remote configuration and management: the sensor manufacturer provides an accessible network server service (Radio Bridge Console [31]), allowing remote sensor configuration and troubleshooting.

- Multiple triggering mechanisms: the sensor can detect several different events through three different mechanisms, namely, wire connection/disconnection (Event A), tamper switch for detecting sensor shell open (Event B), and magnetic trigger for sensor status checking (Event C).

We designed our unit to register different dispenser interactions through judicious use of the sensor module's three triggering mechanisms. These three triggering mechanisms allow the sensor module to detect several different user interactions with the dispenser, such as regular use (i.e., push of the dispenser lever via Event A, wire connection/disconnection), sanitizer bottle replacement by janitorial staff (via Event B, tamper switch), and sensor status checking (via Event C, magnet trigger). As shown in Figure 3, a data packet is sent to the network server containing the events that occurred and their quantity during the reporting interval (set to 10 min in our system). A time-stamp for each data packet captured by the sensors is automatically generated by the sensors, which is used for monitoring sensor operation.

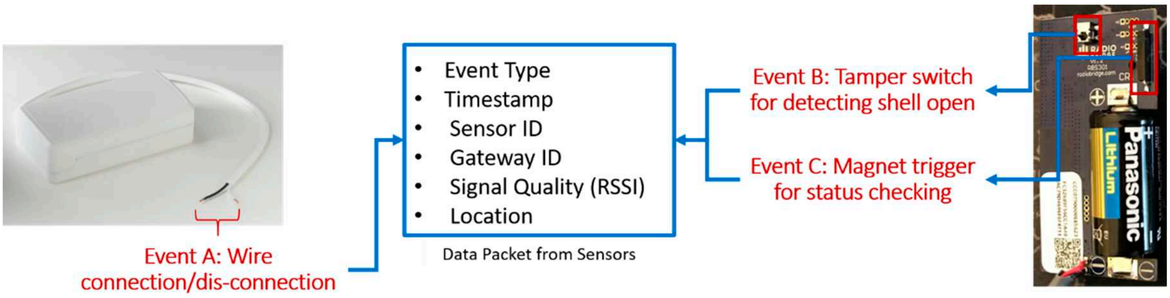


Figure 3. Radio Bridge LoRaWAN Dry Contact Sensor Module, events, and data packet structure.

2.3. Sensor Deployment

2.3.1. Existing Sanitizer Dispenser Stations

The existing sanitizer station used throughout campus is shown in Figure 4. The sanitizer bottle located inside the dispenser is squeezed and releases sanitizer when the user pushes the lever at the bottom. The dispenser needs to be opened to remove the spent bottle and replace it with a new bottle.

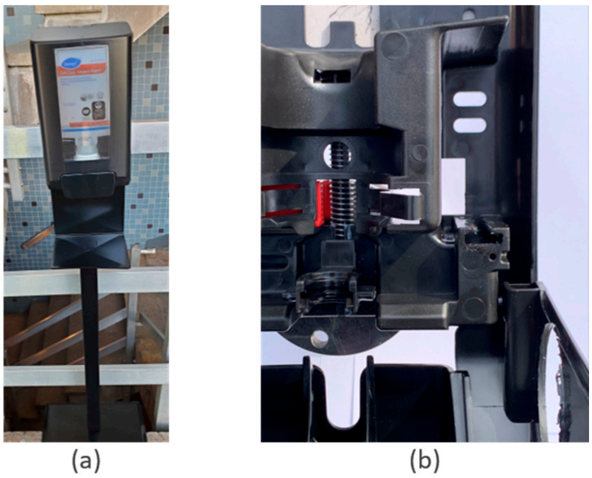


Figure 4. Existing sanitizer station with dispenser bottle (Diversey Intellicare Dispenser II, 1.3 L, 9.1″ × 19.5″ × 11.2″): (**a**) shows the dispenser with bottle installed as part of the sanitizer station; (**b**) inside view of the dispenser activation system.

2.3.2. "Plug-and-Play" Sensor Unit Design for Monitoring Dispenser Interactions

The IoT system enables the monitoring of the dispenser and sanitizer usage patterns, and can be used to estimate the volume of sanitizer remaining within the dispenser, which can be used for prediction of which dispensers will be empty and when. By using the dry contact sensor, the system monitors two types of dispenser interaction events: (i) push of the dispenser lever by a user, which indicates when and how much is used (each lever push dispenses a given quantity of sanitizer) and (ii) opening of the dispenser for replacement of the sanitizer bottle. Recording of these two events allows the system to determine the number of "push" events that typically occur between replacement of the sanitizer bottle, which can be used (i) to infer when the dispenser will be empty and (ii) to develop a schedule for dispenser service. To accurately differentiate the two events, we developed two add-on components, a compliant mechanism and sensor module holder, and integrated them with the sensor module for plug-and-play deployment within each dispenser already located in the field.

Compliant Mechanism. The compliant mechanism, shown in Figure 5 was designed to require no change in procedure for maintenance staff when replacing a sanitizer bottle. The device is based on a cantilevered beam and consists of three main components (Parts A, B, and C in Figure 5a). Part A wraps around the sensor module (left-most object in Figure 3), Part B contacts the sanitizer bottle when inserted, and Part C attaches to the sensor holder and contains the compliant beam. When a sanitizer bottle is inserted, Part B is pressed and deflects the beam in Part C, which is attached to Part A and pulls on the sensor module. The sensor module has an internal tamper switch that is depressed by an extrusion on its lid to detect when the lid is removed. The lid extrusion can be easily removed, providing external access to the tamper switch. The sensor module holder, shown in Figure 5b, has an extrusion on its face that contacts the tamper switch when the compliant mechanism is undeflected. Insertion of the sanitizer bottle causes the compliant mechanism to deflect, pulling the sensor box away from the sensor module holder and releasing the tamper switch from the extrusion, registering this event.

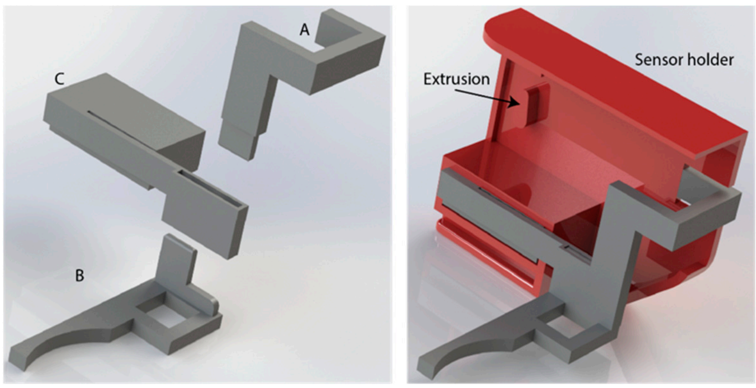


Figure 5. 3D-printed components to provide "plug-and-play" deployment and operation within sanitizer dispensers: (**a**) compliant mechanism and (**b**) sensor module holder.

The compliant mechanism can be 3D-printed without the use of support material and is held together with an interference fit. The angle of the beam relative to the fixed portion creates an active load on the sensor box, keeping the tamper switch closed when a bottle is removed. Once a bottle is inserted, the beam will remain deflected (tamper switch open).

Sensor Module Holder. The sensor module holder and long-arm microswitch assembly detects the movement of the dispenser's hand-actuated lever and triggers the "push" event. The sensor module holder is also 3D-printed. The design leverages the existing "T-Slot" feature on the original dispenser box for alignment and installation. The entire assembly is field-installed using a plug-and-play approach in less than 1 min per dispenser (Figure 6).

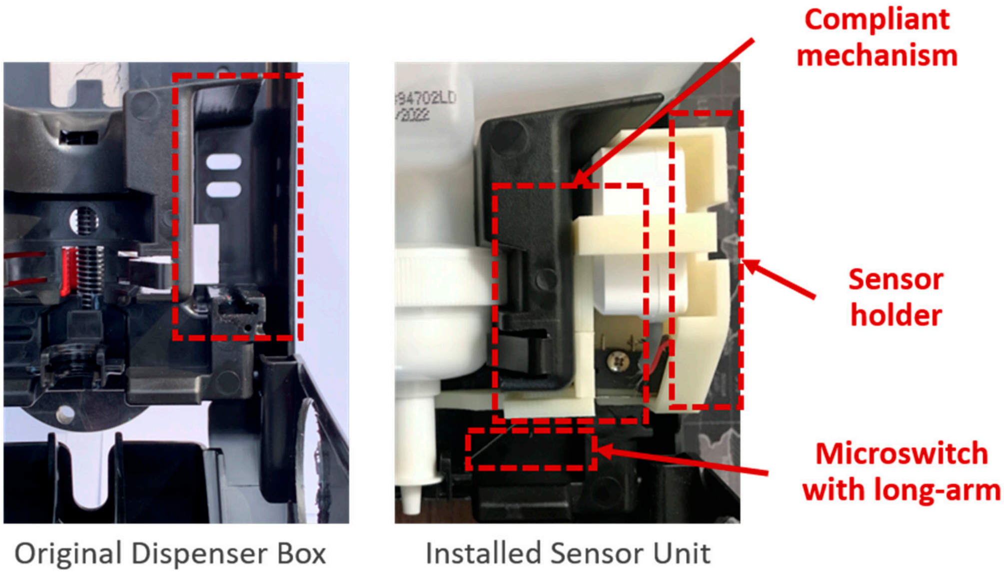


Figure 6. Sensor holder design for "plug-and-play" deployment in existing dispensers.

2.4. Wireless Network

The wireless network infrastructure includes (i) a wide-area network for communicating data collected by the sensor modules; (ii) a network server for receiving the sensor data; and (iii) an application server for hosting the received data, data analysis program, and reporting dashboards.

2.4.1. Wide-Area Network

The Long-Range Wide-Area Network (LoRaWAN) is used to connect the sensor modules located within the distributed dispensers. We used the MultiTech Conduit gateway (MTCDT-247A [32]) for creating the network, which has the following advantages:

- Private WAN: the wireless network can be created using a single gateway without paying for access to a cellular network.
- Long-range communication: the signal coverage range can be up to 10 miles (16 km) with line-of-sight and approx. 1–3 miles (1.5–5 km) around/inside buildings.
- Cost-effectiveness: the LoRa network follows a "star topology", with which a single gateway (USD 600) can cover up to hundreds of end-node devices for decreased cost of implementation.

In addition, although we did not implement this, it is possible to access existing open LoRaWAN networks that have seen deployment around the world.

2.4.2. Network Server

We used the Radio Bridge Console [31] as a network server, which is provided by the sensor manufacturer for receiving data and configuring sensors. Figure 7 shows an example of sensor configuration, during which the sensors were set to record only the "wire connection" event and accumulate all such events detected during a 10-min interval. (As either connection or disconnection indicates the dispenser lever has been pushed, recording only one of them is sufficient for indicating that the lever has been pushed.) A sample data packet received from the sensor is provided in Figure 8, which shows the sensor name (to identify the sensor, as signals from multiple sensors are sent to the console), time-stamp, event type, and signal quality encapsulated in the received data packet. Notably, the application programming interface (API) is provided by the console, which is an uplink for relaying data packets to the subsequent application server for analysis.

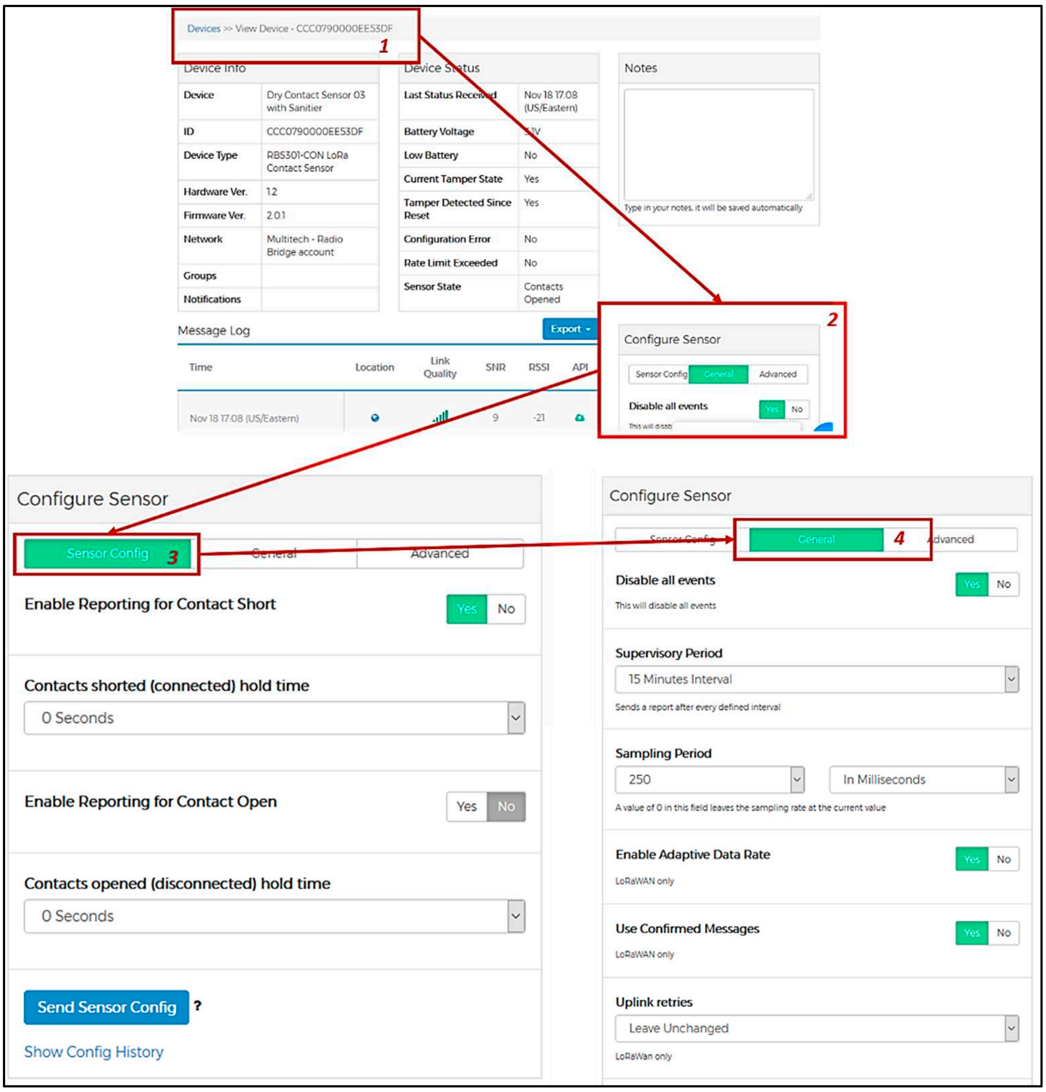
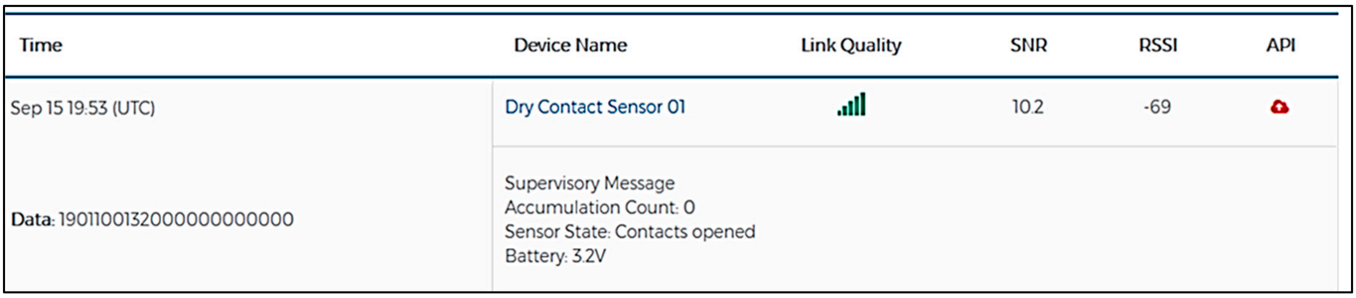


Figure 7. Sensor configuration in Radio Bridge Console.



Time	Device Name	Link Quality	SNR	RSSI	API
Sep 15 19:53 (UTC)	Dry Contact Sensor 01		10.2	-69	
Data: 19011001320000000000000	Supervisory Message Accumulation Count: 0 Sensor State: Contacts opened Battery: 3.2V				

Figure 8. Sample of received sensor data packet.

2.4.3. Application Server

The TagoIO platform [33] was selected as the application server for storing, analyzing, and visualizing the sensor output. By processing the received data packet, the application server is designed to realize the following functionalities:

- Sensor status checking: the received data packet is used to monitor the sensor operational status, such as signal quality (via the received signal strength indicator, RSSI) and battery life.

- Real-time tracking of sanitizer usage: both the "push" and "replace" events are analyzed to monitor the number of push events after the most recent replacement, which tracks sanitizer usage.
- Visualization: dispenser conditions and their locations are presented graphically.
- Usage-pattern discovery: the recorded sanitizer usage data can assist in discovering historical patterns, such as the temporal and spatial usage trends on campus, which can help in assessing compliance with hand hygiene recommendations.
- Early warning of empty sanitizers: rule-based alarms and notifications can be set to notify the facility managers and operators about sanitizer dispensers close to empty and those that are malfunctioning.

Notably, the sensor status checking and real-time tracking of sensor events (e.g., push and replace) were realized by running the authors' program (in Python) on the TagoIO platform with an API (the TagoIO library) provided by the platform (Figure 9). Data visualization and pattern discovery were conducted via *ad hoc* analysis programs (mainly using the libraries Pandas and Matplotlib in Python). The notification function is a web application provided by TagoIO when sensing data are streaming into the platform. The codes and programs used in this study were available at the authors' GitHub repository (https://github.com/JunqiZhao/IoT-Analysis/tree/master/Code, accessed 7 July 2021).

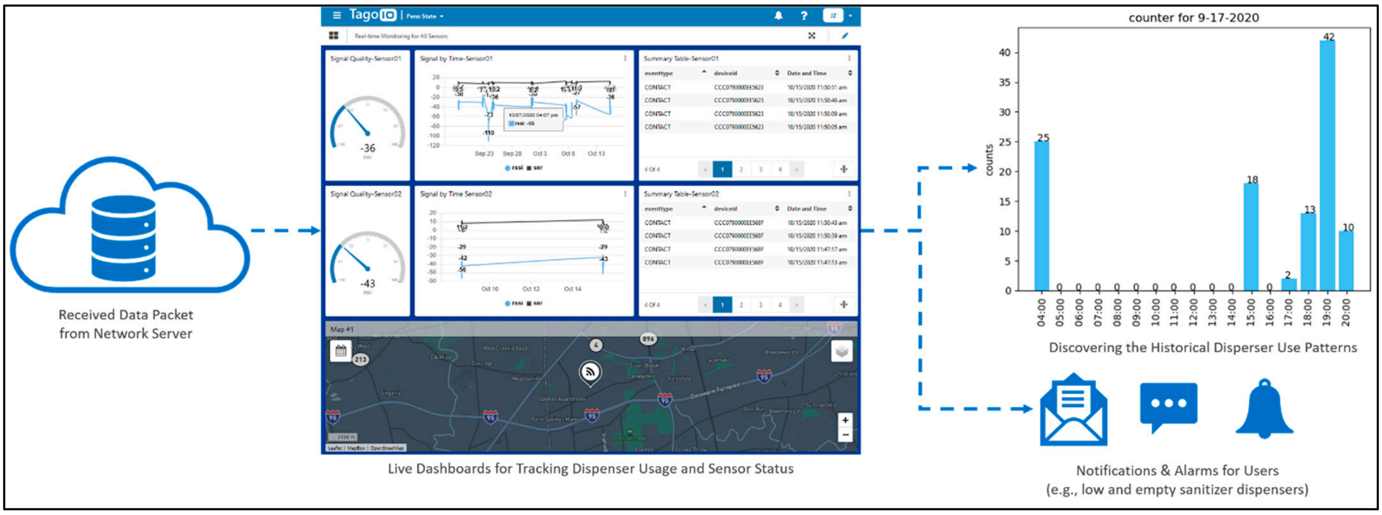


Figure 9. Functions of the application server.

2.5. Test of Sanitizer Dispenser Network Operation

After the design and development of the proof-of-concept prototype, this study proceeded to validate the proposed system through a two-step procedure. First, for a single end-node sensor unit, we conducted a lab experiment to test the performance of different sensor configurations for reducing the missed detection of sensor events (see Section 2.5.1). Second, we further deployed 25 end-node sensors on sanitizer stations in a building as a field test, which helped to validate the operation of proposed sensor network in a real-world application scenario (see Section 2.5.2).

2.5.1. Test of Sensor Configuration

During our initial testing of the sensor module, we observed that, when the dry contact input was rapidly connected and disconnected, the event could miss being detected. Further investigation uncovered two possible reasons for this: (i) the fastest sampling rate of the sensor module is every 250 ms (4 Hz), so connect/disconnect cycles faster than this may be missed; or (ii) the sensor module does not register the event when sending information to the network server. To address these issues, we reconfigured the sensor mode to be "quasi-real-time", in which the sensor keeps tracking the connect/disconnect events but stores this information on the sensor module, then sends out the cumulative counts at a fixed interval (e.g., every 10 minutes). Such an approach helps to mitigate the chance of conflict between dry contact detection and data communication.

A test was conducted to evaluate the effectiveness of reducing missed detections after the sensor module was configured as described above (see Figure 10 for comparison). Two dry contact sensors were connected then disconnected rapidly (about one connect and disconnect per second) 10 times, during which one of the sensors was reconfigured for data transmission at 1-min intervals and the other operated in real time. We repeated the test 10 times and compared the detected events from the two sensor modules. As the two sensors were connected/disconnected at the exact same time, the difference in the number of detected events could reflect the effectiveness of sensor configuration in reducing misdetection. The results of this test are discussed in Section 3.1.

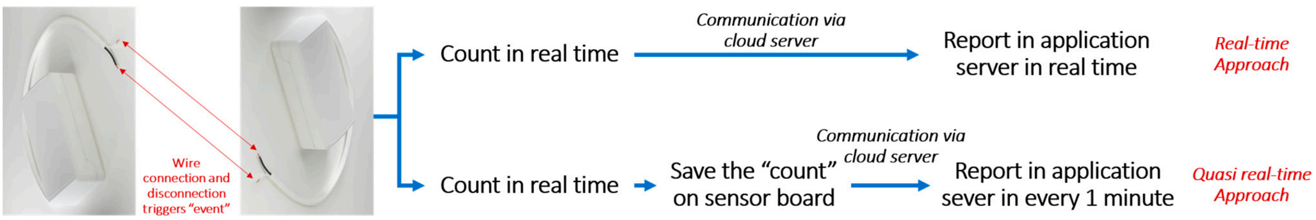


Figure 10. Comparison of two sensor configuration methods.

2.5.2. Field Test of Sanitizer Network Operation

To test the operation of the proposed approach in a real-world scenario, we further deployed the developed prototype on a university campus as a case study. The Hammond Building on Penn State's University Park campus was selected for deployment of the developed sensor units due to its size and the large number of installed sanitizer stations. The Hammond Building is a four-story (with sub-basement) building that was constructed in the 1950s using reinforced concrete with an aluminum frame curtain wall and internal metal walls. It has a total area is 159,912 sq. ft. [34] and represents an extremely challenging environment for radio-frequency propagation. As shown in Table 2 and Figure 11, a total of 24 sensors were deployed in sanitizer stations throughout the building. The gateway was deployed on the second floor, near the center of the building. The gateway was connected to the building's IT network via a 1000 BT wired connection.

Figure 11. Building layout with sensor module deployment and gateway indicated.

To test the gateway coverage and sensor signal quality, we kept all the sensors operating for five consecutive days from 1 to 5 January 2021. All the sensors were configured with a 10-min reporting interval that reported all the detected events within that interval. The test results are presented and discussed in Section 3.2.

Table 2. Sensor module deployment.

Device	Location
Gateway	2nd Floor (213) × 1
Sensors	1st Floor × 7 2nd Floor × 14 3rd Floor × 3

3. Results and Discussion

3.1. Test of Sensor Module Configuration

The objective of the sensor configuration test was to identify the proper sensor configuration for reducing the missed event detections. The results of the sensor reconfiguration test are provided in Table 3 The error rate in this test was defined as the ratio of missed event detections under different configurations. Results in Table 3 show the interval-based approach had an average error rate of 0.06 among 10 independent experiments. However, the real-time approach had an average error rate of 0.7, indicating over 70% of contacts in the experiments were missed. These results suggest that configuring the sensor module to an interval-based event transmission approach can effectively reduce the number of missed events when compared with the real-time approach. The results also indicate that the data transmission was the primary issue leading to missed event detection as both real time and interval-based approaches had the same sampling rate. As we discuss above, the sensor module can miss an event when transmitting data across the network. Of these two mechanisms, the second was the primary cause of missed events. Therefore, the interval-based sensor configuration was selected for a subsequent field test.

Table 3. Test results of sensor reconfiguration.

	Real Time		**1-min Interval**	
Experiment	Count	Error Rate	Count	Error Rate
1	3	0.7	9	0.1
2	2	0.8	10	0
3	2	0.8	9	0.1
4	3	0.7	10	0
5	3	0.7	7	0.3
6	3	0.7	10	0
7	5	0.5	10	0
8	3	0.7	9	0.1
9	3	0.7	10	0
10	3	0.7	10	0
Average	3	0.7	9.4	0.06

3.2. Test of System Operation in the Field

The field test aimed at validating the operation of proposed sensor networks in a real-world application scenario. In this initial study, we evaluated the signal coverage of the deployed sensor network and whether the messages from the sensors could be successfully detected when deployed at scale. The field test results are summarized in Table 4. After deployment of the sensor network in the Hammond Building, we first examined signal quality by sensor location, as shown in Figure 12 with sensor location illustrated in Figure 11. We compared the average signal quality, measured by RSSI, of the received signal from each sensor module over a five-day period. The results show the average RSSI of 23 sensors was −85 dBm, with all RSSI values above −120 dBm.

Table 4. Results of field test (order by error rate).

Location	Average of RSSI	Received Messages	Error Rate
Westmost entry	−108.5	2	0.997
212 classroom	−64.83	6	0.992
213 lobby	−37.86	7	0.990
219 classroom	−84.43	7	0.990
Mail room	−102.86	7	0.990
R111	−62.57	7	0.990
R309	−81.86	7	0.990
220 large classroom	−79.1	690	0.042
D139	−78.4	690	0.042
214 classroom	−55.6	695	0.035
R211	−63.48	696	0.033
R212	−63.47	696	0.033
R222 west elevator	−77.22	696	0.033
Stairs near walk thru	−78.03	696	0.033
153	−98.97	697	0.032
221 classroom	−86.05	697	0.032
215 classroom	−55.01	698	0.031
Stairs by parklet	−102.45	698	0.031
201H east elevator	−95.68	699	0.029
217 classroom	−74.12	700	0.028
3rd floor east elevator	−100.11	702	0.025
R319	−94.35	703	0.024
R235	−96.29	704	0.022

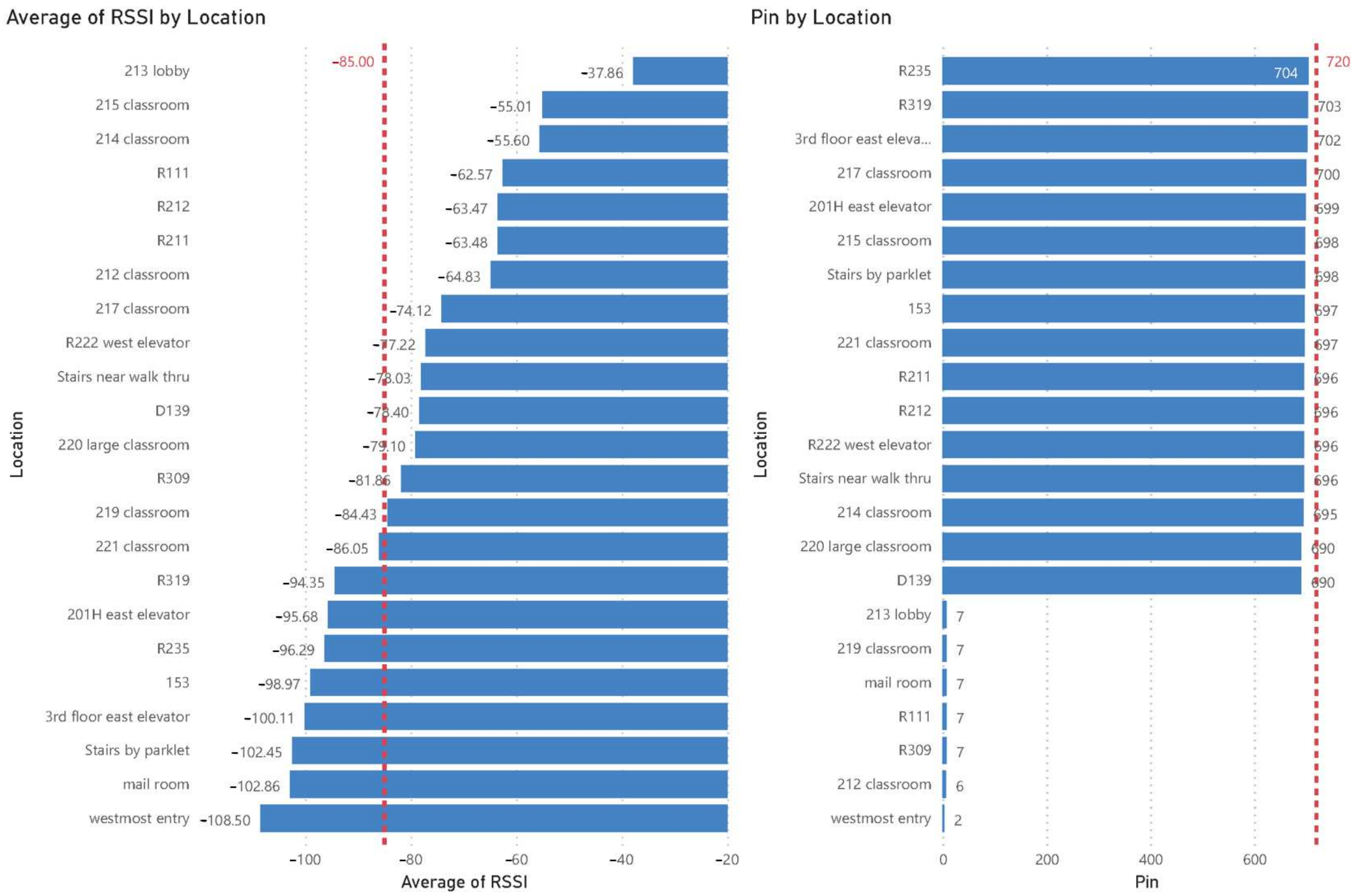


Figure 12. Sensor signal quality and received events by location (from field tests).

The results suggest that the received signals were of fairly good quality according to the standards suggested in [35,36]. Even the messages from sensors deployed on a floor different from the gateway location floor (such as R319 on the third floor and D139 on the first floor) could be successfully captured with low error rate of around 0.03. It is also important to note that data from one sensor installed near Room 205 were missing. This may not have been caused by low signal quality since signal quality was good for even the sensors installed on the first and third floors, farther away from the gateway. Room 205 was also close to Room 213, where the gateway was installed.

We then evaluated whether the deployed network registered all events sent from the sensors. If the sensors worked as configured, a total of 720 messages should have been received from each sensor (each sends out a message every 10 min over five days). The error rate in this test also denoted the ratio of event messages from the sensors that were missed. As shown in Table 4, 16 sensors worked properly, as we observed an average error rate of 0.03, and around 700 messages were received from each sensor. Other than the one sensor (Room 205) with the lost connection, seven sensors showed unstable connections with very few messages (no more than 7) received.

Figure 13 shows a further comparison of the number of received messages by sensor signal quality. Results showed that the low signal quality may not necessarily lead to the missing of messages from the sensors. For example, the sensor placed at the "stairs by parklet" worked properly even without a high-quality signal. The sensor with a strong signal quality could also miss packets, such as the sensor in the 213 lobby, closest to the gateway. Further work should be conducted to investigate the factors besides signal quality affecting the number of events received.

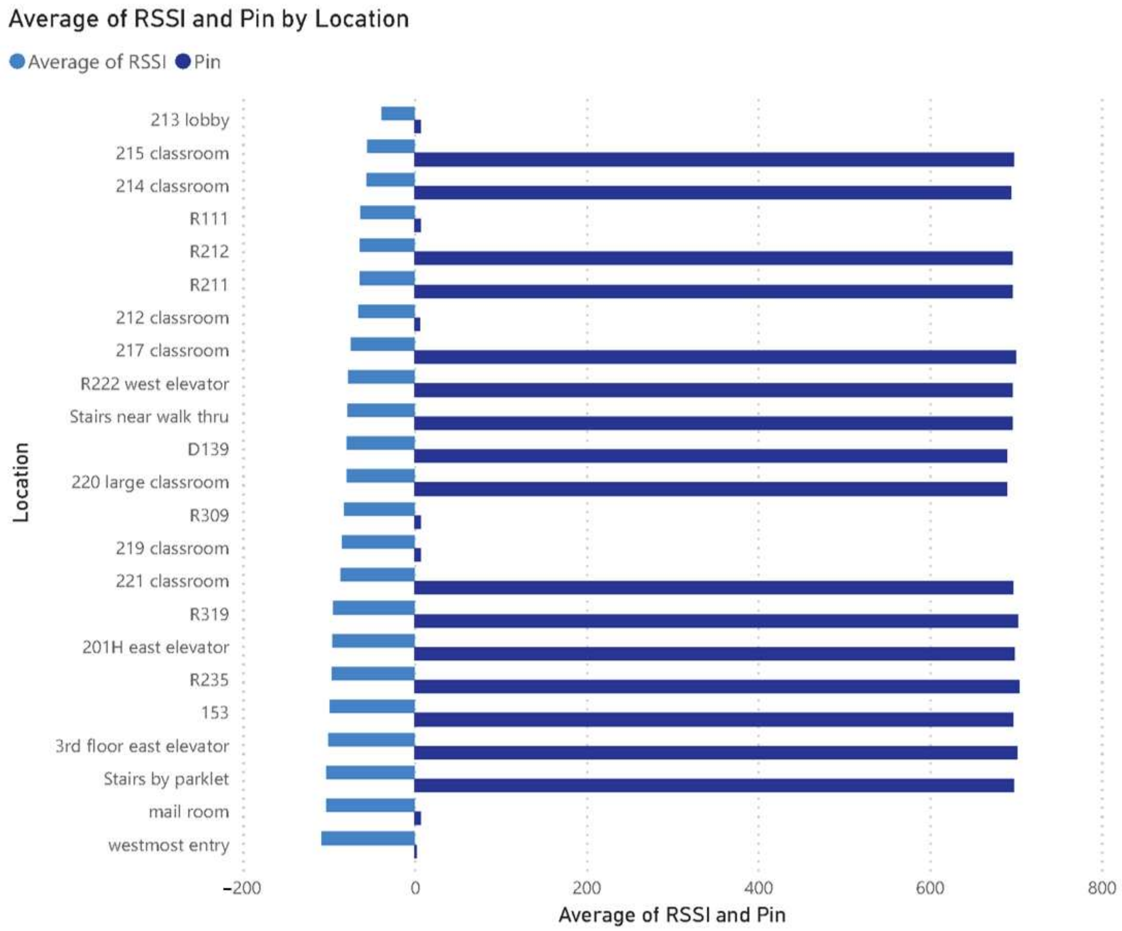


Figure 13. Comparing received messages with signal quality from the real-world field test. The sensors were ranked by their signal quality (high to low).

In summary, the test results suggest that the LoRaWAN network created by a single gateway has an acceptable signal coverage (measured by received signal quality) in a multi-story building on campus, which can support the scalable deployment of a sensor network in an urban environment. Most of the deployed sensors also demonstrated acceptable performance with relatively low missed packet rate, which indicates the deployed sensor units can work properly in the configured LoRaWAN network. It is also worth noting that signal coverage alone may not fully explain unstable sensor performance (denoted by a large number of missed events from sensors with good signal quality), which warrants further investigation in next research stage.

4. Conclusions, Limitations, and Further Work

4.1. Conclusions

In this study, we developed an IoT-based system for monitoring the usage of sanitizer dispensers in a public facility. The system integrated low-cost wireless sensors, 3D-printed housings, LoRaWAN, and cloud-based computing techniques into a proof-of-concept system. The modules were deployed in a building on the university campus for testing the system's operation in the real world. The field test showed that using a LoRaWAN network with a single gateway can successfully connect with sensors distributed throughout the entire building with fairly good signal quality. The developed system is able to detect events caught by the sensors for further analysis. In addition, configuring the sensor modules to transmit data at fixed intervals can effectively reduce the missed detection of events compared with a real-time approach. It is, however, important to note the factors besides signal quality that can impact the system operation, which warrant further investigation. Overall, research results demonstrate the potential of leveraging the IoT-based Sanitizer Station Network for tracking public health within large facilities, which ultimately contributes to alleviating the burden of public health during and after the pandemic.

4.2. Limitations and Further Work

The work discussed in this paper represents of a proof-of-concept system. Several limitations are noted regarding this initial study and warrant further research. First, due to the limited duration of the field test, there were limited data for estimating how many sanitizer station usages (i.e., push events) were needed to empty the sanitizer bottle. Obtaining such information will help to estimate the remaining sanitizer in the bottle and the time intervals between replacement. In addition, a rigorous statistical test regarding the system performance was not conducted in this initial study to assess the system performance, such as a systematic test of whether the error rate of the real-time approach was significantly higher than the interval-based approach. An extended field test is warranted for rigorous statistical analysis. In addition, issues other than sensor signal quality may impact the sensor operation stability, which warrants further investigation. Lastly, there were no "replacement" events detected from the field test. We tested if a bottle replacement event could be detected by removing and replacing a bottle during the field test, demonstrating the effectiveness of the compliant mechanism; however, further field validation is required to verify the 3D-printed module can distinguish the replacement events during the regular use of sanitizer stations.

Further studies will be conducted to fully realize the functionality of the proposed system and extend the current system for a broader application scenario. Below we outline the further works built on the current study.

First, to enhance the facility usage monitoring, we will calibrate the sanitizer dispensers regarding the number of push events needed to empty a full sanitizer bottle. Such information is helpful to infer sanitizer usage based on the utilization of dispensers.

Next, the information captured from the sensors can be integrated with applicable cloud services for scalable deployment. One such extension is integrating sensor location information with the geographic information system (GIS), such as using the ArcGIS Velocity cloud. Combining facility usage with location information would facilitate intelligent route planning and scheduling for optimizing the facility (i.e., sanitizer stations) maintenance workflow. To improve the scalability of the current system, we can also ingest the sensor's captured data to cloud servers such as Azure Event Hubs and IBM Watson. These IoT platforms would facilitate the usage of captured data across users with diverging interests and leverage more powerful intelligent tools for developing predictive models based on captured data.

Additionally, given that the current system focuses on detecting the "contact" events, the system can be readily adapted to monitor a broader range of similar public hygiene facilities, such as soap dispensers and trash cans. Moreover, the contact events captured in buildings are typically triggered by occupants. The detected contact events can be used as a proxy of occupants' behavior, which allows us to investigate the interaction between occupants and the building environment. One such application we are exploring is assessing the impact of occupants' behavior (e.g., window open/close) on indoor air quality [37] and building energy consumption. These applications ultimately contribute to the smart and healthy buildings environment.

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Article

Using IoT in Supply Chain Risk Management, to Enable Collaboration between Business, Community, and Government

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Abstract: The internet of things (IoT) and social media provide information related to disasters that could help businesses to strategically mitigate risks and optimize their supply chain during difficult times. This paper proposes a framework to show how business or supply chain enterprisers can collaborate with community and government in disaster supply chain risk management. Businesses must have an established risk mitigation plan, update it periodically and implement promptly. Community collaboration can build a resilient society, and government should play an important role in leading both financial and non-financial support during natural disasters and pandemic management. The IoT and social media are new mechanisms as a vocal point to enable government, ensuring trustworthiness of information, to provide the community with a means to express needs and feedback, and to assist business services to meet the changeable preferences under risk threats. Social media can be a collaborative effort between all the parties and helps make value added decisions efficiently in supply chain risk management.

Keywords: risk mitigation; social media; intervention policy; internet of things; community collaboration

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1. Introduction

In analyzing supply changing risk, the internet of things (IoT) has become an integral part of people's lives on a global scale, leading to challenges in supply chain risk management and contingency planning. Societies, businesses, and governments need to build resilience to cope with the associated and unpredicted risk in supply chain management.

There is extensive literature on risk management from the point of view of supply [1], information material and product flow risk [2], and global risk [3]. However, risk management frameworks have not widely included the IoT as part of 'traditional' strategies. The IoT has enabled the efficient propagation of social media, which has forced corporations to collaborate not only with industry sectors but also with political sectors [3] and social enterprises [4]. Di Domenico et al. [4] stated (p. 887):

> *These collaborations involve the formation of a political-economic arrangement that seeks to reconcile wealth creation with social justice, and the efficient functioning of markets with the welfare of communities.*

This has urged us to seek a new framework for IoT-driven supply chain risk management. This study uses an online open access survey data to discover how the community, business, and government can coordinate in building resilience during the COVID pandemic. An IoT based-supply chain risk management framework is developed to illustrate risk management strategies in this paper.

2. Supply Chain Risk Management

In this paper, we have emphasized the partners of collaboration to include the business, individual economic (consumers), and political (policy makers) sectors. We therefore reconceptualised the supply chain risk management definition, and we did so by combining the definitions of [5–7]:

> *The management process of supply chain activities for maximizing customer satisfaction and realizing a sustainable competitive benefit through the coordination and collaboration of every partner in the network both in physical process and information flows.*

In this definition, data on activities, customer satisfaction, and expected benefit can be achieved by IoT, social media, and traditional communication tools.

Due to globalization as well as unpredictable natural disasters, the definition of supply chain risk management can be redefined as follows, based on the previous definition of [6,8]:

> *The management of supply chain risks through coordination or collaboration among all supply chain partners to create a dynamic perspective of knowledge creation and transfer and to ensure profitability and continuity.*

Under this definition, supply chain risk management looks at the sources of risk discussed in [3,9] as:

- supply risks: inventory, raw material price, quality of material and design of material
- operation risks: manufacturing capacity and process, changes in technologies and operating
- demand risks: market changes and demand distortion
- information security risks: information system security, freight, and transportation breaches
- macroeconomic risks: changes in wage rates, interest rates, exchange rates, and commodity prices
- policy risks: national regulation restrictions and international/geographical sanctions
- competitive risks: market shares between competitors and technological advantages
- resource risks: resource scarcity, dated technology, finance, and market.

Risk management aims to mitigate the risks, and ensure that the supply, demand, product, and information sectors are profitable and that there is continuing collaboration with all partners, including community and political agencies.

Previous research has discussed coordination and collaboration in risk management through IoT [10,11], and there are many theories on how social media affects citizens' resilience [12,13] and the involvement of political agencies [3]. However, there is no theoretical framework for bringing all businesses, communities, and policy makers into one network, linked by IoT and social media, to improve supply chain risk resilience.

3. Political Coordination in Supply Chain Risk Management

When supply chain risk is caused by globalization or a natural disaster, businesses and communities face unpredictable risks from economic, political, logistical, competitive, cultural, infrastructure, and environment challenges [3,14]. Generally, one supply chain player's operation system may be disrupted and then in turn interrupt other supply players. If resources in the environment face a supply challenge, the allocation of resources impact community welfare, so political intervention becomes necessary. Policy makers can act as negotiators and decide to mitigate risks and maximize benefits, thereby contributing to the welfare of the whole community. Policies need to consider how to support vulnerable businesses as well as the social and environmental impacts.

Political intervention aims to provide high resilience for both business and individual economic agents, through financial subsidies to reduce their level of risk impact so that they can recover from the disruption as quickly as possible. On the other hand, a policy may also create a barrier for risk mitigation, if it has not been updated to accommodate the new risk phenomenon for the supply chain. In addition, policy regulation is characterized as having a limited capacity to mitigate large-scale social and environmental risks, so it may not be able to strengthen social resilience [15]. Sometimes, policies have generated additional costs by their unintended effects on competing social groups [15,16]. Therefore, the power of a policy may be derived from social actions or social order derived from human action [16], both of which can be obtained from IoT.

4. IoT for Community Collaboration in Supply Chain Risk Management

IoT has linked the digital technology of the internet, wireless network, and sensors to physical technologies [11] such as computers and mobile phones. The literature has focused on the application of IoT to business operation and communication in the supply chain. [7] discussed how to use a smart supply chain in a business system, and [11] defined IoT based on a review of technology, interpersonal communication, application, business, environment, analytics, development, process, and networking. The consumer feedback loop has been discussed in [17] for a blockchain-based demand forecast system that consumer preferences can be fed into. This paper defines IoT based on [11] (p. 938):

Technology, which is intuitive, robust, and scalable, that enables digital transformation of the connected world and people through internet and communicates all the relevant information in real time across the value chain.

Social media is a well applied communication tool using IoT technologies that can capture social actions in risks and uncertainty, provide the community with needed information when disruptive phenomenon happen, and help reduce the uncertainty of the situation [12]. Social media is closely linked to social domain, a domain response to a disaster through knowledge accumulated through case studies, the anthography of the social group, systematic discussions and actions, and the use of narrative to analyze social groups. Social media is influenced by social networks, which are the relationships between people and the structures that are formed by understanding their interaction patterns. Each member in the domain is tied to one another, demonstrating the structure and process of the social network [18]. In addition, a social domain and network are dynamically bonded in a risk situation by the IoT technologies. Social media empowered by IoT can include social domain or network in supply chain risk management.

Cross-sector community and policy collaboration require an open information system, where each actor can share their perception of risk levels and impacts; some researchers call this an inter-organizational collaboration [19]. The major contributor of social media is through internet podcasting or chat platforms, such as Facebook, signal, Viber, Telegram, WhatsApp, Microsoft, Band, WeChat, Skype, Twitter, and so on. Some of the information is transferred by traditional channels, such as TV, newspapers, telephone, radio, etc.

Because supply chain risks are complex, to mitigate the risks, there is a need to bring in the outside players of government and community using IoT and social media to help tackle the issue of being more prompt, dynamic, and connected.

5. Build an IoT Based-Supply Chain Risk Management Framework

This study uses COVID-19 pandemic online shopping as a case study to argue how the IoT has been utilized to resolve the risk situation. The data used are open access data and reports that have been published via the internet, such as the survey results shared by International Post Corporation, Australia Post, the Australia Bureau of Statistics, and government documents.

First, community members are under stress and panic during a disaster and uncertainty, if they have never experienced the same type of disaster and they do not know how to cope. When people have different perspectives that are related to their sociodemographic backgrounds, they respond differently from one to another. Sometimes, a relatively small number of the public react in a typical way which could amplify the issue into a society-wide issue. The public has a natural instinct to change their demands for goods (which may be more than they need) and consequently, this demand may affect supply. Businesses who have to learn and cope with these consumer-driven changes in order to keep a stable supply chain during a disaster could overcome and thrive from the disaster with success.

Consumers' panic buying has been shown as the norm in many disasters if they are foreseeable; for example, the COVID-19 city curfews from March 2020 caused a toilet paper shortage in Australia. The public is generally concerned about material shortages, service shortages, or inconveniences. While, the situation can be softened by providing support to the community, issuing accurate and positive media information, promoting high social responsibilities, increasing the supply of goods, and creating policy interventions on supply.

During the COVID-19 period, there has been a shift of online purchasing from international retailer to domestic retailers. Figure 1 shows the survey conducted by International Post Cooperation [20]. In Australia, there has been an increased demand in using smart technologies of mobile phone, laptop computer, tablet, and Smart TV for shopping [20,21]. In Figure 2, 57% of shoppers started to support local retailers, and from the business side there were 73% of small and medium Australian businesses who expressed that they changed their business operations model to help build company and society resilience and mitigate the challenges [21]. The buyers were also increasing their utilizations of different devices, with 91% using mobile phone in 2020 compared with 87% in 2019. It is surprising that Smart TVs have become popular shopping equipment, increasing up to 60%. This followed a high usage of credit cards to buy online. These utilizations of smart technology present new opportunities for businesses.

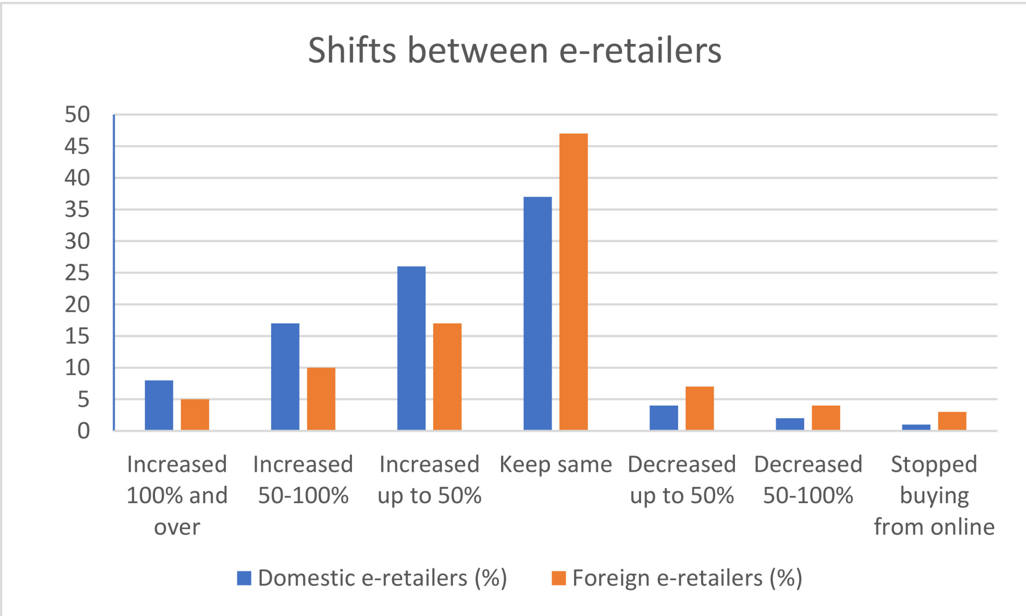

Figure 1. Domestic e-retailers vs foreign e-retailers during COVID-19.

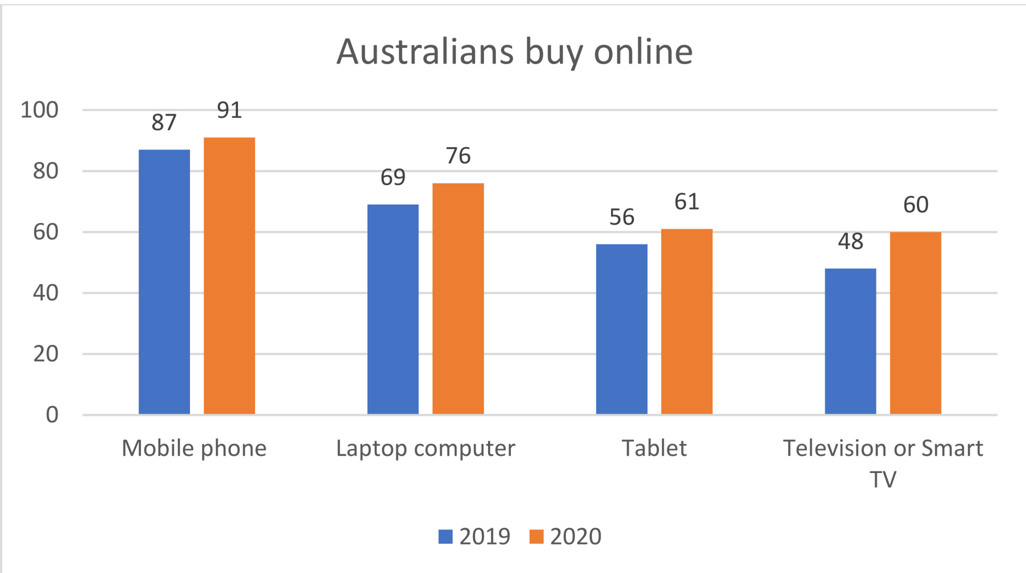

Figure 2. How Australians buy online.

Second, businesses are the central risk-mitigating players in a disaster. The successful suppliers are the ones who have turned their business orientation to online marketplaces named software as a service, including updating online stores and social media profiles and building up strong social connections with customers via online channels as well facilitating order fulfillment for stock, delivery, and pick up point. These companies have also improved the availability of real time data, for example, by providing delivery information via mobile phone messages and by using photographic evidence rather than signature receiving. The IoT based-supply chain management has helped successful companies to connect with customers in the COVID-19 lock down period. It can also measure customer satisfaction. Figure 3 shows the survey satisfaction [20]. Parcel tracking and delivery speed show more space for improvement than the delivery location, cost, and return. This feedback information can be a part of big data generated via online software services to further develop the adding value decision.

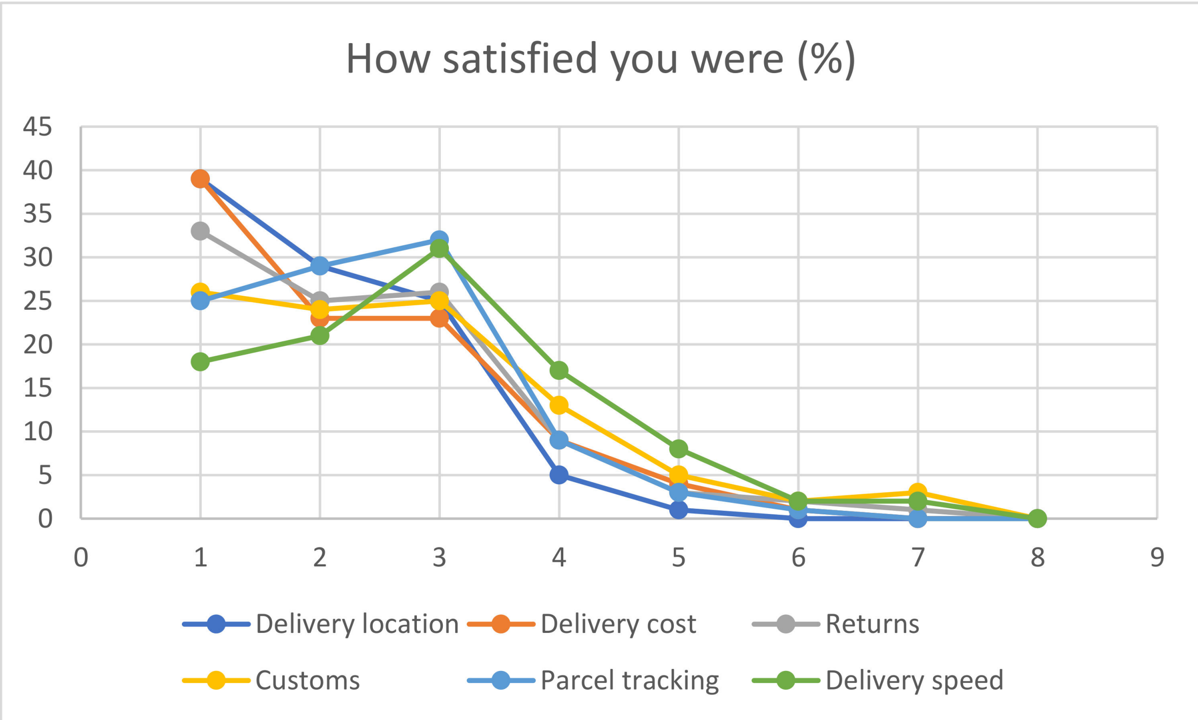

Figure 3. Satisfaction feedback for value adding projects.

Business owners need updated business plans that can incorporate different levels of risk impacts, and flexible structures to cope with limited resources or disruptive situations while keeping their business competitive. Internally, they will need to periodically review and build flexible procurement processes and flexible delivery channels for customers; for example, developing extra qualified suppliers or a close relationship with customers to be able better understand their unpredicted needs and therefore deliver required product. Businesses need to satisfy consumers and, at the same time, establish good communication with the political regulations that are issued to respond to the specific disaster. Businesses also need to consolidate their integrity and ethically gain profit without taking advantage of the disaster. On the other hand, the disaster can be a chance for a company to build a reputation and goodwill for future profit. Businesses need to execute special product distribution strategies and ensure higher social welfare to benefit the maximum number of community numbers.

Third, policy makers, who hold the power as an authority coordinator, need to intervene and maintain stability. They need to provide financial and non-financial support and release the right information to the public and businesses to mitigate risk. Policies for supporting individuals and households have been spread in many countries to reduce the economic impact of the Coronavirus. For example, in the US, there are several economic and various fiscal and monetary policy implementations to cope with the COVID-19 crisis. The EU has implemented a recovery plan for Europe, where there will be €1.8 trillion of stimulus package to reboot a green, digital. and resilient Europe [22].

In Australia, due to the unemployment rate reaching a high of 13.8%, 1.8 million people had their work reduced in the COVID lock down period in the second quarter of 2020. The Australian Government provided support for employers and employees with the JobKeeper Payment Program. Payments were provided to eligible employers from the 30 March to the 27 September 2020, then extended at a reduced level from the 28 September 2020 to the 31 March 2021 for eligible income recipients, allowed temporary access to superannuation to 31 December 2021, and provided pensioners, seniors, and careers and concession card holders to receive two separate $750 payments and two additional payments of $250 each [23]. After August 2020, there was a job recovery (except in Victoria where lockdowns persisted). By March 2021, the economic environment is almost back to normal [24]. These stimulus packages contributed to a year over year increase in demand for household goods, while after Job-Keeper ended, the retail industry still faces big challenges.

Since social media should be validated and updated to reduce confusion and therefore enable the public to obtain the best information they need to make their decisions. The government can regulate businesses to enable the best outcome for the community and the allocation of natural resources. Normally, governments have quickly set up community-supporting services, the most powerful ones providing financial subsidies together as well as calling for volunteers, to help communities survive a disaster. Governments also have stronger influence in disaster strategic decision-making; a well-considered disaster plan with the quick set up of an expert team for decision-making would help society to build resilience. A social media resource established by government is considered to be trustworthy by community and businesses. In addition, the government can easily centralise leadership in a disaster.

During the COVID-19 pandemic, the setting of a curfew showed government leadership and a quick response to mitigate the disaster. The Australia Government shifted to using Facebook media as its official news channel to issue updates in case numbers in order to get larger audiences. They urged businesses to issue restrictions on the number of people in-store and limit the number of high-demand goods, such as toilet paper and milk in Australia. They also decided which businesses or services should open or close. The government also quickly created additional services for older people to help them with their shopping. Since, in general, older people do not use the internet, traditional communication methods such as phone calls were used.

An IoT based-supply chain risk management framework will help researchers and practitioners quickly access the necessary and prioritized information from abundant sources. This framework is a collaborative structure between businesses and external players of government and community, with an information flow that is appropriate and efficiently applied in supply chain risk management. How can a framework help reduce risk impacts by collaboration?

The framework (Figure 4) shows supply chain material flow, information flow, and political intervention process flow, as well as related risks. Under low-risk circumstances, supply chain management runs as normal to maximize profit: products are processed to transport to consumers according to market demand, IoT, and social media coordinate with business operations and common market promotions, policy, and regulation intervene for long-term business environment and material.

Supply chain management changes pace when disasters and uncertainty take place. The media provides information for a typical disaster, then the public, businesses, and governments receive the media and make their own decisions or action plans. Some of the reactions are rapidly shared on social media, and they form a dynamic and interactive information system through IoT.

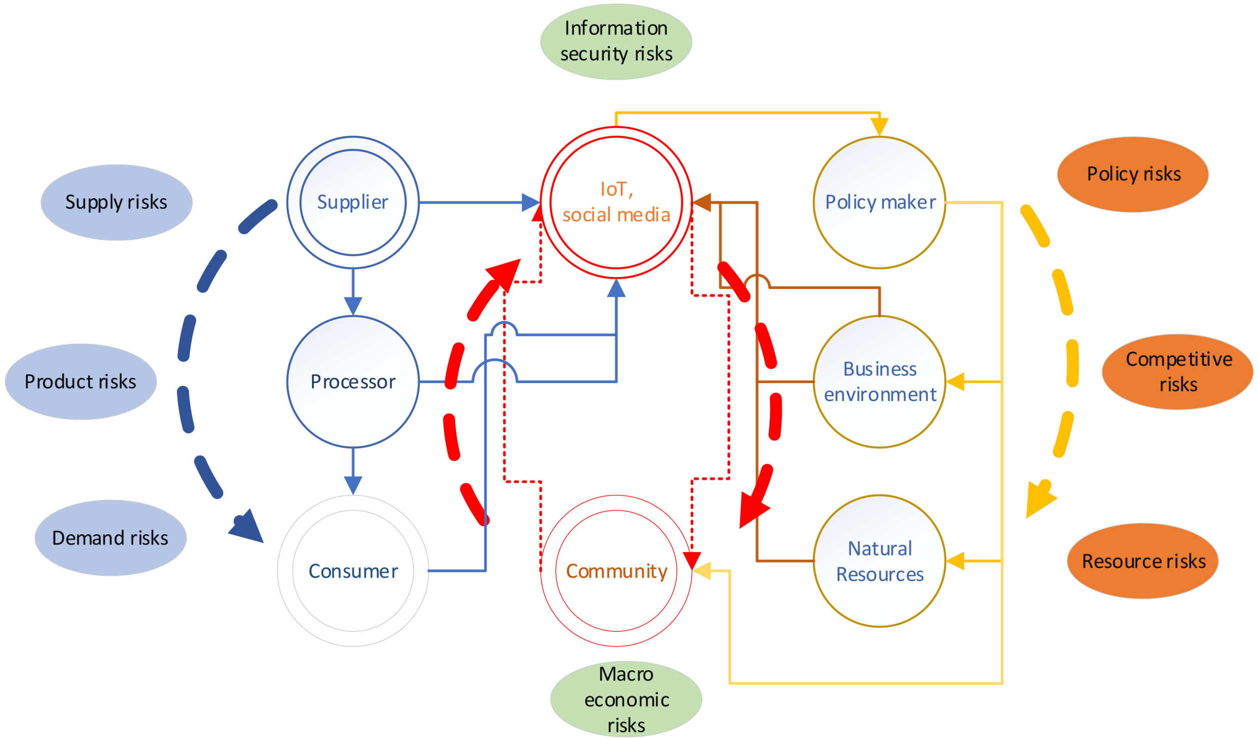

Figure 4. IoT-based supply risk chain management and information flow.

6. Validating the Framework through Case Studies

The COVID-19 pandemic is new to society, and countries that successfully coped with the pandemic showed high awareness in business markets, quick adaption and high resilience. This showed in other disasters, such as earthquakes in Japan, drills are conducted regularly, so people have built a resilience in dealing with earthquakes. In Australia, bushfire prevention and decision-making to cope with bushfires have been widely implemented across the community.

In the disasters, businesses were heavily impacted by restricted opening hours, restricted customer attendance, and logistics disruptions. In some countries, there were financial subsidies for businesses and workers which has stimulated a different economic phenomenon, for example, COVID-19 has accelerated online shopping, and the countries that had the lowest proportion of online shopping had the biggest increase. While, it also generates the biggest bottleneck that was the delivery of online purchases during the lockdown, and online shopping for some services was closed because of a lack of delivery services. A systematically designed supply chain network is needed, such as by providing the closest pick-up spots, etc., to optimise transport and minimise the bottleneck impacts.

From the discussion what we saw during the COVID-19 pandemic, the proposed framework demonstrates good utilisation of IoT and social media, which helps external partners to collaborate in mitigating risk during a disaster. In addition, there are some other issues, such as supply chain network and community support, they can be tackled by the support of an IoT- based system. Overall, the framework can be used for supply chain risk mitigation by following these steps:

(1) Collect/validate/release necessary information via social media
(2) Communicate and update the risk level and its potential impacts
(3) Develop and implement risk mitigation plans
(4) Encourage support and build resilience for community and business

Under the framework, the community would seek the best opportunities to adapt to risk influencing the situation, while businesses will need to respond quickly and accordingly to cater to community needs and provide IoT-based services to meet demands and to collect feedback. Policy makers always are an invisible hand to influence the level of resilience to be built in community and businesses for healthy economic environments.

7. Conclusions

To create an effective risk mitigation instrument, only validated information should be shared; flexible business supply chain models should be established; the powerful risk mitigation enabler of government should create right strategies and supports (financially and non-financially); and there must be resilience in community and business. The use of effective information tools for collaborations would help mitigate risk during disasters.

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smart cities

Article

IoT-Enabled Solid Waste Management in Smart Cities

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Abstract: The Internet of Things (IoT) paradigm plays a vital role for improving smart city applications by tracking and managing city processes in real-time. One of the most significant issues associated with smart city applications is solid waste management, which has a negative impact on our society's health and the environment. The traditional waste management process begins with waste created by city residents and disposed of in garbage bins at the source. Municipal department trucks collect garbage and move it to recycling centers on a fixed schedule. Municipalities and waste management companies fail to keep up with outdoor containers, making it impossible to determine when to clean them or when they are full. This work proposes an IoT-enabled solid waste management system for smart cities to overcome the limitations of the traditional waste management systems. The proposed architecture consists of two types of end sensor nodes: PBLMU (Public Bin Level Monitoring Unit) and HBLMU (Home Bin Level Monitoring Unit), which are used to track bins in public and residential areas, respectively. The PBLMUs and HBLMUs measure the unfilled level of the trash bin and its location data, process it, and transmit it to a central monitoring station for storage and analysis. An intelligent Graphical User Interface (GUI) enables the waste collection authority to view and evaluate the unfilled status of each trash bin. To validate the proposed system architecture, the following significant experiments were conducted: (a) Eight trash bins were equipped with PBLMUs and connected to a LoRaWAN network and another eight trash bins were equipped with HBLMUs and connected to a Wi-Fi network. The trash bins were filled with wastes at different levels and the corresponding unfilled levels of every trash bin were monitored through the intelligent GUI. (b) An experimental setup was arranged to measure the sleep current and active current contributions of a PBLMU to estimate its average current consumption. (c) The life expectancy of a PBLMU was estimated as approximately 70 days under hypothetical conditions.

Keywords: Internet of Things; solid waste management; trash bin; LoRaWAN; Wi-Fi; smart city; remote monitoring

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1. Introduction

The Internet of Things (IoT) is a concept that refers to the ever-expanding network of internet-connected devices that are currently in use all over the world. Despite the current Covid-19 pandemic, the Internet of Things industry is growing, and it is estimated that around 30 billion IoT connections will exist by the end of 2025 [1]. Advanced smart sensors, cloud computing, big data, lightweight communication protocols, open-source server programs, and web development tools are the enabling technologies that accelerate the development and deployment of domain-specific IoT systems [2]. These interconnected devices can bridge the gap between the physical and digital worlds to enhance life, culture, and productivity. IoT has already exhibited promising approaches towards domain-specific applications such as Smart Homes [3], Smart City [4], Agriculture [5], Wearables [6,7], Smart Grids [8], Industrial Internet Telehealth [9], and Smart Supply chain Management [10].

IoT plays a pivotal role in enhancing smart city applications through real-time monitoring and management of city processes. One of the biggest challenges associated with smart city applications is solid waste disposal, which impacts our society's health and nature. Solid wastes are produced as a result of human and animal activities and are typically discarded as useless [11]. Annually, the world produces 2.01 billion tons of urban solid waste, with at least 33% not being handled in an environmentally friendly way. By 2050, global waste is estimated to reach 3.40 billion tons, more than doubling population growth over that period [12].

The conventional waste management process begins with waste being generated by residents in cities and disposed of in trash bins at the point of creation. At a predetermined schedule, municipal department trucks gather the garbage and transport it to the recycling centers. Municipalities and corporations struggle to keep up with the outdoor bins to determine when to clean them or whether they are completely filled or not. One of the most pressing issues of our time is the prevention, tracking, and treatment of these wastes [13]. The conventional method of manually inspecting waste in bins is a time-consuming procedure that requires more human labor, time, and money which can be eliminated with today's technology [14].

Several WSNand IoT-based remote monitoring systems have been developed and deployed to address the aforementioned limitations of conventional waste management systems [15,16]. For tracking the bins, some of the monitoring systems used short-range wireless networking techniques including Bluetooth, Infrared, ZigBee, and Wi-Fi [17–19]. Similarly, a few works described smart bin monitoring systems that employs wide area network technologies such as NB-IoT, Sigfox, and LoRa [20–22].

As most homes are equipped with wireless internet connections, it is inferred that the Wi-Fi-based solution is well suited for monitoring the household bins. This will minimize the additional infrastructure expense. However, it is unsuitable to monitor trash bins in public places. Similarly, LoRa-based monitoring techniques are appropriate for monitoring bins in public areas. However, these methods are not preferable for monitoring bins at home because they would incur additional costs for the implementation of gateways and other facilities. According to the literature, none of the current solid waste management methods discuss the need for a hybrid architecture to efficiently manage solid waste in smart cities. Therefore, this work proposes an IoT-based solid waste management system for smart cities. The main contributions of this work in contrast to the existing solutions are as follows.

- Hybrid network architecture to monitor the household and public trash bins.
- Solar energy harvesting facility to extend the life time of the end nodes.
- A GPS module is embedded to evaluate the Geo-location of the trash bins
- An intelligent GUI is employed to view the status of every trash bin.

The remainder of this article is organized as follows. Section 2 presents the related work. Section 3 describes the proposed network architecture and Section 4 presents the results of the experiments performed. Finally, Section 5 concludes this article.

2. Related Work

Improper waste discharge, lack of systematic waste collection and management schemes, and ineffective waste management practices have all resulted in severe environmental issues and high waste disposal costs [23]. Because of the positive outcomes of IoT services, various waste management studies focused on IoT technologies have been undertaken by researchers to address the aforementioned issues involved in solid waste management. Construction industries, food processing industries, etc. consistently produce a portion of waste that has notable residue enhancing the significance of the application of waste management practices and sustainability principles [24].

Several works have been published that cover various aspects of waste management technology. A basic framework that recognizes the saturation of trash bins is presented in [25], in which the gathered data are transmitted via a wireless mesh network to conserve power and increase operating time. Besides, the smart bin employs a duty cycle strategy to cut down on power demand and increase operating time. For experiment validation, this approach was tested in an outdoor environment, which demonstrated the feasibility of the system. However, the system still has some unclear issues with the implementation. In [26], a food waste collection system in which data were gathered using radio-frequency identification (RFID) technology and distributed through a wireless mesh network is presented. However, the system fails to address the data gathering possibilities from the trash bins which are located in far places as cities cover a wide area. An automated line-following automobile with a robotic hand for waste collection is proposed in [27], but it lacks any algorithms to make the waste assemblage more efficient. An intelligent bin emphasized system is proposed in [28]. To prevent waste disposal outside the bin, this work recommended a method in which monitoring happens not only within the bin but also in the immediate area around it. Infrared sensors are mounted in the bins, which sense discarded garbage from a bin as well as to measure the bin's filled level.

A waste treatment and management system based on LoRaWAN technology is proposed in [29], a path optimization for the waste collection trucks is also mentioned in this work. Furthermore, an IoT-based network framework is proposed, but it did not offer lucidity about coordination and optimization for all garbage bins in the system. Another work in [30] developed a working prototype of smart trash bins. The proposed work focuses on segregating different forms of waste for better treatment and recycling. An integrated GPS module provides geotagging to the bins, a gas detector that senses hazardous gases, an infrared sensor that determines the filled level of the bin, a sound sensor for noise emission control, and a temperature and humidity sensor are all used with each bin. Sensors are linked to a microcontroller, which collect data and send it to a gateway through a LoRa transceiver module. The sensor data from multiple garbage bins will be received using a gateway module with a LoRa transceiver. The data will be processed locally, and the processed data will be sent to the cloud via TCP/IP and the MQTT protocol. The cloud server is enabled in such a way that alerts can be sent according to the waste levels of the bins. Furthermore, an AI-based algorithm runs to provide an optimized route for the waste-collecting trucks. An automated cloud-based sensing framework with mobile app-based control is presented in [31]. This work's unique feature is the ability to detect foul gases as well as the amount of waste present in the bins. The proposed work in [32] suggested an intelligent trash bin monitoring system that aims to detect the filled levels of the bins and send them to a central monitoring station at far locations. This system was designed to learn from previous experiences and forecast future states based on variables such as traffic congestion in the environment where the waste bins are located, cost efficiency balance, and other factors that are difficult for humans to observe and analyze.

From the literature, it is evident that the current systems are not covering all aspects for a full-fledged deployment of smart waste management systems in smart cities. The sensors and communication technologies adopted for the network architectures are to be evaluated in real-time for the feasibility of the developed systems. The frameworks need to be designed to manage household bins and public bins in smart cities. Moreover, the sensing nodes need to be power efficient and self-powered under long-term monitoring aspects of smart waste management systems.

3. Network Architecture of the Developed System

The network architecture of the developed IoT enabled solid waste management system is shown in Figure 1. It follows a hybrid network architecture to manage the trash bins in public places and residential areas effectively. The architecture comprises end sensor nodes, namely, Public Bin Level Monitoring Unit (PBLMU) and Home Bin Level Monitoring Unit (HBLMU) for monitoring the trash bins at public places and residential areas, respectively.

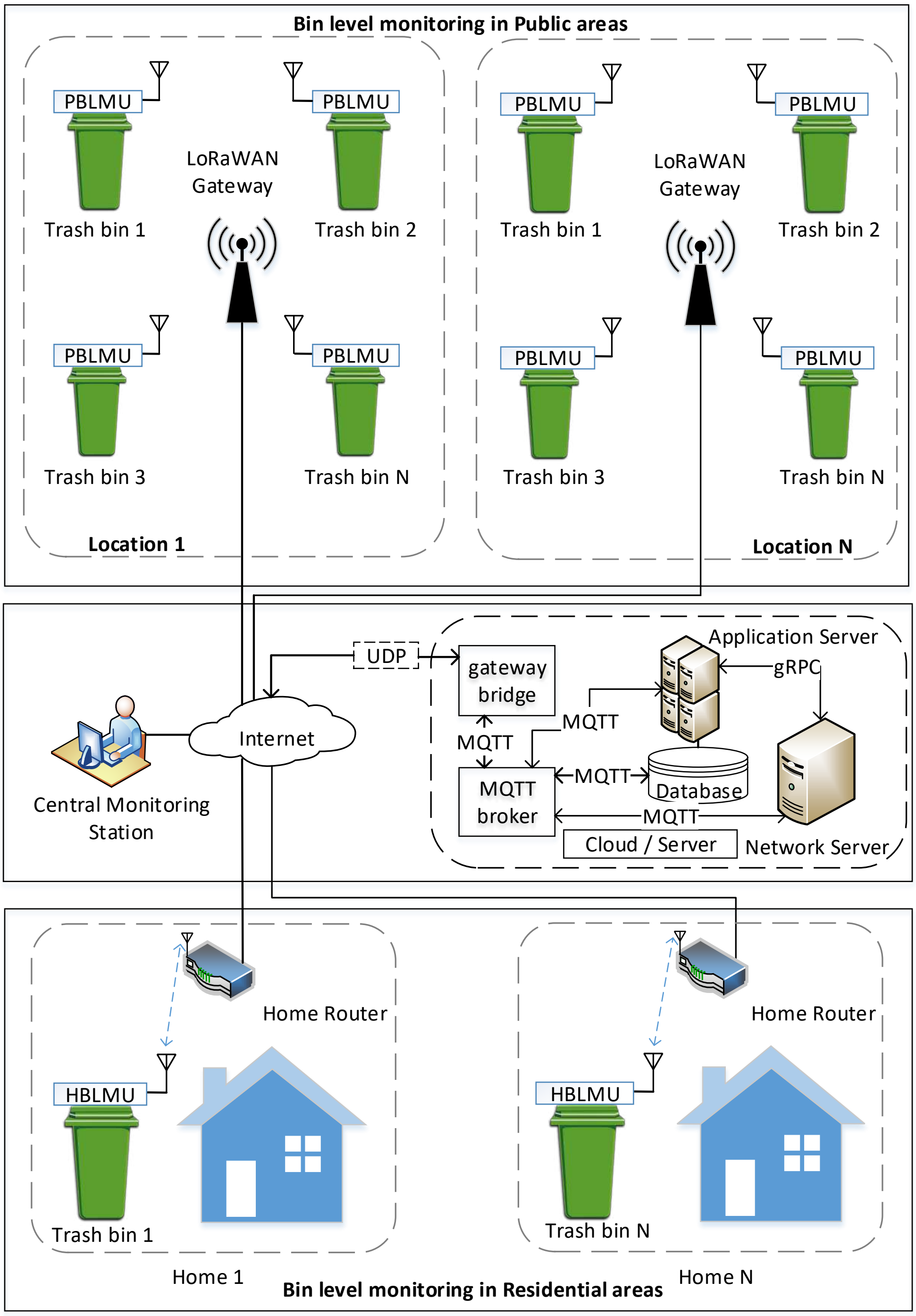

Figure 1. The network architecture of the developed system.

A LoRaWAN networking architecture is adopted for the deployment of PBLMUs, whereas a Wi-Fi-based communication is adopted for HBLMUs as the trash bins are associated with homes. The PBLMUs use a frequency of 915 MHz to relay unfilled level and geo-location data from trash bins to the LoRaWAN gateway. The data from the PBLMUs are collected by the LoRaWAN gateway and uploaded to the server for storage and visualization, whereas a Wi-Fi module is integrated in the HBLMUs to get connected with the home routers for uploading data to the central monitoring station. The data are published into the server from the PBLMUs and HBLMUs through the MQTT broker which follows a publish-subscribe communication model. The PBLMUs and HBLMUs are the publishers that send data to the predefined topics of MQTT broker and the central monitoring server is the MQTT broker's subscriber, receiving data from it. The features such as low power consumption, rapid data transmission, lightweight nature, and ease of implementation make MQTT protocol very attractive for IoT-based remote monitoring systems. Through the intelligent GUI, the authorized persons can monitor and analyze the unfilled levels and the respective geo-locations of all the trash bins for the efficient waste collection.

3.1. Design of the PBLMU

The PBLMU is designed to collect the unfilled level and geo-locations of the trash bins located in public places. The block diagram of the designed PBLMU is shown in Figure 2. It comprises of an ultrasonic sensor and a GPS module to measure the unfilled level and the geo-location of the trash bins, respectively. A LoRa module is equipped with the PBLMU to establish the LoRaWAN network with the LoRaWAN gateway. Further, a power management unit is integrated to provide the required supply voltages to all the components of the PBLMU. Additionally, a solar panel is attached with the power management unit for energy harvesting and self-powering of PBLMUs since they are powered with batteries. A brief description of the components of the PBLMU is provided here.

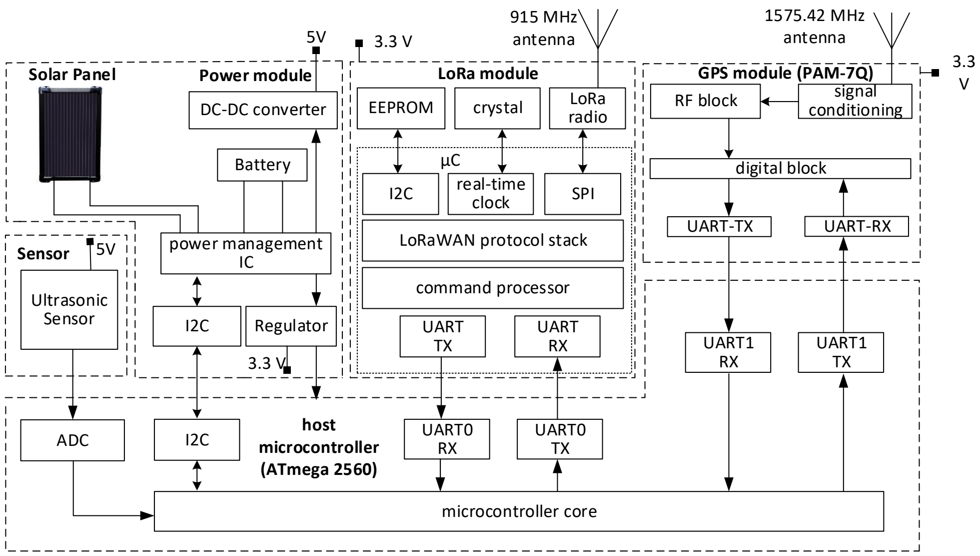

Figure 2. Block diagram of the Public Bin Level Monitoring Unit (PBLMU).

3.1.1. Ultrasonic Sensor

The ultrasonic sensor equipped in the PBLMU is a MB1010 LV-MaxSonar-EZ, which is lightweight, small in size, and commercially available. It is a cost-effective and dependable sensor with high accuracy, stable range detection, and a high-quality beam. With this sensor, high-frequency sound waves (42 kHz) are produced, and the sensor evaluates the back-received echo. A wide range detection of solid waste ranging from 0 m to 6.45 m is possible with this sensor covering objects from very short to long range. This sensor is so accurate that there is no dead zone within the sensing range. The sensor outputs three different types of data at the same time: RS232 serial output, analog voltage output, and pulse width output. The sensor's actual operating temperature range is −40 °C to +65 °C but the recommended temperature range is 0 °C to +60 °C. When the sensor is in triggered operation, it provides the desired reading range, allowing the unfilled level of a trash bin to be measured. A sensor operating in free-run mode, on the other hand, can continuously measure and output the range information.

3.1.2. GPS Module

Several trash bins must be placed to manage solid waste over a large area. For the garbage truck to collect garbage, the geolocation coordinates for each trash bin is necessary. Manually recording the geolocation data of a large number of trash cans is a time-consuming task. Furthermore, the geolocation data aid in the identification of moved trash bins, stolen trash bins, as well as determining the shortest and most effective route for garbage collection. To collect the geolocation coordinates of each trash bin, the PBLMU is integrated with a PAM-7Q GPS antenna module. Embedded antenna, low power consumption, clear interface, high sensitivity of −161 dBm, and sophisticated interference suppression are all features of the PAM-7Q, ensuring optimum efficiency even in hostile environments. The PAM-7Q's unique feature is its ability to achieve RHCP with a smaller patch antenna. Installation costs are kept to a minimum with the simple design and easy interfacing of an 18 mm × 18 mm patch antenna. To minimize the PBLMU's average current consumption, the GPS module is configured in a power-saving mode called ON/OFF service.

3.1.3. LoRa Module

Each PBLMU is integrated with an RN2903 transceiver module to send data over a long distance while using minimal power. The RN2903 module achieves high interference immunity by using spread spectrum modulation. Every transmission is configured to use US902-928 MHz ISM band in a pseudo-random fashion to make the system more resistant to interference. The RN2903 module is operated by a 3.3 V DC supply and communicates with the host microcontroller using a UART. The RN2903 has a sensitivity of −146 dBm and a transmitting capacity of 18.5 dBm that can be adjusted. It can also be programmed and managed over a UART port using ASCII commands. The RN2903 consumes 124 mA when transmitting at full power, and 13.5 mA in reception mode.

3.1.4. Host Microcontroller

The host microcontroller is the heart of the PBLMU; it is responsible for controlling all the functions of the PBLMU. In the PBLMU design, a high-performance, ultra-low-power, and advanced RISC architecture-based 8-bit Atmel ATmega 2560 microcontroller serve as the host microcontroller. The host microcontroller's peripheral features include four 8-bit PWM channels, a 16-channel ADC, four USARTs, a master/slave SPI serial port, and an I2C interface. The host microcontroller interfaces the MB1010 sensor via the ADC channel, the PAM-7Q GPS module via UART0, and the RN2903 LoRa transceiver module via UART1 in the PBLMU design. It runs at a clock frequency of 8 MHz and has a 3.3 V operating voltage. Additionally, it has a temperature range comparable to that of the GPS module, which is −40 °C to 85 °C.

3.1.5. Power Management Unit

The sensor requires a 5 V operating voltage, while the other components and the controller require a 3.3 V operating voltage. To meet the 5 V and 3.3 V requirements, a power management unit is integrated into the node design. The power management unit comprises of a solar panel, a battery of 2500 mAh capacity, and a circuit for energy harvesting and battery charging. A low-power charger chip (BQ25505) is adopted to extract energy from the solar panel and to charge the batteries. It can obtain energy from a solar panel with a voltage as low as 100 mV. The BQ25505 features an ultralow quotient current consumption of 325 nA, integrated maximum power point monitoring from the solar panel and a battery health indicator. To prevent excess charging, the chip has a under-voltage threshold and over-voltage threshold of 3 V and 4.2 V, respectively. The ultrasonic sensor is powered with a boost DC-DC converter (MCP16252T) as it requires a 5 V supply voltage. It operates in PFM/PWM mode automatically and achieves a typical efficiency of 96 percent. The MCP1825S LDO regulator keeps the voltage at 3.3 V, to meet the power requirements of LoRa module, host microcontroller, and GPS module.

3.1.6. LoRaWAN Gateway

Each PBLMU in the proposed IoT-enabled solid waste management system needs to be monitored from the central monitoring station. As the PBLMUs in a specific region create the Wide Area Network using non-IP-based communication protocols such as the LoRa protocol, each region requires a gateway to allow internet connectivity between the PBLMUs and the server. To function as the gateway in the proposed system, a commercially available microchip LoRa gateway is preferred. The LoRa gateway configures the network address, IP address, default subnet mask, server IP, server up port, and server down port in accordance with the system requirements. The LoRa radio board and the LoRa core board are the LoRa gateway's two primary components. The PBLMUs' data are received via the SMA radio connector on the radio board and fed to the RFSW1012-SPDT switch, which generates two independent RF outputs. Before demodulation, the RF outputs are filtered using two distinct frequencies. The microcontroller in the LoRa gateway's core board gathers data that have been transmitted by the radio board and then wraps the data in a JSON format prior to transmitting it to the Ethernet controller. Further, the Ethernet controller adds a UDP header to the packets, and these packets are sent to the server by way of a network switch.

3.2. Design of the HBLMU

Similarly, the HBLMU is designed to collect the unfilled level and geolocation of the trash bins installed at homes. The block diagram of the designed HBLMU is shown in Figure 3. It comprises an ultrasonic sensor and a GPS module to measure the unfilled level and the geolocation of the trash bins respectively. A Wi-Fi module is equipped with the HBLMU to establish wireless connectivity with the home router which is acting as the access point to get connected to the cloud server. Further, a power management unit is integrated to provide the required supply voltages to other components of the HBLMU. Additionally, a solar panel is attached with the power management unit for energy harvesting and self-powering of HBLMUs as they are powered with batteries. The functionality and specifications of the ultrasonic sensor, GPS module, and power management unit are alike to that in the design of PBLMU, the remaining components of the HBLMU are described here.

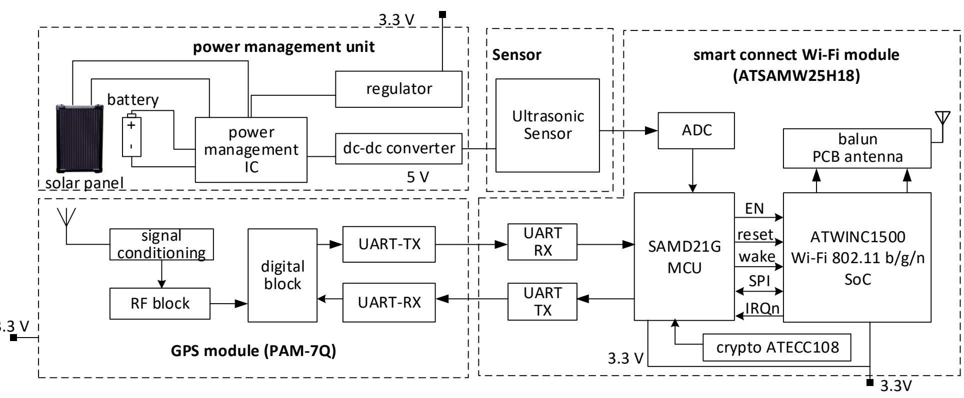

Figure 3. Block diagram of the HBLMU.

3.2.1. Wi-Fi Module

The Wi-Fi module in the HBLMU is a Microchip Smart Connect ATSAMW25H18 SOC. It is certified and incorporated with the 802.11 IP stack. It is composed of an ARM cortex M0+ microcontroller (host computer) and an ATWINC1500 Wi-Fi network processor. The host machine operates at a 48 MHz clock frequency. It includes an on-chip memory management engine that reduces the load on the host computer. It includes an 8 Mb internal flash memory for firmware updates via OTA. Secure network access is established using TLS and SSL protocols. Additionally, it supports network protocols such as DHCP, DNS, UDP, HTTP, and HTTPS. The controller's operating voltage is normally 3.7 V. It features a ten-bit DAC and a fourteen-channel 12-bit ADC. ATSAMW25H18 is the best option for the HBLMU design due to its extremely low power consumption, over-the-air software update capability, and built-in security features.

3.2.2. Home Router

Attributed to the reason that the HBLMUs are used to track the unfilled levels and geolocations of household trash bins, the home router is used to establish connectivity between the central monitoring station and sensing nodes. The wireless router used in this experiment is a TP-Link TL-MR6400. It complies with IEEE 802.11/n/a and IEEE 802.11b/g/n wireless standards and supports data transfer rates of up to 300 Mbps.

3.3. The Server and the GUI

The server's hardware configuration includes an Intel Core i7-8700T processor, 16 GB RAM, and a 500 GB hard drive running Ubuntu 20.04 LTS. The software package provides open-source components such as Redis, PostgreSQL, ChirpStack gateway bridge, Eclipse Mosquitto, ChirpStack network server, and ChirpStack application server, as well as an intelligent GUI. The Eclipse Mosquitto message broker is used to implement the MQTT protocol, which uses a publish/subscribe model to transport data. Redis is an in-memory database used to store transient data, while PostgreSQL is used to store long-term data. The intelligent GUI is designed using the C Sharp programming language on the .NET platform. The .NET core 3.0 includes the gRPC framework, a lightweight and highly performant RPC framework that enables real-time message push without polling. After decoding and systematically storing the bin level data, the generated graphical representation of the main window, all area icons, and all trash bin icons are graphically mapped to the PBLMU and HBLMU measurements. To quickly identify the trash bin level, each level is assigned with a color code.

4. Results and Discussion

The fabricated HBLMU and PBLMU are shown in Figures 4 and 5, respectively. Significant experiments were conducted to validate the feasibility of the developed IoT-enabled solid waste management system. First, an experiment was conducted to validate the developed IoT system by monitoring the corresponding unfilled levels of the trash bins through the intelligent GUI. Second, an experimental setup was arranged to measure the sleep current and active current contributions of a PBLMU to obtain its average current consumption. Finally, the life expectancy of a PBLMU was estimated under hypothetical conditions.

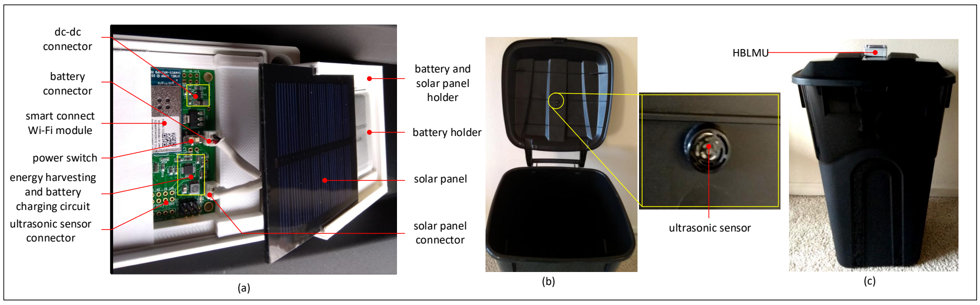

Figure 4. (**a**) Various components of the fabricated HBLMU. (**b**) Installation of HBLMU on a trash bin. (**c**) Front view of the HBLMU equipped trash bin.

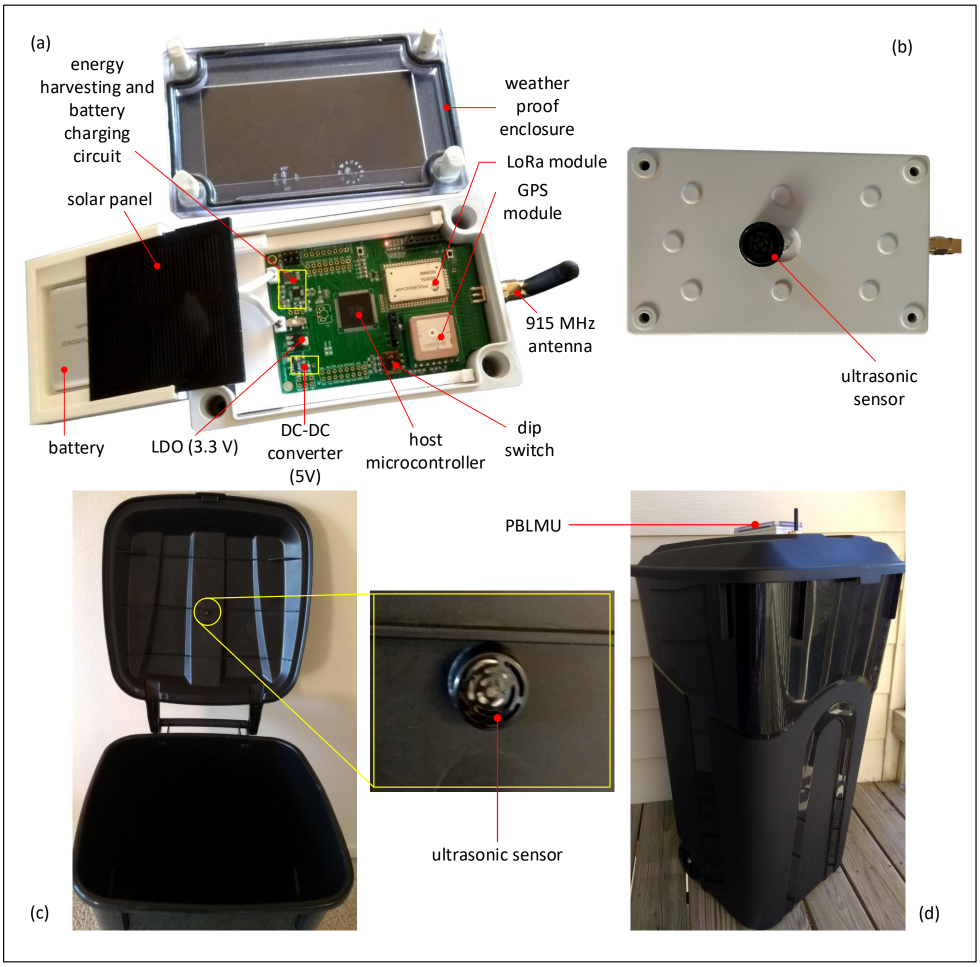

Figure 5. (**a**) Various components of the fabricated PBLMU. (**b**) Rear view of the fabricated PBLMU. (**c**) Installation of PBLMU on a trash bin. (**d**) Front view of the PBLMU equipped trash bin.

4.1. Validation of the Developed System

The trash bins used in our study have dimensions of 40 cm × 40 cm on the top, 30 cm × 30 cm on the base, and 82.5 cm in height. An experiment was carried out in both indoor and outdoor environments to validate the developed IoT system, where 8 bins were installed with PBLMUs and connected to a LoRaWAN, and another 8 bins were installed with HBLMUs and connected to a Wi-Fi network, respectively. The firmware of the PBLMU and the HBLMU were programmed to send unfilled data every 5 min. The trash bins were filled with paper, card boxes, bottles, and clothes at different levels, and the corresponding unfilled levels of the trash bins were monitored in the Intelligent GUI.

Taking into account the readings from the PBLMU, HBLMU, and the trash bin's maximum unfilled level, the intelligent GUI assigns a color code to each trash bin. Table 1 shows the threshold unfilled levels of the trash bins for various color codes.

Table 1. Mapping table for the threshold unfilled levels and color code.

Unfilled Bin Level in cm	Color Code	Status
Equal to 82.5	Green	Empty
Greater than 70	Green	Lightly filled
Between 30 and 70	Orange	Partially filled
Less than 30	Red	Almost full

Figure 6 illustrates a screenshot of the developed intelligent GUI, which depicts the global level (home icon), levels of different regions, and Region 1's trash bin levels.

The intelligent GUI was designed in a hierarchical fashion to allow for real-time monitoring of the trash bin's exact level and location. The intelligent GUI's primary icon (at the top level) is a progressive bar that is synchronized with all PBLMUs and HBLMUs in the IoT-enabled solid waste management system. The primary icon's color code corresponds to the trash bins lowest unfilled value. When the user clicks on the home icon, the intelligent GUI automatically displays the regional icons. Additionally, the region icon functions as a progressive bar whose status is determined by the number of unfilled PBLMUs and HBLMUs in that region. The color code assigned to the region icons corresponds to the lowest level of unfilled trash bins in that region. When a user clicks on a region icon, the intelligent GUI displays all trash bins in that region. Additionally, the trash bin icons function as a progressive bar whose status is determined by the sensor value of the PBLMU or HBLMU. From the illustration, the main icon is red because the unfilled value of trash bin 1 is 11.2 cm, which is less than 30 cm (threshold value). This immediately alerts the user that some trash bins in the IoT-enabled solid waste management system are approaching capacity. The color of the region icons varies; Region 1 is red because the unfilled value of trash bin 1 is 11.2 cm. Regions 2 and 3 are highlighted in orange because the trash bins' unfilled level is between 30 and 70 cm. As the unfilled amount of all trash bins in Region 4 exceeds 70 cm, the region is green in color. When a user hovers or clicks on a trash bin icon, the exact unfilled level of the bin as well as its geo-location coordinates are shown.

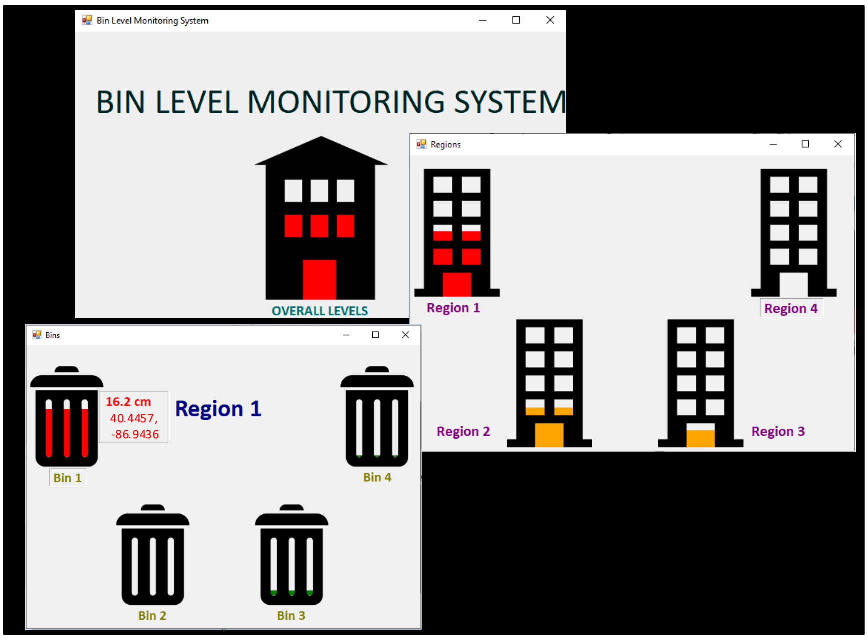

Figure 6. Screenshot of the Intelligent GUI.

4.2. *Average Current Consumption of a PBLMU*

We used an INA233 evaluation module to assess the active and sleep mode current contributions of a PBLMU while operating the LoRa module at a spreading factor of 7, power level of 10 dBm, bandwidth of 125 KHz, and a coding rate of 4/5 . Table 2 shows the nomenclature of the mathematical symbols used in the equations. The measured current consumption in active and sleep modes are as follows.

PBLMU's active current contribution:

$$\begin{aligned} Q_{PBLMU_a} &= ([I_{EHC_q} + I_{LDO_q} + I_{DC-DC_q} + I_{HM_a}] \times T_{HM_a}) + \\ &(I_{GPS_a} \times T_{GPS_a}) + (I_{LoRa_a} \times T_{LoRa_a}) + \\ &(I_{sensor_a} \times T_{sensor_a}) \\ &= 0.3316\ A \times s \end{aligned} \quad (1)$$

PBLMU's sleep current contribution:

$$\begin{aligned} Q_{PBLMU_s} &= (I_{EHC_q} + I_{LDO_q} + I_{DC-DC_q} + I_{HM_s} + I_{LoRa_s}) \times (T - T_{HM_a}) \\ &= 0.1115\ A \times s \end{aligned} \tag{2}$$

Average current consumption of a PBLMU:

$$\begin{aligned} I_{PBLMU} &= \frac{Q_{PBLMU_a} + Q_{PBLMU_s}}{T} \\ &= 1.5\ \text{mA} \end{aligned} \tag{3}$$

Table 2. Nomenclature of mathematical symbols.

Parameter	Description
I_{EHC_q}	Quiescent current of BQ25505 energy harvesting IC
I_{LDO_q}	LDO's quiescent current
I_{PBLMU}	PBLMU's average current consumption
I_{DC-DC_q}	DC-DC converter's quiescent current
$Q_{Battery}$	Capacity of battery
I_{HM_a}	Host machine's current consumption in active mode
$PBLMU_{days}$	PBLMU's life expectancy
T_{HM_a}	Host machine's time period in active mode
I_{GPS_a}	GPS module current consumption in active mode
I_{LoRa_a}	LoRa's active current consumption
I_{LoRa_s}	LoRa's sleep current consumption
I_{sensor_a}	Sensor's active current consumption
T_{GPS_a}	GPS module time period in active mode
I_{HM_s}	Host machine's current consumption in sleep mode
T_{LoRa_a}	LoRa's time period in active mode
T_{sensor_a}	Sensor's time period in active mode
T	Transmission time period

4.3. Life Expectancy of a PBLMU

The PBLMU's life expectancy was determined under the hypothetical scenario under which the battery's voltage is optimal before its power is depleted. Assume a standard battery has a capacity of 2500 mAh and the following calculation is used to determine the life expectancy of the sensing nodes.

$$\begin{aligned} PBLMU_{days} &= \frac{Q_{Battery}}{I_{PBLMU}} \\ &\approx 70\ \text{days} \end{aligned} \tag{4}$$

Once the battery is fully charged it can power a PBLMU for approximately 70 days without any interruption.

5. Conclusions

The development and validation of a hybrid network architecture approach to efficiently manage trash bins in public places and residential areas of cities were discussed in this paper. All facets of an IoT system have been developed, including the design of end nodes, i.e., PBLMU and HBLMU; long-range data transmission with LoRa network for public places and Wi-Fi connectivity for homes; long-term data storage; and hierarchical visualization of trash bin level with the intelligent GUI. Experiments were conducted to validate the developed IoT system, as well as to estimate current consumption and maximum life expectancy of the end node. First, the trash bins had been filled with waste, and the corresponding unfilled levels on the Intelligent GUI were monitored. Second, based on the measured active and sleep current contributions, the PBLMU's average current consumption is calculated as 1.5 mA. Finally, the life expectancy of a PBLMU was estimated as approximately 70 days under hypothetical conditions. According to the obtained results, the proposed IoT-enabled solid waste management system is well suited for monitoring real-time trash bin information in smart cities.

Future work in this area, trash bin information (unfilled level and geolocation coordinates) obtained through the proposed IoT system can be used for framing geographic information system (GIS). Furthermore, optimum routes can be obtained through machine learning algorithms for waste collection trucks.

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Abbreviations

The following abbreviations are used in this manuscript:

PBLMU	Public Bin Level Monitoring Unit
HBLMU	Home Bin Level Monitoring Unit
IoT	Internet of Things
GPS	Global Positioning System
GUI	Graphical User Interface
IR	Infrared
AI	Artificial intelligence
LoRaWAN	Long Range Wide Area Network
RFID	Radio Frequency Identification
LoRa	Long Range
TCP/IP	Transmission Control Protocol/Internet Protocol
MQTT	Message Queuing Telemetry Transport
NB-IoT	NarrowBand-Internet of Things
Wi-Fi	Wireless Fidelity
WAN	Wide Area Network
RHCP	Right Hand Circularly Polarized
ISM	Industrial, Scientific, and Medical
UART	Universal asynchronous receiver/transmitter
ASCII	American Standard Code for Information Interchange
RISC	Reduced Instruction Set Computer
PWM	Pulse Width Modulation
ADC	Analog to Digital Converter
USART	Universal Synchronous Asynchronous Receiver Transmitter
SPI	Serial Peripheral Interface
I2C	Inter Integrated Circuit
PFM	Pulse Frequency Modulation
IP	Internet Protocol
SMA	SubMiniature version A
SPDT	Single Pole Double Throw
RF	Radio frequency
JSON	JavaScript Object Notation
UDP	User Datagram Protocol

SOC	System on a Chip
OTA	Over-The-Air
TLS	Transport Layer Security
SSL	Secure Sockets Layers
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
DAC	Digital to Analog Converter
RPC	Remote Procedure Call
LDO	Low Dropout

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smart cities MDPI

Article

A Holistic Intersection Rating System (HIRS)—A Novel Methodology to Measure the Holistic Operational Performance of Signalized Urban Intersections

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Abstract: Signalized urban intersections are key components of urban transportation networks. They are traditionally viewed and designed as primarily motorized traffic facilities, and thus their physical and operational designs have traditionally aimed at maximizing traffic throughput subject to constraints dictated by vehicular safety requirements and pedestrian crossing needs. Seen from a holistic viewpoint, urban intersections are hubs or effective centers of community activities of which traffic flow is only one. Those hubs have direct and indirect impacts on the overlapping traffic functionalities, the environment, public health, community wellbeing, and the local economy. This study proposes a new rating system, the Holistic Intersection Rating System (HIRS), aimed at appraising signalized intersections from a more inclusive viewpoint. This appraisal covers traffic functionality, sustainability, and public health and community wellbeing. This rating system can be used as a guide to conceive, plan, or design new intersections or revamp existing ones. HIRS rates signalized urban intersections based on the level of use of relevant enabling technologies, and the physical and operational designs that allow those intersections to operate holistically, thus leading to a more human-centric and sustainable operational performance. HIRS was validated using a panel of experts in construction, transportation, and public health. The Relative Importance Index (RII) method was used to weigh the HIRS features. The rating system was piloted on a sample of 20 intersections in different cities in the UAE. The results revealed glaring gaps in services to or the consideration of pedestrians, cyclists, and nearby households. The sample intersections scored a mean of 32% on the public health and community wellbeing section, 37% on the pedestrian subsection, and 15% on the cyclist subsection. Such relatively low scores serve as indicators of areas for improvements, and if mapped to their specific features and their relative weights, specific physical and operations designs and technology integration can be identified as actionable items for inclusion in plans and/or designs.

Keywords: transportation system signalized urban intersections; rating systems; public health; sustainable operational performance

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1. Introduction

An urban transportation system is a system composed of a set of physical transport infrastructure components, modes, and operational norms that enable the movement of freight and passengers [1]. In the recent past, transportation planners, designers, and operators focused on transportation systems' improvements that enabled motorized travelers and freight modes to move efficiently between origins and destinations. Economics was the overriding criterion, and sometimes the only one. However, in more recent times the focus has shifted from movement to the more encompassing issues of mobility and accessibility, and thus sustainability and equity aspects of transportation systems that capture emerging environmental and health challenges have become central themes [2]. Signalized urban intersections, as key components of urban transportation systems, were traditionally designed to maximize motorized traffic throughput or some variant of it [3] and resulted from mostly economics-motivated thinking. Other factors that influence the design and operational performance of signalized intersections were not measured nor valued fully in the planning and design phases. At best they were often lumped together as externalities or issues of viability and only qualitatively addressed. In fact, the previous urban signalized intersection rating systems, such as "performance evaluation of signalized urban intersections under mixed traffic conditions", focused on rating only the vehicular service that intersections provide without considering other important elements in intersections design or operation [4]. HIRS is a step towards a more encompassing intersection rating system that bridges the gap in current thinking.

The Holistic Intersection Rating System (HIRS) is a new rating system that utilizes a holistic operational performance of signalized urban intersections. For the purpose of this work, "holistic" means a belief that the physical and operational features of an intersection, as well as the enabling technologies, both hard and soft, are all part of a complex bigger than their physical and operational sum and are intimately interconnected and explainable only by reference to the surrounding environment/community/area where the complex resides. This view is motivated by a belief that intersections serve a function far more encompassing and impactful than that implied by the current/traditional traffic operation- and economics-centric view. HIRS views intersections as activity nodes with community- and human-centric reach and impact. Included in the rating system are enabling technologies and physical and operational designs that both enable and support the holistic view noted earlier. In a way, HIRS also serves an awareness and advocacy role: it introduces transportation planners, designers, and operators to the relevance of those elements and how to systematically integrate them to (1) enable equitable operational performance, (2) support sustainability, and (3) foster public health and community wellbeing. Promoting those aspects leads to a better service for pedestrians, cyclists, and households located nearby signalized urban intersections. The HIRS rating system is composed of two main sections. The first section concerns motorized/vehicular traffic, and the second is devoted to public health and community wellbeing, which contributes positively to sustainable solutions at signalized intersections.

1.1. Problem Definition

Transportation systems are an integral element and shaper of the built environment. In times past, the focus of urban transportation systems was to facilitate the movement of motorized vehicles [2]. However, less attention was given to other users such as pedestrians, cyclists, and nearby residents [5]. In many cases, considerations for pedestrians and cyclists—and the needs of the surrounding environs—were accounted for only as constraints, if at all. From a more holistic viewpoint, urban transportation should be about both mobility and accessibility in relation to purposeful destinations, ones that meaningfully fit into the urban fabric and meet all needs (not just economics-centric ones) of system users. That is to say, transportation is about moving and facilitating access to system traffic, motorized and nonmotorized, regardless of whether it is serving a derived need or not [5]. Equally important now, especially given the many global challenges, transportation systems should be operated to promote sustainable means and solutions that contribute not only to eliminating excesses and protecting the environment, but also to enhancing health and community wellbeing. HIRS was designed with this in mind. It rates urban signalized intersections (new or existing) with respect to the inclusion of enabling technologies (T) and physical and operational designs (PD and OD) that are deemed necessary for an encompassing, more holistic performance. For the purpose of this paper, enabling technologies (ET) include hardware such as vehicle and pedestrian detection cameras and sensors and/or soft technologies such as detection and control protocols and algorithms and wireless communication. Physical design (PD) refers to specific or specialized components or features within the intersection's right-of-way that serve one or more of three functions: (1) a core control and guidance role, (2) a supplemental role as delineation/accentuation or emphasis function, or (3) to mitigate unintended consequences. Operational designs (ODs) capture functionalities, norms, rules, and policies, the adherence to which is a necessary but mostly not a sufficient condition for optimum functioning of the intersection. In this context, and for the purpose of this paper, optimum and holistic are almost synonymous. Once sufficiently calibrated and tested, HIRS becomes a tool to guide planning and design decisions on urban signalized intersections. With optional built-in flexibility, the rating system may be customized for use in different jurisdictions and/or with varying policy emphases.

1.2. HIRS: Aims and Objectives

The work presented here is part of an effort to advance the intersecting notions of sustainability, public health, and community wellbeing in transportation systems. The objective of the research is to create a tool, the rating system HIRS, to help assess—and then scale up—those notions in signalized urban intersections. HIRS uses a holistic view that captures and values physical and operational features that support mixed-traffic needs, sustainability, public health, and community wellbeing. As a first step, existing rating systems that for the most part were created to rate highway links (as opposed to nodes) were evaluated for their relevance. The strengths and weaknesses of those systems were evaluated with an eye on applicability and relevance to signalized urban intersections. Secondly, an extensive search was conducted that aimed at understanding the relevance and utility of technologies and physical and operational designs that have the potential to support the holistic view of intersections and as such should be incorporated in the proposed rating system. The proposed rating system will help transportation authorities and professionals assess signalized intersections, as activity nodes within urban networks, more holistically by measuring the level of integration of enabling technologies and physical and operational designs (henceforth called features) that, when fused into the "mini-system" the intersection is, give rise to a more holistic operational performance or service level. HIRS can be used as a guide by traffic planners and designers to revamp existing signalized urban intersections to support the integration of relevant enabling technologies and physical and operational designs.

1.3. Significance of HIRS

HIRS is unique in the following respects:

- It explicitly acknowledges the importance of public health and community wellbeing in the design and operations of signalized intersections. It incorporates and weights pertinent features that effectively act as "pathways" to health and community wellbeing. In previous rating systems, such features were missing or, at best, only implicitly considered. The case for HIRS follows from the notion that when seen from a holistic viewpoint, signalized urban intersections are integral components of an urban transportation system with direct and indirect links to public health and community wellbeing. It is no longer a luxury that we design and operate those intersections in isolation from the bigger context. In fact, the American Society of Civil Engineers (ASCE) code of ethics explicitly notes health and welfare. It states that "Engineers should take into consideration that the lives, safety, health and welfare of the general public are dependent upon engineering judgments, decisions and practices" [6]. Traditional health and welfare were thought of more as the domain of the public health profession. Not anymore. HIRS is at the heart of this transport–health nexus.
- It recognizes the worth of active modes of transportation (walking and cycling) and accords them due weight. Previous rating systems such as "performance evaluation of signalized urban intersections under mixed traffic conditions" focused on rating the performance of signalized urban intersections with respect to vehicular traffic [4]. As typical of most traditional rating systems, of which this study is one, a unimodal-

centric approach treats pedestrian and cyclist traffic as "background, noise, or source of friction". However, the transportation profession is changing in favor of a unified multi- or intermodal view of design and operations of transportation systems and their subsystems. Technological advances are both enabling and accelerating the change. Active modes of transportation are no longer part of the background. They are mainstream, and for good reasons: they reduce the number of auto trips and they have positive health benefits, not least of which are those resulting from the physical exercise that users perform during their transit between origins and destinations [7]. HIRS embodies this holistic view of all modes.

- It addresses two relatively new topics in urban transportation: the readiness of existing infrastructure to support autonomous vehicles (AV) and the effects of transportation systems on the mental health of users and residents of surrounding environs. HIRS aims to improve services that an intersection provides to users regardless of mode and level of technology penetration. Pedestrians, cyclists, and AVs are equally recognized and supported, consistent with the notion of creating complete streets [8,9]. HIRS also incorporates and rates features that affect the mental health of transportation system users and nearby residents. Subtle but significant issues of viability such as community severance and noise and light pollution have direct and indirect health impacts both on intersection users and nonuser nearby residents. HIRS captures and values the notion that a transportation system should not impede but, rather, facilitate the transit of users between points of interest while at the same time augmenting their experience through the promotion and enforcement of known positive health enablers (as physical designs, sound, and visual effects). Besides governmental agencies with traditional health-centric roles, now transportation units are increasingly seen as health-promoting agents; their traditional role of creating and maintaining the transportation system to support economic efficiency is now being augmented with promoting environmental sustainability, public health, and community character [8]. In the end, it is almost impossible to disconnect the notions of economic and environmental efficiency and technological advancement from social sustainability. The health of individuals and communities spans all those contemporary notions. HIRS is square at the intersection of all those conceptions.

1.4. Research Significance

Signalized intersections are key elements of urban transportation networks. They are deciders of network level-of-service (LOS), however that is determined. Their influence as nodes of control and tempering of vehicular traffic is thoroughly researched and established, but not their influence on other traffic—and certainly not on the surrounding environment. It is no surprise then that LOS has traditionally been vehicular traffic-oriented, a view that is hardly complete or equitable. Viewed more holistically, urban intersections are transit nodes for human and/or community-centric activities with economic, environmental, and socially derived needs and influences. It is in this sustainability-inspired context that HIRS will be applied and used.

Unlike previous systems which rate such multicomponent highway sections all in one go, HIRS views and rates an intersection as a system with physical and operational features, boundaries, and flows across those boundaries. With such a critical role for intersections, HIRS aims at improving (or, at minimum, preserving) operational performance and making an intersection that not only blends into its context (as would the traditional view) but proactively enriches it. Specifically, HIRS rates intersections on the level of incorporation of relevant enabling technologies (ETs), physical designs (PDs), and operational designs (ODs), features that, together, elevate the intersection's role to a human and community-centric activity node. Viewed this way, vehicular traffic flow through an intersection is treated as a human/community activity that, at a fundamental level, is more than a purely operational or economic one.

1.5. Literature Review

HIRS builds on and expands on already existing rating systems of civil infrastructure facilities but takes the notion of rating to a higher and more encompassing level. An extensive literature search was done on all previous infrastructure facility rating systems to assess their relevance and strengths, and to determine gaps that must be addressed as part of the development of HIRS. HIRS reframes the discussion of infrastructure civil systems as shapers of the built environment with a more integrative and proactive human-centric role. The summary below describes the purposes of existing transport infrastructure rating systems.

The Green Guide for Roads Rating System is a rating system for roads that was developed by Clark et al. [10]. This rating system is composed of seven main sections that include mobility for all, transportation planning, energy and atmosphere, materials and resources, environmental impacts, community impacts, innovation, and the design process. I-LAST Illinois was developed by the Illinois Department of Transportation, the American Consulting Engineers Council, and the Illinois Road and Transportation Builders Association. This system is composed of nine different sections which cover planning, design, environment protection, water, transportation, lighting, materials, and innovation [11,12]. Green Roads is a rating system for infrastructure developed by the University of Washington and CH2M HILL in 2009. This rating system is composed of five main sections. They include environment and water, construction activities, materials and design, utilities and controls, access and livability, and creativity and effort [13]. BEST-In-Highways is a rating system that was developed by the recycled materials resource center located at the College of Engineering at the University of Wisconsin. This rating system is composed of 10 sections. They include social requirements, including regulation and local ordinances, greenhouse gas emissions, energy use, waste reduction (including ex situ materials), waste reduction (recycling in situ materials), water consumption, social carbon cost saving, life cycle cost, traffic noise, and hazardous waste [12,14,15]. Those four rating systems that have been used previously are not designed to rate the infrastructure facility at the operational phase. However, HIRS is designed to rate the signalized urban intersection at the operational phase.

Green LITES is a rating system that has been developed by the New York State Department of Transportation (NYSDOT) to help in developing transportation and infrastructure systems in a sustainable way. This rating system is composed of eight different main sections which include bridges, pavements, drainage, signals and lighting, snow and ice, facilities and rest areas, roadside environment and signs, and innovative/unlisted actives [16]. This rating system rates different components of a highway transportation system while HIRS focuses only on one component of the transportation system, which is a signalized intersection system. INVEST infrastructure is a "web-based self-evaluation tool". This rating system has four main sections which include a system planning for states, a system planning for regions, project development, and operations and maintenance [17]. CEEQUAL is the international evidence-based sustainability assessment, rating, and awards scheme for civil engineering [18]. This rating system was developed by a team from the Institution of Civil Engineers (ICE). It has 12 different sections that include project management, land use, landscape issues (including rural landscape and townscape), ecology and biodiversity, the historic environment, water resources and the water environment, energy and carbon, material use, waste management, transport, effects on neighbors, and relations with the local community and other stakeholders. Sustainable Transportation Access Rating System (STARS) is a rating system developed by the Santa Cruz County Regional Transportation Commission. This rating system has four main sections on integrative process, access, climate and energy, and benefit/cost [19]. Envision was developed by the Zofnass Program for Sustainable Infrastructure at Harvard University and the Institute for Sustainable Infrastructure. This rating system is composed of five main sections which include quality of life, leadership, resources allocation, the natural world, and climate and risk [20]. None of those above-mentioned rating systems rates signalized urban intersections, however; only HIRS rates signalized urban intersections from a microscopic point of view.

Green Pave is a rating system developed by the Ministry of Transportation in Canada [21]. The system was developed to improve the sustainability of pavements as a component of the transportation infrastructure. This rating system consists of two main components. The first component is design, and the second is construction. This rating system focuses on the pavement component at the design and construction phase. By contrast, HIRS's focus is on the signalized urban intersection. Pavements are only indirectly accommodated (i.e., only to the extent they contribute to or impact operational features of the intersection).

A landslide hazard rating system for Colorado highways is a rating system that helps in quantifying hazards and risks of landslides on Colorado highways. This system was developed based on the existing rock-fall rating systems used by the Colorado Department of Transportation. The new system is composed of 11 hazard factors and 8 consequence factors. The hazard factors include the following: soil/rock, use classifications, rock strength, permeability, jar slake test, discontinuity orientation, and bedrock geology. This rating system's main focus is to rate the highway based on the hazards and risk factors [22,23]. However, HIRS rates the signalized urban intersection based on the level of performance on which the intersections are operating. The subject matter of this rating system is unrelated to HIRS, but its structure and valuation scheme are relevant.

The study conducted by Yue and Wong [4] provides a quantitative evaluation of the signalized intersections under mixed traffic conditions. The evaluation of those intersections is done based on only five parameters: degree of saturation, the separation ratio, average stopped delay, queue length, and conflict ratio. This rating system rates the signalized urban intersection based on only five items which are all related to vehicular traffic. However, HIRS has 44 features and both equitably and explicitly accommodates vehicle users, pedestrians, cyclists, and non-intersection-user nearby dwellers.

To conclude, most of the rating systems that came into existence in the past had three main weaknesses. First, the previous rating systems focused on judging how green the highways are. In other words, from a sustainability point of view, they focused on rating highways based on the application of sustainable construction activities and the usage of recycled materials. However, these previous rating systems ignored transportation services that highways provide to vehicle drivers, pedestrians, cyclists, and people living within close proximity.

Moreover, all the previous rating systems did not include the effect of autonomous vehicles on our transportation systems. The HIRS system helps in improving the services that the transportation facility provides for all of the different users. A complete street is one that is designed and operated to allow safe access for all the users. Second, the previous rating systems did not include the factors that affect the mental and physical health and wellbeing of users. Transportation systems do, however, affect the health of users and can help in shaping communities. Thus, a comprehensive transportation system allows users to transit from one place to another without compromising their health. Governments should be committed to creating a transportation system that promotes public health. In addition, transportation systems should be operated in a way that positively impacts society and the environment.

Finally, most of the rating systems that have been used before aimed at rating the highway in general without focusing on the details of the different components of the highway, whereas HIRS rates only signalized urban intersections. Development of a new rating system (HIRS) would help the traffic authorities to improve on how signalized urban intersections are currently operating by taking into consideration all the different users and the impact on society and the environment.

2. Methods

2.1. Research Proposition

The key proposition of this research is that the use of suitable enabling technologies and physical and operational design features such as those included in HIRS will improve and make more holistic the operational performance of signalized urban intersections. Rating intersections with respect to those features using suitable tools such as HIRS is a necessary step. This proposition is depicted in Figure 1.

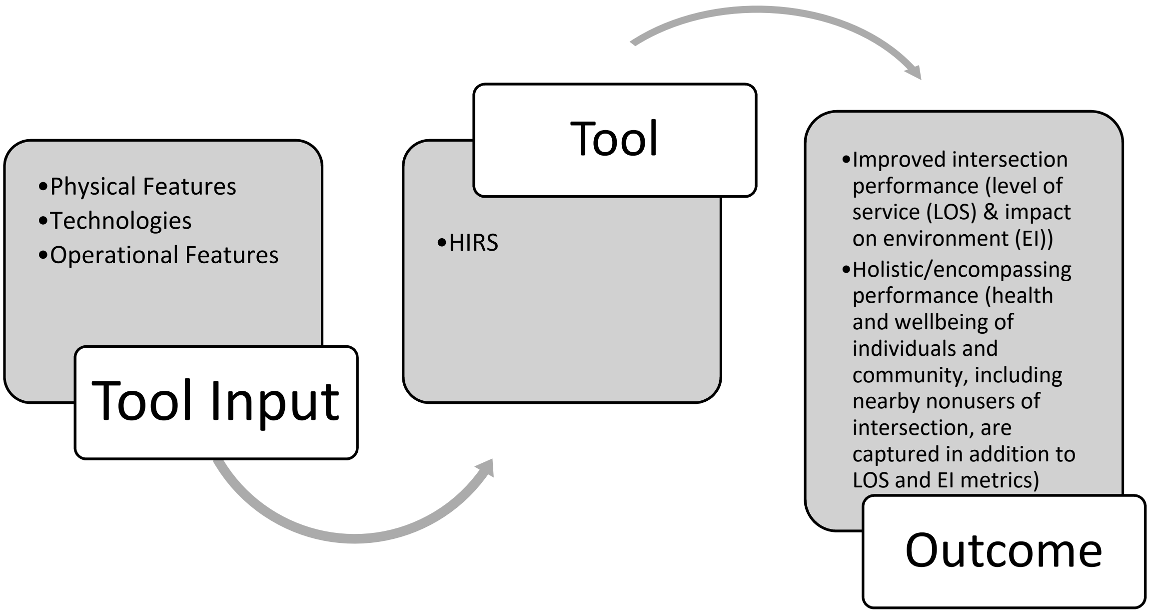

Figure 1. HIRS conceptual implementation framework.

2.2. Research Methodology

This research uses both qualitative and quantitative means to answer the following research question: At what holistic level do signalized urban intersections perform? Or, from a detailed outcome-oriented view, what is the level of integration of sustainability measures and public health- and community wellbeing-supporting features in the physical and operational designs of signalized intersections?

The qualitative means involve evaluating existing rating systems previously used for different components of a highway. The weaknesses and gaps in those rating systems were identified to inform the development of the new rating system. Another extensive literature review was carried out to identify all pertinent enabling technologies, both hard and soft, physical design features, and operational design practices and protocols that are currently available and/or are actually in use. All technologies and design features/protocols identified in this search were then used in the HIRS theoretical framework. A quantitative approach was used where all HIRS's features were validated through a panel of experts in the fields of transportation and public health. Members of the expert panel were tasked with assessing the significance of each feature through an importance score. Based on the data collected from the panel and using the Relative Importance Index (RII) formula, more weightage of each item was given accordingly under the respective subsection established (so that it is clear, HIRS has 44 features or entries: the 44 features are divided into, or belong to, a total of nine subsections. The nine subsections are grouped into two main sections). Later on, HIRS was then validated (or tested) using data from 20 existing signalized urban intersections from different cities in the UAE. The final score, out of 100, for each of the 20 signalized urban intersections reflects the degree to which the operations at the intersection in question are holistic (as holistic is defined in this research). Later on, results based on data from the 20 signalized urban intersections were analyzed using statistical measures to gain a deeper insight into the spread and the central tendency of the results, as well as the features that fed the relative strengths and weaknesses of the respective intersections. Last, based on the analysis of the results, recommendations were given to improve the weaknesses in some areas.

2.3. *Brief Description of HIRS*

HIRS is a tool that is to be used to rate the level of integration of enabling technologies and physical and operational design features into the design of signalized urban intersections which together give rise to a more holistic operational performance of those intersections. Technologies in the context of HIRS cover electronic and mechanical devices and protocols that improve the safety and operational performance of the signalized urban intersection, such as vehicle and pedestrian detection hardware that enables signal coordination and preemption. Physical design covers designs that can be applied to the intersection area to improve the performance of the intersection, such as road diet/narrowing and pedestrian and cyclist detection. Operational design/features include new/innovative operational practices or protocols that improve the performance of signalized urban intersections, such as adaptive timing schemes, flashing warning green lights, and signal count-down features.

HIRS rates a signalized urban intersection based on the level of integration and/or presence of enabling technologies and physical and operational designs/features that are the building blocks of holistic performance of the intersection. A holistic operation, as explained in the introduction, is one that engenders fitting traffic functionalities, sustainability, and public health and community wellbeing. HIRS has two main sections: one pertains to servicing of motorized traffic, and the other pertains to actively fostering public health and community wellbeing. Under those two sections fall nine subsections (that are not strictly non-overlapping). They are traffic signal management, special features for vehicular service, autonomous vehicle readiness, sustainable solutions at intersections, ways and features to reduce noise pollution, ways and features to reduce light pollution, convenience and safety of pedestrians, convenience and safety for cyclists, and physical and psychological health effects of transportation systems. In those nine subsections fall 44 features (or entries) on technologies and physical and operational designs. Figure 2 shows a simplified structure of HIRS. More information on the specifics of the technologies and physical and operational design features of HIRS is presented in the following three sections. Section 2.3.4 presents how HIRS assesses the level of usage of technologies and physical design and operational features for this survey.

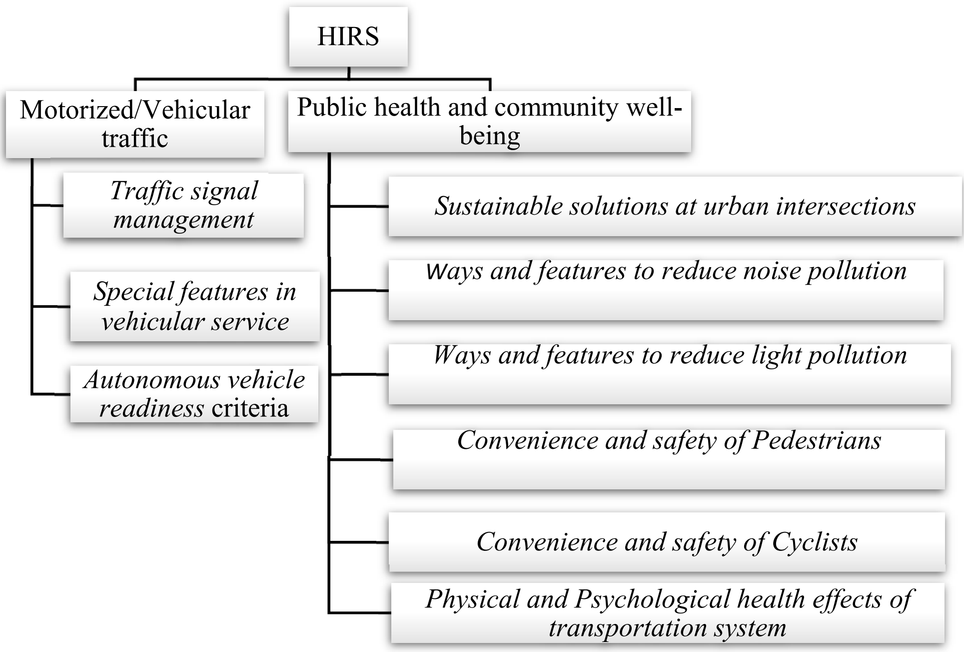

Figure 2. HIRS structure.

HIRS is a rating system designed for appraising signalized intersections from a more inclusive viewpoint. HIRS rates the signalized intersections based on the presence or absence of the technologies and operational and physical design features that lead to improvement in traffic functionality, sustainability, and public health and community wellbeing. This is in order to achieve a better service for the direct and indirect users of the intersections, such as motorized vehicle users, pedestrians, cyclists, and people living in households near the intersections.

HIRS is composed of 44 items (a brief overview is shown in Appendix A), and the 44 items are weighted accordingly based on their importance using the RII method, in order to give important items more weight than the less important ones.

2.3.1. Enabling Technologies

The following enabling technologies are used in the HIRS rating system for signalized urban intersections. These include both proven protocols or programs, and hardware or physical elements. More details on those technologies can be found in topical specialized literature. **Signal coordination:** when the traffic signals are closely spaced, optimum green time intervals would be staged through specific time offsets so that vehicles pass through a set of signals over a section of the road with minimum interruptions. Good signal coordination saves time, conserves fuel consumption, and reduces pollution [24]. An intersection that is part of a coordinated system would likely experience fewer stops, less noise, lower levels of pollution, and likely lower than typical crash exposure. **Dynamic signal optimization:** here, optimum green intervals are updated in real time for every cycle based on prevailing traffic conditions. Dynamic signal control systems have an edge with higher throughput, reduced delays and emissions, and improvement of travel times [25]. **Traffic signal priority** is a system that prioritizes the movement of approaching transit (or emergency response) vehicles using a signal receiver and a transmitter-equipped vehicle. The signal controller then preempts the signal operation by either prolonging the green or shortening the red interval to ensure minimum flow disruption of subject vehicles [26]. **Red light running camera (RLR)** is a system to capture red-signal crossing violations. Use of RLR cameras leads to a significant reduction in all types of RLR crashes [27]. **Traveler information system** is an information system that provides three main types of real-time data, namely emergency advisories, traffic conditions, and road conditions, through dynamic message signs, phone messages, internet websites, and radio transmissions. This system requires the presence of sensors on the road to detect relevant conditions and conveys real-time data to a central traffic control center. Advisories are then delivered to the drivers either using dynamic message signs or phone messages or internet websites and radio. This system helps in optimizing the utilization of road capacity and congestion [28]. **Incident detection system** is a system that uses sensors to detect incidents and traffic roadway data. Once an incident occurs, an emergency response is broadcast from the traveler information system. This system leads to a reduction in fuel consumption (less CO, NO, and hydrocarbon emissions). In addition, it reduces the average delay time caused by incidents [29]. **Turn off street lighting:** streetlights are equipped with motion sensors that turn off the lights when there is no need for light. Such practices reduce the light pollution caused by streetlights [30]. **Warning light:** flashing amber lights placed on the pavement in front of the pedestrian sidewalk increases the safety of pedestrians [31]. **Crossing audio-tactile:** provides audio-tactile indications to notify pedestrians with visual disabilities on when and when not to cross, which increases the safety of visually impaired pedestrians [32]. **Signal detection and actuation:** bicycle detection devices are used to detect the presence of bicycles and alert the signal controller. There are four types of bicycle detectors that could be installed in the signalized intersection: microwave radar, loop induction, video detection, and push button. This system reduces the delay time of cyclists at the traffic signal intersection [33].

2.3.2. Physical Design Features

The physical design features that could be utilized in HIRS to be rated for signalized urban intersections are as follows: **Median refuge island:** a raised area designed to allow pedestrians to cross one direction of the street at a time, which increases the safety of the pedestrians [31,33]. **Raised crosswalk:** an elevated crosswalk above adjacent driving lanes. It serves a dual purpose of making pedestrian and cyclist crossings smoother and continuous, and it acts as a traffic calming feature [31]. **Bike parking:** there are two types of bicycle parking: bicycle racks (fixed objects made of metal to which the bicycles are secured) and bicycle lockers (they vary in design) [33]. Both increase the convenience for cyclists. **Bike boxes:** a designated area located at the head of travel lanes at the intersection. This area provides cyclists with a safe and visible way to get ahead of queuing vehicles during signals' red phase [33]. **Intersection crossing marking:** these are pavement markings that designate paths for cyclists to cross the adjacent lane, thus increasing the safety of cyclists [33]. **Bicycle lanes:** lanes that are marked by solid white boundary lines and a bicycle symbol to indicate exclusive use for bicycles [33]. **Context-sensitive design:** this is a set of standards and practices aimed at maintaining harmony with the intersection's surrounding environment. The dictates of these practices vary widely but all aim at minimizing disturbances and thus ensuring the intersection fits harmoniously in its surrounding physical, ecological, and social environment [34]. Deliberate use of natural native material, colors, plants, architecture, and visual effects are all specific examples. Context sensitivity is known to contribute positively to quality of life for the community as the natural environment is a critical component of the community itself [34]. Biophilia (love of nature), a related notion to context-sensitive design, is also accounted for in HIRS.

HIRS also accounts for the use/presence of biophilic design elements. The components of a biophilic design that have been included in HIRS as advanced physical design features are as follows: **Green street:** a stormwater management technique that involves using permeable pavement vegetation to capture rainwater instead of directing into sewer systems [35]. **Urban trees:** planting trees on the side of the streets [36]. **Edible landscaping:** planting edible plants on the side of the streets [36]. **Light color pavement:** pavements that have a lighter color (lighter than black) are more reflective than a black pavement [36]. Studies have proven that contact with nature, which comes in different forms in the built environment such as biophilic design and green space, helps in reducing stress levels, leads to faster recovery rates from illness, reduces mental fatigue, and increases concentration levels [37,38].

2.3.3. Operational Design Features

The HIRS rating scheme accounts for the following intersection operational features: **Flashing green light:** traffic signals that are equipped with a flashing green light. A flashing green light notifies drivers that the pedestrian signal has been activated and the vehicles' signal will turn red soon [39]. **Traffic signals with countdown timer: this feature helps drivers be more precisely informed of different control intervals, thus enhancing drivers' response** to control as it lets the drivers know when the traffic signal will turn from green to red, which causes a safer response from the drivers [40]. **Yellow box junction: this is** a yellow framed box with crisscross lines inside the box painted in the center of the intersection. A yellow box indicates that vehicles are not allowed to enter the box unless they can exit the box. The use of yellow boxes helps guard against traffic blockages at the center of intersections and thus ensures the continued flow of traffic in all directions [41]. **Traffic signal equipped with battery backup system:** traffic signal equipped with battery backup system allows the traffic signal to function smoothly for a limited number of hours even after a power failure. This minimizes disruption of flow and occurrence of crashes during power downtime [42]. **Use of clean modes of power generation (for traffic lights and traffic signals):** powering traffic signals and smart message boards by sustainable energy sources such as wind turbines and solar panels reduces air pollution [43]. **Planting vegetation on the side of the road:** this helps in absorbing noise generated by vehicles [44]. **Planting dense vegetation** such as hedges, medium-height green barriers, trees, and integration of vegetation in walls of nearby buildings serve the purpose of noise reduction [45]. **Placement of sound barriers:** this can be in the form of boxes made of different materials to absorb energy waves (sound waves). Materials such as wood, stucco, masonry, metal, or any material that absorbs vehicle-generated noise may also be used [44]. **Use of full cutoff fixtures to eliminate light above the horizontal level:** this fixture reduces light pollution from streetlights as it focuses the light downwards, thus preventing light "leaks" at or above 90 degrees [30]. **Advance stop line and sign:** a stop line and a sign marked/placed in advance of crosswalks to improve the safety and visibility of pedestrians [31]. **Advanced signing:** a sign that is placed to warn the drivers of an impending pedestrian crossing [31]. **Marking and crossing signs:** these are used to alert drivers of pedestrians crossing at specific points [31]. **Street pedestrian crossing signs:** these are "redundant" signs placed on lane edges or road centerlines to augment the basic must-have signs, thus further enhancing pedestrian safety [31]. **Signs and high-visibility markings** are similar to conventional signs and markings but have higher retroreflectivity and high conspicuity (higher visibility characteristics) to grab the drivers' attention [31]. **Road diet/narrowing:** this narrowing of the roadway can be achieved by reducing lane width and using excess space to increase the widths of bicycle lanes or sidewalks. Such narrowing induces speed reduction, thus further enhancing pedestrian and cyclist safety by way of reducing drivers' reaction distance and lessening the severity of injuries when crashes occur [31]. **Traffic signal with pedestrian countdown signal** displays the time left for the pedestrian to cross the roadway. Precise information enables better informed decisions and crossing speed selection, thus enhancing safety [46]. **Warning tactile ground surface indicators** are raised (protruded) studs on the ground surface to assist users, especially the visually challenged, with directions/orientation and locations of decision points or nearby hazards (for example, ahead of train/tram platform or a warning of the presence of stairs) [47]. **Directional warning tactile ground surface indicators:** raised studs oriented in parallel lines to indicate the direction of travel for pedestrians and the visual challenged [47]. **Bicycle signal heads:** three-lens electronic traffic control devices used with the conventional traffic signal/hybrid beacons to enhance cyclists' safety. These heads are installed at heights and with orientations fit for cyclists [33]. **Colored bicycle facility:** colored pavement sections within the bicycle lanes enhance cyclists' safety [48]. **Use of creative signs that have humor/emotions/emojis content:** the presence of humor/emotions/emojis on lenses of traffic signal heads aims to evoke positive emotions among users. Signs with facial expressions were found to positively affect drivers psychologically [49,50].

HIRS also accounts for the requirements of autonomous vehicles or AVs (these are vehicles that drive autonomously and navigate and perform necessary maneuvers by detecting obstacles, traffic lanes and road edge boundaries/markings, and surrounding vehicles [51]). While those vehicles will operate within existing infrastructure, they necessitate that specific elements of existing infrastructure be maintained to higher standards than for conventional (human-operated) vehicles. **Quality of lane markings and clear signs:** presence of clear traffic signs and highly retroreflective lane markings are necessary to enable AVs to recognize surrounding environments and perform critical operations such as lane keeping, lane departure, left turn assists, stopping, and yielding [52]. **Traffic signal detection:** this refers to the installation of multiple traffic signal heads at different angles to help AVs detect traffic signals in challenging ambient light and climatic conditions, such as low-angle bright sunlight [53].

2.3.4. How to Use HIRS

As inputs to assessing how holistic an intersection operation is, HIRS uses the level of adoption of enabling technologies and the physical and operational features noted in the previous section and assigns a weighted score as shown in the five-level scale in Table 1. The relative weights of different features were developed with input from the panel of experts. For instance, if a given signalized urban intersection has a final score of 30 (about 96%), this denotes that the subject signalized intersection has a very high level adoption of the technologies and physical and operational features that are the ingredients of holistic operational performance. Similarly, a final score of 5 points means the intersection has a very low level of use of the same features. A perfect score is 31.25, which means the intersection has all 44 features. In this case, each feature gets a score of 1, and each is multiplied by its weight of relative importance. For example, if an item is present at the intersection, the intersection is awarded 1 point for it and the weight of the item is 0.66, then this item's contribution to the total intersection score is $1 \times 0.66 = 0.66$ (if it is not present, then the intersection is awarded 0 points, and thus its contribution is $0 \times 0.66 = 0.0$). The points awarded for each item follow a binary scale, either a 0 or a 1. The 0 to 31.25 range is divided into five categories, or levels of usage of the features (i.e., the technologies and operational and physical features) that make the intersection's operations holistic. The categories ranged from "very low" to "very high" as shown in Table 1. A score of 80% or higher means the intersection is "very highly" equipped for a holistic operation. The list of technologies and features that make intersection's operations holistic on which those scores are based is a dynamic one; as more of those technologies and features come online and become usable at intersections they will be added to the number of features, which will grow beyond the 44 presented at this stage.

Table 1. Level of usage of enabling technologies and physical design and operational feature breakdown for HIRS survey.

Final score = 0–6.25 (Percent final score: 0–20%) Very low level of usage of technologies and physical design and operational features	Final score = 6.25–12.5 (Percent final score: 20–40%) Low level of usage of technologies and physical design and operational features	Final score = 12.5–18.75 (Percent final score: 40–60%) Moderate level of usage of technologies and physical design and operational features	Final score = 18.75–25 (Percent final score: 60–80%) High level of usage of technologies and physical design and operational features	Final score = 25–31.25 (Percent final score: 80–100%) Very high level of usage of technologies and physical design and operational features

2.4. Establishing the Relative Importance of HIRS Features (Items)

HIRS was validated using a panel of experts in the fields of transportation and public health. The experts were separately asked to rate the importance of each of the 44 features under the subsections. Table 2 shows the experts' inputs for a sample of the features in HIRS. The weightage of every feature of each subsection was established using the experts and using the RII formula. A brief overview of HIRS's structure is shown in Appendix A.

Table 2. Sample of experts' inputs.

HIRS 44 Items	Extremely Important	Very Important	Important	Somewhat Important	Not at All Important
Item 1: Signal coordination	2	4	1		
Item 2: Dynamic signal optimization	4	2	1		
Item 43: Use of creative signs that have humor/emotions/emojis		2	2	3	
Item 44: Context sensitivity		2	4	1	

3. A Case Application of HIRS

To demonstrate how HIRS works in the real world, data were collected from 20 signalized urban intersections. Data collectors and field crews verified the presence or absence of each of the 44 items/features that make up HIRS at each of the subject intersections. For example, if the tested intersection is equipped with a signal coordination system, 1 point will be awarded to that intersection; otherwise, 0 is awarded. The points awarded for each feature are then multiplied by the weightage factor (that was calculated using RII based on experts' input) to obtain the score for that feature. At the end, the sum of the scores from all 44 features will make up the final score for the intersection at hand. The final score that each of the 20 tested signalized urban intersections accumulated (out of the perfect score of 31.25) is the relative holistic operational level the intersection is currently operating at.

4. Analysis of Results and Discussion

Table 3 and Figure 3 summarize the final scores and level of adoption of the holistic features for the 20 intersections in the study sample. While there is no such thing as a passing score per se, all 20 intersections did not fare well; all fell in the middle and lower tiers, none were in the lowest tier, and none were in the two high tiers. None of the three intersections in the table are particularly holistic. Even for the best one, 50% of the holistic operations-enabling technologies and features are missing. In short, the results point to a serious lack of relevant holistic operations-enabling features (HOeFs) and, thus, a lack of promising potential to augment operations at those intersections and make them the holistic urban facilities they can be.

Table 3. Intersections' final scores.

Signalized Urban Intersection No.	Final Score out of 31.2 Points	Final Score, Percent	Level of Usage of Technologies and Physical Design and Operational Features
1	15.35	49%	Moderate
2	14.38	46%	Moderate
3	14.56	47%	Moderate
4	14.42	46%	Moderate
5	15.07	48%	Moderate
6	12.47	40%	Moderate
7	12.12	39%	Low
8	11.81	38%	Low
9	12.67	41%	Moderate
10	10.03	32%	Low
11	11.32	36%	Low
12	10.51	34%	Low
13	7.57	24%	Low
14	11.32	36%	Low
15	13.16	42%	Moderate
16	10.64	34%	Low
17	10.52	34%	Low
18	10.09	32%	Low
19	9.36	30%	Low
20	9.49	30%	Low

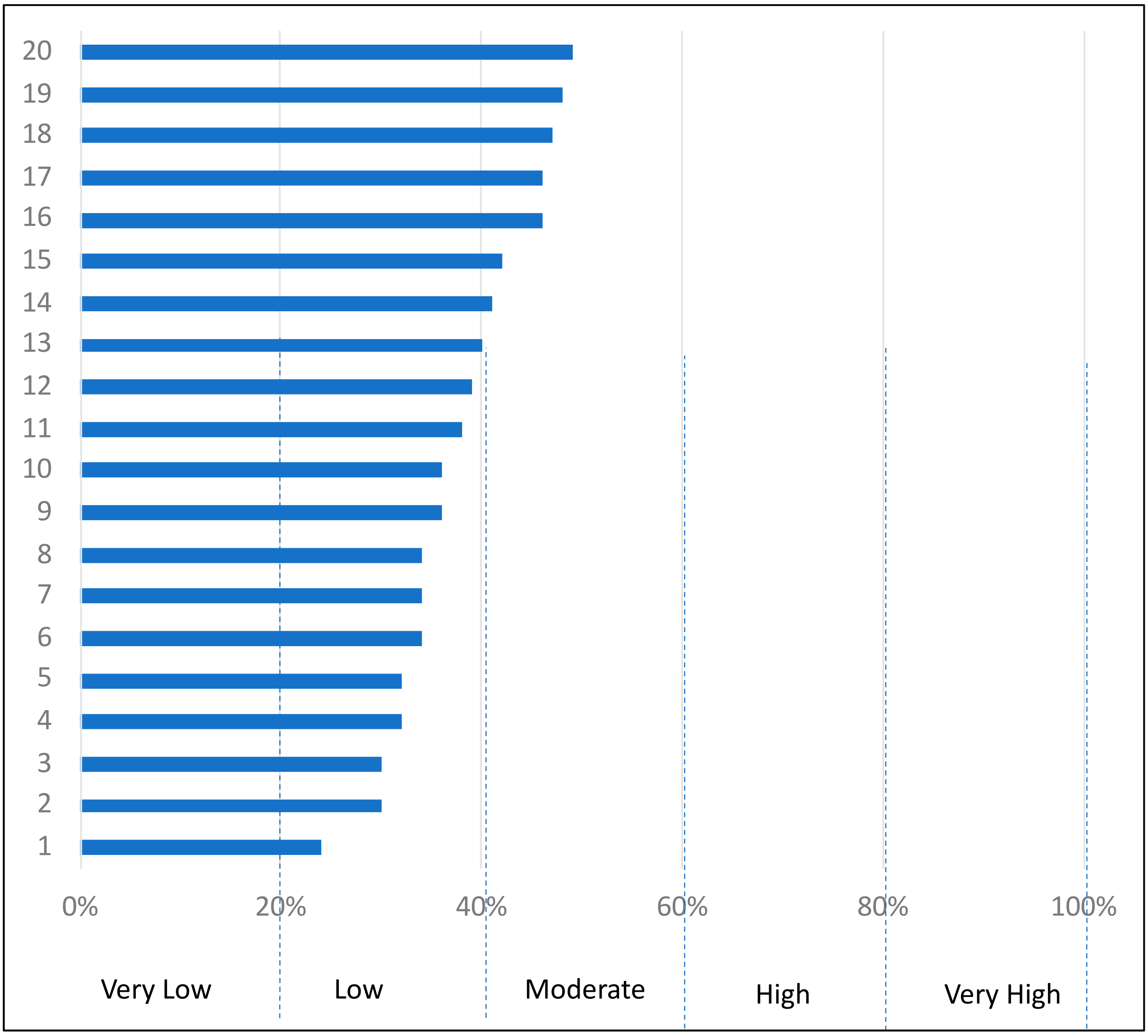

Figure 3. Percent final scores and level of holistic features.

A statistical analysis was conducted to quantitatively assess the central tendency and spread of the results. The mean score for all 20 signalized urban intersections was 11.84 (out of 31.25), or 38%. This low score indicates a low usage of the holistic operations-enabling features (HOeFs). Moreover, the maximum score among the 20 intersections was 15.35 (out of 31.25), or 49%; the minimum score was 7.57 (out of 31.25), or 24%. That is, even the best of intersections in the sample does not fare well; it is using just about half of the HOeFs needed to enable a holistic operation. The mean and maximum values point to a clear deficiency among the study intersections. If we are to assume that the sample is a good representation of all signalized intersections in their home city (and country), that points to a significant potential to further enhance their operations through targeted additions of missing HOeFs. Intersections with more HOeFs, thus higher scores, are enablers of sustainable and healthier urban living of the tested signalized urban intersections, based on the items that this study tackles. Moreover, analysis of specific sections within HIRS reveals existing biases.

The detailed analysis for different sections in HIRS that was performed for the tested 20 signalized urban intersections indicated that the tested intersections scored a mean of 53% on the "motorized/vehicular traffic" section (items/features geared towards vehicular traffic and drivers). This analysis indicates that the intersections are equipped with half of the technologies and physical design and operational features needed for holistic operations (and rated by HIRS). While this is good in that it results in an improved service to vehicle drivers, the section on public health and community wellbeing is not as positive.

The mean score on public health and community wellbeing is 32%. This part of HIRS focuses on the service for pedestrians, cyclists, and people living nearby. A grade of 32% is a failing one; it indicates that the tested signalized urban intersections are missing most of the enabling technologies, physical designs, and operational designs or features that enable or support positive outcomes on the physical and mental health of the pedestrians, cyclists, and people living nearby. While things are changing in some parts of the world, nonmotorized modes, particularly the active ones (pedestrians and cyclists), are still not getting sufficient attention from road design and traffic engineers. A staggering 270,000 pedestrians lose their lives every year around the world, many at signalized intersections [31]. In 2015, more than two cyclists in the United States lost their lives every day due to bicycle–vehicle collisions [54]. However, improvements can be made easily by integrating the enabling technologies, physical design, and operational features that are listed under the "public health and community wellbeing" section.

The standard deviation (SD) of the final score of the 20 tested signalized intersections using HIRS was equal to 2.15. This indicates that the final scores of the signalized urban intersections' operation performance are close to the low mean calculated earlier, which is not an encouraging result. Finally, all the values (mean, max, min, range, SD) indicate that there is a serious problem with the tested signalized urban intersections in that there is much to be desired—and integrated—in their physical design and operations to make them holistic. A summary of the mean, maximum, minimum, and SD of the final scores of the 20 signalized urban intersections can be seen in Table 4.

Table 4. UAE signalized urban intersections' score on HIRS.

Tested Signalized Urban Intersections' Holistic Operational Performance		
Statistical Measures	**Final Score (out of 31.25)**	**Percent Final Scores**
Mean (avg.) final score	11.84	38%
Maximum final score	15.35	49%
Minimum final score	7.57	24%
Standard deviation Final score	2.15	–

While these results may be interpreted to point to a missed opportunity and thus a potential to improve operations at those intersections, this is true only if we are to assume that all urban signalized intersections are of similar functionality and equal importance. However, this is not exactly accurate since, based on the class of roads, some intersections are serving roadways that emphasize vehicular mobility while others are part of accessibility roads, and this necessarily means that the nonvehicular traffic and community needs are not the same. This implies that only one set of feature/technology importance scores or scoring system may not be exactly equitable; a varying scoring scheme, one that is roadway class-sensitive, might be a more suitable scheme.

5. Conclusions

Signalized intersections in urban areas are critical elements for the functioning of the transportation network. Those intersections are integral to the good functioning of the bigger urban system. Intersections, signalized or not (but more so signalized ones), are dynamic nodes through which pathways to public health and community wellbeing pass and, therefore, can be optimized for maximum positive (minimum negative) impacts. Those nodes can be designed (physically and operationally) to modulate the impacts on traffic, community character and feel, health, and the environment to meet desired ends. Multiple criteria are combined to determine the level of effectiveness and sustainability of operation of such facilities.

The evaluation and ranking of the operations of those intersections with respect to their intended functionalities and the consequences of those functionalities on the surrounding community and the users of the intersection is a complex undertaking, as multiple interrelated criteria must all be weighed, considered, and given their due importance. The complexity and multitude of the operations of those sections and the factors involved in the operation, however, do not preclude the necessity of scoring and comprehending the holistic view of the operations at the core of transportation planning. Multiple technical techniques and considerations can all be combined to produce a relatively easy-to-comprehend yet encompassing score scheme that speaks to how well an intersection is operating, however "well" is defined.

A combination of extensive literature research, a survey of relevant technologies and operational concepts, and the judgment of experts on the relevance of the relevant technologies and design considerations were all combined in a purposeful way to enable HIRS to be a convenient tool to rate intersections with respect to how holistic their functionality and operations are. The system presented in this paper to rank intersections with respect to how holistic their operations are is a manifestation of the need for, and the possibility of, a convenient one-stop approach to an overview of how well intersections are operating.

On the other hand, it is also necessary to build flexibility and robustness with respect to how realistic transit operations are progressing. Signalized intersections in urban areas, by virtue of their functionality and purpose, are subject to standards, policies, political pressures, efficiencies, and redundancies of technologies. A system with robustness built therein to accommodate those restrictions, demands, and necessities is critical. HIRS has in it the robustness needed to make the proposed system usable in different places and in different settings based on the level and nature or functionality expected from such intersections and/or the links it connects. HIRS has flexibility built into it to accommodate new practices and technologies as they come online. These can be incorporated into the system relatively easily. The validation process and, thus, the relative weights established in this paper are not fixed, nor are the scores presented in this paper final; input from additional experts in the fields of transportation and public health will continue to be incorporated. Slight changes in the relative weights are expected. In addition, more items/features will likely emerge that will have to be incorporated in HIRS.

HIRS is a user-friendly and easy-to-use tool. It can be adapted to different localities and different network conditions and constraints. Specific local, climatic, and cultural conditions may impose limitations and/or dictate special considerations and/or weighting schemes. HIRS's structure is modular and flexible; such additions (or customization) can be readily incorporated. Both HIRS's depth and breadth can be improved where views and ratings from additional experts in transportation and public health, as well as those from other relevant professions such as policy and planning, can be incorporated.

The binary award point scale used in this work may, as applicable, have to be converted to a linear (or not) continuum between 0 and 1. Even though the spirit of HIRS is at the heart of the sustainability debate, specific sustainability metrics may need to be incorporated. The concepts of HIRS can be extended to other transportation network components such as urban arterials and roundabouts. Some of this work is currently underway and will be reported in future publications. These and other features/improvements will be incorporated in the HIRS software (e-HIRS) currently under development.

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Appendix A

Table A1. A Partial Overview of HIRS's Structure.

Holistic Intersection Rating System (HIRS)				
Section A: Motorized/vehicular traffic				
Subsection 1: Traffic signal management				
Subsection 1 Items:	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2)*
Item 1: Signal coordination	The three main parameters of traffic signal coordination, namely cycle length, split, and offset, are designed to allow the vehicle to cross multiple traffic signals on a section of the road [25].	1 point: The platoon of vehicles are able to cross multiple traffic signals on a section of a road in one go. 0 points: The platoon of vehicles are not able to cross multiple traffic signals on a section of a road in one go.	0.83	
Subsection 2: Special features				
Subsection 2 Items:	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2)*
Item 1: Flashing green light or a countdown timer	Flashing of a green light alerts the drivers that the pedestrian signal is activated; this procedure notifies the driver that the green light will end soon.	1 point: Traffic signal has flashing green light. 0 points: Traffic signal does not have flashing green light.	0.51	
Section B: Public health and community wellbeing				
Subsection 1: Sustainable solutions at signalized urban intersections				
Subsection 1 Items	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2)*
Item 1: Usage of clean mode of power generation (for traffic lights and traffic signals)	Powering the traffic signals, electronic boards, and traffic lights with eco-friendly energy sources such as wind turbines and solar panels [44].	1 point: Usage of ecofriendly energy sources to power the traffic lights, traffic signals, and electronic boards. 0 points: Nonusage of ecofriendly energy sources to power the traffic lights, traffic signals, and electronic boards. 0 points: Absence of Item 1.	0.66	
Subsection 2: Ways and features to reduce noise pollution				
Subsection 2 Items:	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2) Score (1)*(2)*

Table A1. *Cont.*

Holistic Intersection Rating System (HIRS)				
Item 1: Absorption of the sound wave	Energy dissipater available on the side of the road (made up of wood, stucco, masonry, metal).	1 point: Energy dissipater available on the side of the road (made up of wood, stucco, masonry, metal). 0 points: Energy dissipater not available on the side of the road (made up of wood, stucco, masonry, metal).	0.54	
Subsection 3: Ways and features to reduce light pollution				
Subsection 3 Items:	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2) Score (1)*(2)*
Item 1: Turn off the lights when not needed	Traffic lights equipped with motion sensors to shut off the light when the intersection is totally empty (no pedestri-ans/vehicles/cyclists).	1 point: Traffic lights equipped with motion sensors. 0 points: Traffic lights are not equipped with motion sensors.	0.51	
Subsection 4: Pedestrian service				
Subsection 4 Items:	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2) Score (1)*(2)*
Item 1: Median refuge island is wide enough to accommodate pedestrians and cyclists	The median refuge island is wide enough to accommodate pedestrians and cyclists.	1 point: If the median refuge island is wide enough to accommodate the pedestrians. 0 points: If the median refuge island is not wide enough to accommodate the pedestrians.	0.94	
Subsection 5: Cyclist service				
Subsection 5 Items:	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2) Score (1)*(2)*
Item 1: Bicycle lanes	Lanes that are designated by solid white lines and a bicycle symbol that indicates that this lane is exclusively for bicycles.	1 point: Presence of bicycle lane at the intersection. 0 points: Absence of bicycle lane at the intersection.	0.94	
Subsection 6: Psychological effect of transportation				

Table A1. *Cont.*

Holistic Intersection Rating System (HIRS)				
Subsection 6 Items:	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2) Score (1)*(2)*
Item 1: Components of biophilic design green street	The sides of the street of the intersection are planted.	1 point: If the sides of the street of the intersection are planted. 0 points: If the sides of the street of the intersection are not planted.	0.63	
Total score =				

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smart cities

MDPI

Article

iBikeSafe: A Multi-Parameter System for Monitoring, Evaluation and Visualization of Cycling Paths in Smart Cities Targeted at Cycling Adverse Conditions

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Abstract: The fast transformation of the urban centers, pushed by the impacts of climatic changes and the dramatic events of the COVID-19 Pandemic, will profoundly influence our daily mobility. This resulted scenario is expected to favor adopting cleaner and flexible modal solutions centered on bicycles and scooters, especially as last-mile options. However, as the use of bicycles has rapidly increased, cyclists have been subject to adverse conditions that may affect their health and safety when cycling in urban areas. Therefore, whereas cities should implement mechanisms to monitor and evaluate adverse conditions in cycling paths, cyclists should have some effective mechanism to visualize the indirect quality of cycling paths, eventually supporting choosing more appropriate routes. Therefore, this article proposes a comprehensive multi-parameter system based on multiple independent subsystems, covering all phases of data collecting, formatting, transmission, and processing related to the monitoring, evaluating, and visualizing the quality of cycling paths in the perspective of adverse conditions that affect cyclist. The formal interactions of all modules are carefully described, as well as implementation and deployment details. Additionally, a case study is considered for a large city in Brazil, demonstrating how the proposed system can be adopted in a real scenario.

Keywords: internet of things; smart cycling; smart cities; bicycles

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1. Introduction

Among the most urgent challenges in this century, the development of sustainable and resilient cities has driven much attention lately [1,2]. Actually, while this century reported most people living in cities worldwide, for the first time in our history, this intense urbanization process has created continuous pressure on urban centers. In this complex environment, mobility has been a major issue, directly impacting the sustainability of modern cities [3].

Conversely, most recent efforts toward mobility efficiency have been harnessed to improve traditional transportation based on motor vehicles, with massive investments dedicated for widening roads to allow more cars, indirectly incurring in the emission of additional tons of pollution gases yearly. In this sense, alternative transportation should be promoted instead, putting cleaner and more sustainable modals like bicycles at a prominent place. Hopefully, investments in smart cycling are rising, with many large cities experiencing innovative mobility solutions centered on public transportation connected to last-mile cycling [4]. Furthermore, the COVID-19 Pandemic and the resulted social distance measures have played an important role in strengthening this sustainable mobility trend [5].

Promoting cycling for transportation, nevertheless, has its challenges. Among them, cyclists riding in an urban area will be subject to some adverse conditions that may affect their health and safety [6,7]. In the first place, air and noise pollution, high UV radiation, inadequate luminosity, extreme (too low or too high) temperature, and humidity, among other factors, may be easily experienced in a today large city, at different levels, which may impact the health of cyclists in the long term. Besides these adverse environmental conditions, traffic accidents may also negatively impact cycling in a city, and it is reasonable to expect that some areas will report higher historical risks of accidents. Finally, urban violence will also have its role in the perceived quality of cycling in a city, with robberies and stealing occurrences also impacting cyclists. Putting all these together, adverse conditions strongly influence how sustainable cycling will be promoted and maintained as a practical transportation modal in cities.

Adverse conditions associated with cycling can be monitored in different ways. The advent of the Internet of Things (IoT) technologies has opened a strong development trend, making it possible the use of different affordable sensors to monitor a vast number of variables [8]. This way, bicycles can be endowed with sensor units, allowing them to gather essential environmental information to be further transmitted, stored, and processed. In parallel, accidents and urban violence incidents are registered mainly by the governments, usually through traffic agents and police officers, are often stored into public databases that can be openly mined. However, crowd-sourcing approaches may also be adopted in this scenario [9,10]. Then, exploiting all this information and adopting cycling maps in the considered cities as a reference, a better perception of the quality of cycling paths can be achieved.

Therefore, monitored environmental data may be the basis for evaluating the quality of cycling paths in cities, with distributed sensors on bikes and data mining algorithms providing the required information. In this scenario, however, precise identification of the quality of cycling paths requires georeferenced processing of all monitoring samples and historical data, allowing the correct association of paths and quality indicators. As a result, sensors-based bike-centric monitoring approaches have to be equipped with GPS devices, as well as traffic accidents and urban violence records must include GPS coordinates of the area of occurrence. Actually, such GPS-based monitoring paradigm is a common approach that has been adopted mainly in smart city scenarios [8,11].

Finally, the computed quality of the cycling paths in a city should be displayed to the cyclists easily and intuitively, fostering the adoption of the discussed solution. For that, comprehensive maps should be used to display helpful information to the cyclists.

Considering all challenges mentioned earlier and requirements, we believe that the promotion of sustainable cycling will pass through the quality assessment of cycling paths in urban areas. For that, the processing cycle of monitoring, evaluation, and visualization has to be considered as a whole, as depicted in Figure 1.

This article proposes the iBikeSafe, a comprehensive multi-tier approach that performs flexible monitoring, robust evaluation, and innovative visualization of the quality of cycling paths, being an effective solution to inform cyclists about adverse conditions and to indicate governmental policies should improve cycling areas. This proposal is also implemented as a particular system, assembling some independent modules into a unified multi-parameter system, the BrazilCycling, formatting the interactions of those modules for compatibility and performance issues. Finally, a case study is considered for the iBikeSafe-complaint BrazilCycling implementation, demonstrating how a city in Brazil could exploit the proposed approach to promote sustainable smart cycling.

The remainder of this article is organized as follows. Section 2 presents some related works that influenced this article. The proposed iBikeSafe approach is described in Section 3. A practical implementation for the iBikeSafe approach is described in Section 4.

Section 5 presents a case study for the iBikeSafe, taking the city of Natal, Brazil, as reference. Finally, conclusions and references are presented.

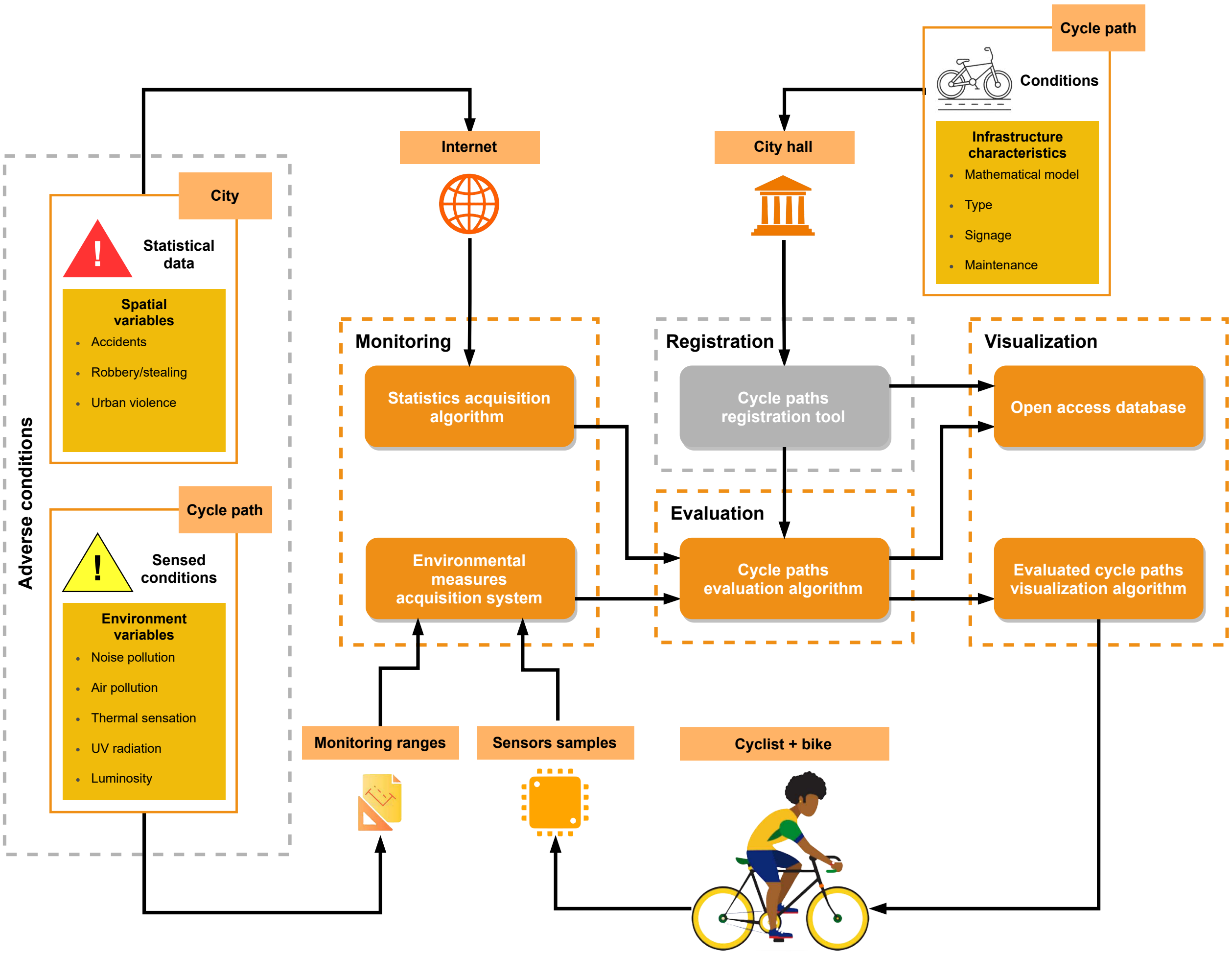

Figure 1. The processing cycle when assessing the quality of cycling paths.

2. Related Works

The daily lives of cyclists in a modern urban context can be subject many risk factors that can potentially degrade their health after long exposition periods. Additionally, large cities may also produce different dangerous situations that may affect safety while cycling, causing injuries or even death in the worst scenarios. Environmental factors that affect cycle paths (temperature, pollution, ultraviolet radiation, light, etc.) can subject cyclists to the development of several long-term health problems. In addition, unfavorable characteristics of the cycle paths (quality of the pavement, signage, etc.) and historical risks of accidents and urban violence occurrences (theft, robbery, etc.) may be indicators of immediate cycling dangers when moving on a city. Putting all these together, cycling in large urban areas may have some inherent risks that should be appropriately known, ultimately supporting the development of more sustainable cities.

Given the importance of understanding the nature and the spatial and temporal characteristics of such problems, the factors that may negatively impact the life of cyclists should be properly modeled. However, it is also extremely important to create tools that help cyclists when choosing their routes (based on concerns with their health/safety) and the development of applications that can guide public authorities when improving those cycle paths. In this context, the iBikeSafe comes as a multi-modular approach responsible for monitoring, evaluation, and visualization of the perceived quality of the cycle paths built in a city. This approach is composed of particular subsystems, which perform some defined activities related to the state-of-the-art in their respective areas.

For the "Monitoring module" of the iBikeSafe approach, two services are expected to be created. The first service is related to the data gathering of environmental conditions (variables), which will be performed by attaching multi-sensor units onto bicycles. Some concepts expected from such a service come from using the Internet of Things paradigm applied to monitoring systems. This type of IoT application is very recurrent in researches found in the literature. Thus, this section discusses some papers from this area that are related to how the Monitoring module was developed for the iBikeSafe approach (Table 1).

In [12], the authors focused on sensing the infrastructure conditions of cycle paths, using micro-controllers and sensors attached to bikes to identify imperfections on the surface of the cycle paths. Actually, this research line is focused on analyzing the infrastructure of cycle paths (or roads) through sensors, bringing some important contributions [2,13]. Differently, in [14] a computational solution was developed to analyze infrastructural data aspects by coupling smartphones to bikes, allowing the collection of data from the GPS and the accelerometer devices already present in the smartphone, supporting the desired analysis.

In our previous work presented in [15], we proposed the development of a system to monitor predefined environmental variables that affect the health and safety of cyclists. Additionally, in [16] we proposed a framework for configurable mobile multi-sensor monitoring units that are capable of measuring both environmental and infrastructure variables.

Table 1. Works focused on the monitoring of cycle paths conditions exploiting sensors attached onto bicycles. Sensing approach features: $\mathbf{F_1}$—environmental sensing, $\mathbf{F_2}$—infrastructure sensing, $\mathbf{F_3}$—multi-sensors solution, $\mathbf{F_4}$—development of a specific sensing unit, $\mathbf{F_5}$—smartphone-based solution, $\mathbf{F_6}$—offline operation.

Paper	Year	Description	F_1	F_2	F_3	F_4	F_5	F_6
Springer and Ament	2020	In that paper, a low-cost mobile monitoring unit was developed to capture data related to the surface of cycle paths. Data acquisition was performed using a set of sensors (IMU, camera, odometer, etc.) attached onto bicycles, along with microcontrollers.		x	x	x		x
Zang et al.	2018	It proposes a device capable of analyzing the surface roughness of roads exclusively for pedestrians and cyclists. For that, GPS and accelerometer sensors embedded in smartphones of the cyclists were considered, in order to collect the necessary data for surface analysis.		x	x		x	
Oliveira et al.	2021	It proposes a framework for the development of generic mobile multi-sensor monitoring units. That framework is composed of a specific hardware architecture, capable of integrating different types of sensors for measuring variables, and a firmware responsible for the dynamic configuration of the measured variables.	x	x	x	x		x
Oliveira et al.	2020	It presents the architecture of a monitoring system for environmental variables that affect the health and safety of cyclists. A prototype of a monitoring unit was developed, which performs georeferenced sensing comprising measurements of luminosity, UV radiation, temperature and humidity.	x		x	x		x

Actually, as an essential characteristic to be remarked, some approaches in the literature need a network with Internet access to operate, while some works have a local storage scheme for the collected data, which can be automatically sent to a cloud service when the device connects to the Internet, as in [15,16]. It is worth mentioning that the assumption of constant (online) monitoring by connected bikes in a city may be unrealistic in many cases, either due to the absence of networking services or due to budget restrictions.

The second service of the iBikeSafe Monitoring module, described in the next section, is related to the gathering of urban statistical data present on the Internet, which may be associated with the area of Big Data. The data collected by this subsystem is related to the immediate risk conditions for cycling, which is extremely important to decide if a cycle path has an acceptable quality for safe and satisfactory cycling practice. For the development of this subsystem, it is proposed to create a web crawler to gather urban statistical data from the Internet and process it, formatting and exporting this information. Some literature have proposed such a data mining process targeted at urban data in different contexts. In [17], the authors exploited this technique to search for some information in order to classify two cities based on safety, infrastructure, and health conditions. Similarly, in [18] a research was conducted to collect general information from thirteen Indonesian cities in order to identify specific aspects.

In a different research line, the work in [19] employed no particular tool to perform an automated search of accidents involving cyclists data in the city of Seoul. Instead, in that paper, data were collected manually by accessing a specific database to identify the safety level for cycling in that city. Although performing such data collection in a non-automatic way, the presented results and discussions in that work are relevant to mature the perception of quality evaluation of urban cycling, contributing to the development of this article.

Finally, in order to better describe and compare the presented related works, highlighting their main characteristics concerning what is being expected for the definition of the iBikeSafe approach, Table 2 summarizes the discussed contributions following a uniform pattern.

Table 2. Works focused on monitoring cycle paths conditions through the collection of statistical data from cities and/or tracks on the Internet. Statistical data collection approach features: **F_1**—automated data collection, **F_2**—number of cities considered in the research, **F_3**—considers data from accidents involving cyclists, **F_4**—considers cycle paths infrastructure data, **F_5**—considers urban security data.

Paper	Year	Description	F_1	F_2	F_3	F_4	F_5
Supangkat et al.	2018	It is performed an analysis of urban data (security, infrastructure and health conditions) of two cities in Indonesia, using the concept of Big Data. The objective of that analysis, developed through tools such as Apache Nutch and Apach Spark, aimed to classify cities within a score range for the mined characteristics.	x	2		x	x
Pramana et al.	2017	It discussed several possible applications of Big Data for official statistics in Indonesia. In addition, three case studies were discussed: prediction of community patterns between cities using Twitter, development of a statistical model for food price prediction, and mobile position data for tourism statistics.	x	13			x
Kang et al.	2016	It was aimed at the collection and analysis of data for the city of Seoul. Among the analyzed data, the authors sought the accident rates involving cyclists and the number of people who practice cycling in the city, as well as some population data. From those, it was possible to understand the general safety panorama for cycling.		1	x	x	

Due to the comprehensive nature of the proposed iBikeSafe approach, only the Monitoring module and its two services are not sufficient to achieve the desired goals. Then, based on the premise of indicating the cycle paths quality for cyclists and the public authorities, the iBikeSafe approach also includes an Evaluation module, which exploits the Monitoring module data as input. This way, research works in those related areas were also considered, discussed as follows.

Implementing the iBikeSafe Evaluation module is crucial to create an important parameter when choosing cycling routes, letting cyclists correctly choose the best paths according to their quality (and not only distance, as usual). Such choice can be based on several aspects: something very personal or a common opinion among cyclists. Usually, they are concerned about travel on cycle paths that make cycling safe and enjoyable, preferring flat cycle paths with good signage, away from the roads and without irregularities [2,4,20]. In addition, cyclists are also looking for safe and well-lit regions with favorable environmental conditions for cycling practice, opening up a wide range of parameters for evaluating cycle paths.

Knowing this, some researchers have already been concerned with developing solutions to evaluate cycle paths according to some of these mentioned parameters. In work presented in [21], authors developed a metric to evaluate cycle paths, but without any system to automate this process. In that work, the authors considered ecological, social, environmental, and technical aspects in order to create a way to guide the city's public authorities in cycle path planning. Differently, works presented in [22,23] employed an alternative methodology to evaluate cycle paths, based on surveys applied to defined cyclists populations. The average results are then used to evaluate the quality of cycle paths.

In our previous work published in [24], we developed a metric for evaluating cycle paths based on Fuzzy logic, which is capable of qualifying them into five different levels based on environmental and infrastructure data. In that work, it is also proposed the development of an application that uses that metric to automatically and periodically evaluate cycle paths.

Table 3 summarizes the works for quality evaluation of cycle paths.

Table 3. Works focused on evaluation of cycle paths in terms of quality. Evaluation approach features: $\mathbf{F_1}$—automated evaluation tool, $\mathbf{F_2}$—survey application, $\mathbf{F_3}$—evaluation metric proposal, $\mathbf{F_4}$—number of cities covered by research.

Paper	Year	Description	F_1	F_2	F_3	F_4
Bjørnskau et al.	2016	The authors applied a survey involving cyclists living in the city of Oslo to understand their perception of the quality of the cycle paths on four very busy streets. In this, it was possible to notice that among the evaluated cycle paths, cyclists preferred to use only an option that gives them a feeling of safety.		x		1
Pesshana et al.	2020	It consists in the development of a conceptual model for bicycle path evaluation from the point of view of utility, safety, ecological, social, environmental and technical parameters. The development of this approach is intended to guide municipal authorities, traffic engineers and transportation planners.			x	n
Vasilev et al.	2017	Authors made a behavioral observation and applied a survey to cyclists in a Norwegian city to explore path users' understanding of sharrows, the type of street markings that indicate that cyclists can ride on the road alongside cars. In addition, that work also analyzed the implications for the safety of cyclists when sharrows are implemented.		x		1
Oliveira et al.	2020	It presents a new cycle path evaluation metric based on the use of Fuzzy logic to process data related to environmental monitoring, collected by sensors, and statistics, acquired from the Internet in an automated way. Processing this, a cycle path is classified in one of five levels (very bad, bad, moderate, good and very good), which are represented by colors.	x		x	n

Since the proposed iBikeSafe approach will collect environmental and infrastructure data of cycle paths, through the Monitoring module services, and qualify it, using the Evaluation module service, it becomes possible to provide valuable data to the end-users: cyclists and governmental authorities. To achieve this final goal, the iBikeSafe approach also encompasses a module that provides a way to present the cycle path data and easily to understand. Composed of two services, the iBikeSafe Visualization module captures data from the Evaluation module to process it, generating maps and historical graphs, and making it available for users access (initially) through a web page.

The cycle paths data visualization by end-users is a crucial topic for works in research lines related to cycling conditions. In the literature, it is possible to find some papers that are based on the visualization of cycle paths, or routes taken by cyclists, through the use of web and/or mobile technologies and with different purposes.

In [25], a web application was developed to allow users to access cycle paths maps, which are registered through the collection of data from volunteer cyclists in Madrid. In [26], the authors performed research that is not limited to just one city, developing a mobile application for cyclists to register cycle paths, being able to indicate imperfections in those paths. Additionally, in that research, the city public authorities can access cycle paths information through a web page, allowing them to make decisions. Finally, in [27], the authors created a digital cycling platform to influence casual cyclists to adopt bikes as their primary means of transport. In that work, a mobile and a web application were developed to present some route and cyclists information.

Table 4 summarizes works in this particular research area.

Table 4. Works focused on visualization of cycle paths. Visualization approach features: $\mathbf{F_1}$—web application, $\mathbf{F_2}$—mobile application, $\mathbf{F_3}$—number of cities covered by the application, $\mathbf{F_4}$—exploits pre-registered cycle paths, $\mathbf{F_5}$—available for access.

Paper	Year	Description	F_1	F_2	F_3	F_4	F_5
Romanillos and Zaltz Austwick	2016	It consists of the description of the objectives, the applied methodology and the results achieved with the development of the Huella Ciclista de Madrid initiative, an application launched with the aim of collecting data about cycle paths (using cyclists as sources) and present processed maps to the users.	x		1	x	x
Khodambashi et al.	2016	The work presents the development of two applications. The first one consists of an Android software that tracks the location of cyclists, creating routes and allowing them to report faults on the paths. The second (web-based) application allows city planners to view failures reported by cyclists and make decisions.	x	x	n		x
Meireles and Ribeiro	2020	The goal of this work is to create digital cycling platforms that can influence casual cyclists. The paper focuses on the overall infrastructure for cycling, assessing the potential influence of using data from mobile apps. For that, a mobile and a web application were developed, showing some information related to the route that users took when cycling, such as route map, distance covered, time of activity, burned calories, etc.	x	x	n		

Therefore, as discussed in this section, the proposed iBikeSafe approach is composed of multiple services covered by different related works, although considering different strategies and technological methods. However, although some services are already addressed in the state-of-the-art, no previous solution has provided a comprehensive approach that encompasses all challenges of monitoring, evaluation, and visualization of the quality of cycle paths concerning adverse conditions for cycling, to the best of our knowledge.

3. Proposed iBikeSafe Approach

Developed to allow the monitoring, evaluation, and comprehensive visualization of cycle paths in urban environments, the iBikeSafe approach aims to indicate the perceived quality of any number of cycle paths in a particular city. As discussed before, such quality will be related to the potential damage that cycle paths may bring to the health and safety of cyclists. Therefore, this approach was carefully modeled to allow executing the expected functions in a flexible and scalable way.

The first goal of the iBikeSafe approach is to perceive adverse conditions that negatively impact the cycle paths quality from the cyclists' health and safety point of view. To make it possible, the iBikeSafe structure comprises the Monitoring module, which provides two services capable of collecting adverse conditions data through mobile sensing and web crawling techniques.

Since iBikeSafe can collect data that may directly or not affect the cyclists, it is necessary to transfer data to the Evaluation module. Then, that module can group the information retrieved from the Monitoring module, processing it through a cycle path qualification service. After that, it is possible to generate easy-to-view data for cyclists and public authorities, employing visual resources like maps and graphs.

The generation of data for visualization purposes is the expected service of the Visualization module. Composed of a function for generating maps and graphs of cycle paths and a function responsible for making such data available through the Internet, this last module of the iBikeSafe approach is crucial in the sense that it provides the ultimately required information to support sustainable smart cycling.

Therefore, this section defines the conceptual modules and the expected services of the proposed iBikeSafe approach.

3.1. Monitoring Module: Environmental Sensing

The use of mobile monitoring units attached to the most diverse objects or people (wearable systems) is a very current and common practice due to the emergence of the Internet of Things. Therefore, researchers worldwide are looking for intelligent solutions aimed at improving the practice of cycling through innovative cycling tools, which have a wide range of applications focused on characteristics such as planning, monitoring, and qualification of cycle paths, among others. In this sense, some solutions focused on monitoring cycle paths have been developed based on the integration of IoT technologies with bikes, eventually supporting the creation of the Internet of Bikes (IoB) concept.

In this way, one of the iBikeSafe services was defined to be responsible for capturing the adverse conditions of cycle paths related to environmental variables that negatively impact the cyclists' lives. Furthermore, such service was associated with the definition and eventual creation of a mobile sensing unit to be attached to bikes, following a set of fundamental requirements (Figure 2).

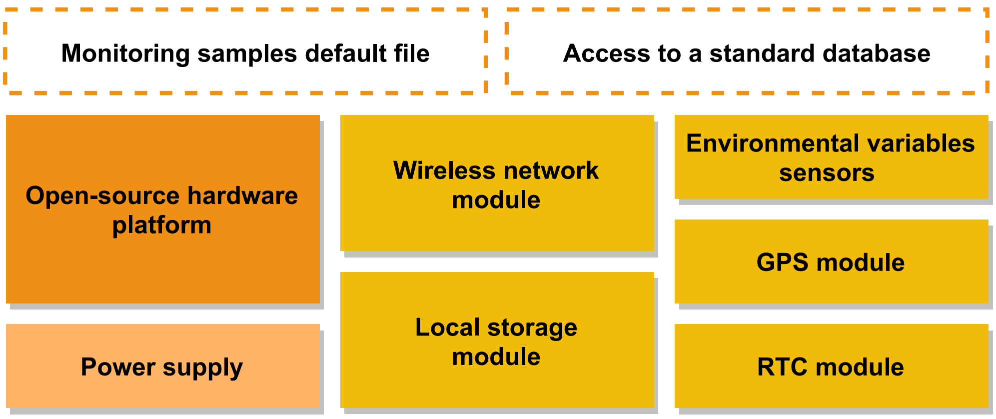

Figure 2. The fundamental requirements of the iBikeSafe sensing unit.

Inserted into the iBikeSafe sensing unit to perform all basic device operations (Figure 3), the open-source hardware platform is the core of the proposed device, having a direct connection with all other components presented in Figure 2. Furthermore, this component is intended to have low-power consumption and low-medium computing capacity, being a small dimensions board. Following these definitions, we can mention some affordable off-the-shelf open-source hardware platforms that can be employed, such as microcontrollers (Arduino, ESP8266, PIC, Raspberry Pi pico, etc.) and single-board computers (Raspberry Pi 2/3/4, Beaglebone, etc.).

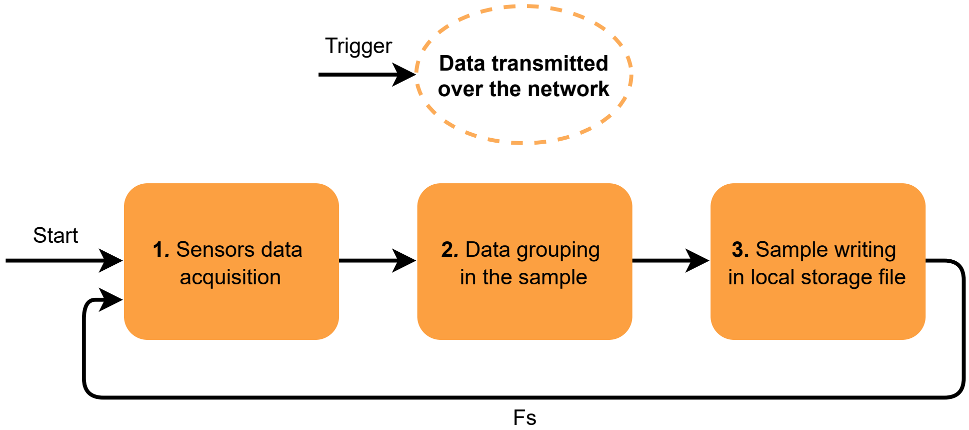

Figure 3. iBikeSafe sensing unit state machine.

In order to use one of these open-source hardware platform options as the iBikeSafe sensing unit core, it is necessary to develop a firmware capable of running the state machine presented in Figure 3. That firmware should work based on the intermittent execution of three states, according to a iBikeSafe approach implementation. For this execution, a variable sampling frequency F_s was defined to represent the interval between the execution of the three synchronous states defined for a generic mobile sensing unit [16].

The first synchronous state of the sensing unit consists of reading the data from the sensors and modules, as depicted in Figure 2 (GPS, RTC, and environmental variables sensors), converting the data to a known information type (latitude, longitude, date, time, temperature, humidity, UV radiation, etc.). After collecting this information, the firmware running on the sensing unit core groups that data into a "sample", identified by a timestamp. In addition, this sample has the location of the cycle path stretch from where the sample was acquired, as well as the environmental data for that geolocation and time.

After grouping a particular sensing data into a sample, this group of information is written in the last line of a *dd-mm-yyyy.csv*file present in the local storage module, which contains all daily monitoring files not uploaded yet. As presented in Listing 1, such "samples file" stores the sensing samples that have not been transmitted yet to the (cloud) database, having its first line dedicated to defining which environmental variables are being informed through an identifier i, with $i > 0$ and $i \leq E$. The variable E defines the maximum number of different types of sensing data (temperature, humidity, pressure, UV radiation, etc.) that is being considered in a system, and, of course, it requires a previous mapping between any id i to a particular sensing data type.

Listing 1: An example of a samples file containing some monitoring samples generated by the sensing unit.

```
1 2 3
17:39:00  −12.282060  12.060282  29.8  73  100
17:40:00  −12.282061  12.060282  29.8  73  100
17:41:00  −12.282062  12.060282  29.8  73  100
17:42:00  −12.282063  12.060282  29.8  73  100
17:43:00  −12.282063  12.060282  29.8  73  100
```

```
17:44:00  −12.282063  12.060282  29.8  73  350
17:45:00  −12.282063  12.060282  29.8  73  100
17:46:00  −12.282064  12.060282  29.8  73  100
```

In all lines of the samples file excepting the first one, the samples grouped in the execution of state two are presented (Figure 3). Since each bike may have a particular configuration of enabled sensor devices attached to it, multiple sensing configurations may be used in a city. Thus, for a particular bike b in the system, for $b > 0$ and $b \leq B$, for a total number of B bikes, there will be a set of possible variables that can be measured by a monitoring unit attached to that bicycle, which is $x_1, x_2, x_3, \ldots, x_{E(b)}$, having $E(b)$ as the variable E for bike b.

Therefore, for each sample line in the samples file, we have the following order of information: time, latitude, longitude, $x_1, x_2, \ldots, x_{E(b)}$, which are all separated by a blank space. Since the sensing unit core collects and stores the samples, following the defined states, sending this collected data to a unified database in the Cloud becomes possible. For this, an asynchronous state capable of sending data through a wireless network (WiFi, GSM, Bluetooth, LoRaWAN, etc.) was created, being responsible for forwarding the information to the Cloud service that contains the database. The activation of this state, described in Figure 3, is triggered according to the iBikeSafe implementation, which can be a device button, an upload interval, or other defined condition.

This way, according to the features defined for the proposed sensing unit, it becomes possible to attach several units to bikes to collect data in a myriad of cities around the world, taking into account the sensing particularities of each considered city. Such data are one of the groups of information required for quality evaluation, as discussed in the following subsections.

3.2. Monitoring Module: City Statistics

Unlike the sensing service of the iBikeSafe approach, the cities statistical data service does not have physical units attached to bicycles to collect the necessary information. Differently, this service is proposed to have several Internet databases as its information source, such as public databases from news corporations and police or government open databases. So, to collect statistical data that indicates some historical risk to cyclists' health and safety, this iBikeSafe Monitoring module service proposes the use of algorithms capable of automatically and periodically searching for this information in some previously defined databases present on the Internet.

In order to perform this function satisfactorily, retrieving truthful and reliable data, a set of operations was defined, as described in Figure 4.

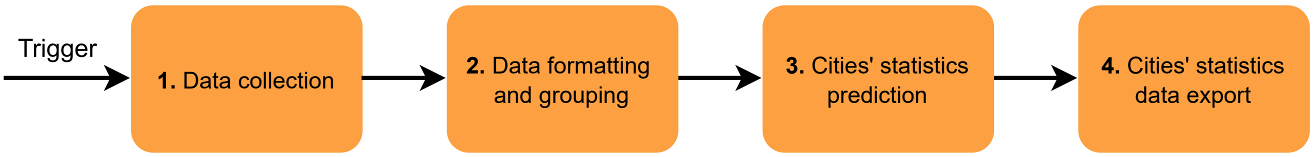

Figure 4. The conceptual diagram of the iBikeSafe statistical data collection service.

Following a periodically triggered process, with the frequency defined according to the iBikeSafe approach implementation, the algorithm responsible for collecting cities' statistical data (that impacts the cyclists' life and safety) has four well-defined states. In the first state, it was proposed that the service uses some automated data collection tool, such as a web crawler, to capture the necessary information in the Internet databases, covering the entire web or only a defined specific set of databases.

Once the search engine collects the data, the algorithm moves to the second state. Then, the collected data are formatted and grouped according to the referring city and later sent to the third state of the algorithm, which will count all data by city, predicting the numbers for each statistical variable and generating a CSV file as the example presented in the Listing 2, referred as the "statistics file".

Listing 2: An example of a statistics file containing information about the monitored cities.

```
1 2
Feira_de_Santana-BR    5    3
Salvador-BR            3    5
Amsterdam-NT           0    1
New_Delhi-IN           6    7
```

The file containing the monitored cities statistics has a pattern name based on the data collection period. Thus, for a monthly monitoring period, we have the *mm-yyyy.csv* statistics file. As for the file content, we have the first line informing the identifiers j, with $j > 0$ and $j \leq S$ of the statistical variables y_j, with variable S representing the maximum number of different types of statistical variables (robbery/theft, urban violence, traffic accidents, etc.) that are being considered in the statistical data collection system and mapped to a specific id j. Additionally, for the following lines after the first one, we have the statistics of each monitored city formatted the pattern: city name and country code, y_1 and y_2.

With the achieved statistics stored in that file, the algorithm that implements the statistical data collection service executes its last state, uploading this file into a Cloud database for use by the Evaluation module. Once the data collected by the Monitoring module, through both the sensing and statistical data collection services, are sent to their respective databases, the Evaluation module is capable of qualifying the cycle paths for a given monitoring period, as will be further explained.

3.3. Evaluation Module

Created to qualify cycle paths according to the adverse conditions captured by the Monitoring module, the Evaluation module performs its function based on the registered cycle paths and the data provided by the Monitoring module. For this, the service responsible for executing this function of the iBikeSafe approach must be able to import the monitoring data from the already discussed databases, importing the cycle paths structural data and processing it to evaluate the cycle paths to the iBikeSafe implementation.

So, for a better understanding of the functioning of this service, a state diagram was created and divided into two blocks, as presented in Figure 5: The data processing and the cycle path evaluation blocks.

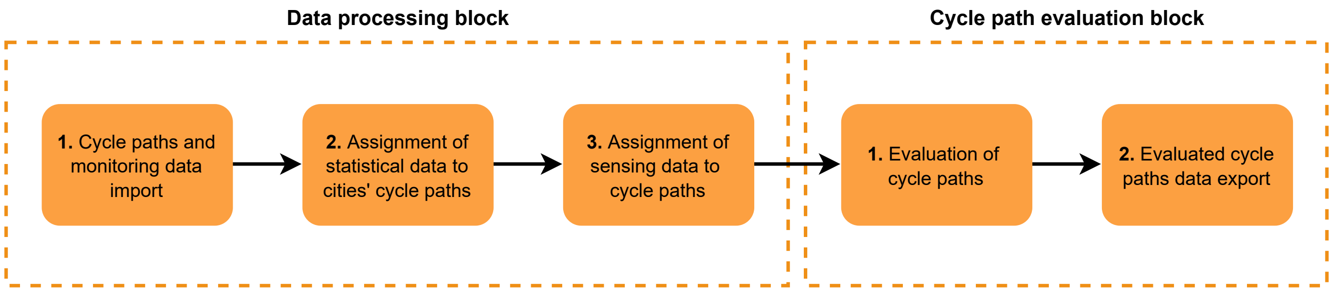

Figure 5. The conceptual diagram of the iBikeSafe evaluation service.

In the states of the first block, the iBikeSafe approach evaluation service performs three operations. First, the proposed algorithm must be able to import the data from both the Monitoring module and the cycle path registration subsystem, which can be a manual input tool accessed by cities' public authorities, as illustrated in Figure 1, or an automatic data collection tool from an existing Internet databases, such as the CycleOSM.

After importing the necessary data for cycle paths evaluation, it is necessary to execute the following two data processing states. These states consist of attributing the statistics of a given city to all its registered cycle paths, taking as reference a city's name comparison, and assigning sensing data to the cycle paths corresponding to geolocation data of each sample. Once these data are processed, each registered cycle path will have its respective data, allowing the execution of the evaluation block states.

The iBikeSafe cycle paths evaluation service uses the monitoring data associated with the registered cycle paths to qualify it, exploiting a technique used for a specific approach implementation. Hence, this approach allows the evaluation of the cycle paths in different ways, being able to use only mathematics or applying artificial intelligence techniques, and generating different quality indicators, such as quality levels, color patterns, and numerical grades.

However, only the cycle paths evaluation does not fulfill the expected goals of this approach, which is to provide valuable and easy-to-use data about the cycle paths quality concerning its potential damage to the cyclists' health and safety. Thus, there is a need for a second state for the cycle path evaluation block, which is the grouping of all evaluated cycle paths according to any particular iBikeSafe implementation to transmit it to the last specified module, which is the Visualization module.

3.4. Visualization Module

Designed to support the visualization of the quality of cycle paths, the Visualization module of the iBikeSafe has two well-defined services. The first service, called "viewable data generator", is responsible for getting the data from evaluated cycle paths, exported by the Evaluation module, and generating files with the viewable data from the cycle path. Such files will then be transmitted to the second service, which defines the generic functions of a flexible visualization app.

All data generated by the first iBikeSafe Visualization module service (maps, graphs, numerical data, etc.) is stored in files identified by the cycle paths evaluation period. The visualization app can access this data to process it for better presentation, showing them to the users according to defined search queries. Figure 6 presents the general functioning of this module, which is based on the integration of the two proposed services.

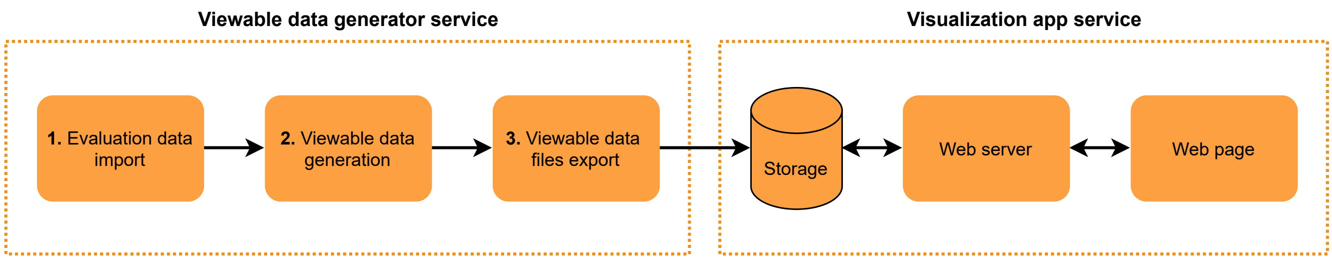

Figure 6. The conceptual diagram of the iBikeSafe visualization services.

Finally, as discussed in this section, the proposed iBikeSafe approach defines a set of modules and services to guide implementing of any quality evaluation system targeted at cycle paths. Actually, in order to implement this approach according to the needs of any particular city, it is essential to highlight that those different requirements will demand different programs and hardware components. Therefore, in order to illustrate a practical application for the iBikeSafe, the following section will present a particular implementation of the proposed approach, focused on quality evaluation of cycle paths in Brazilian cities.

4. BrazilCycling: A Implementation of the iBikeSafe

Based on all defined procedures in the iBikeSafe approach, a particular implementation was designed to demonstrate how it can be used practically. Such implementation, referred to as BrazilCycling, is based on previous works of the authors and additional specifications, being described as follows:

- BikeSensor [15]: Representing the sensing service of the Monitoring module, it is a system for sensing environmental variables through multi-sensor units attached to bicycles;
- BikeData [24]: Consists of the city statistical data collection service of the Monitoring module, which searches for this information through a web crawling application;
- BikeWay [24]: Applied in order to be the Evaluation module service, this system can evaluate cycle paths registered through the BikePathGen subsystem. For that, adverse conditions of cycle paths are processed by a metric based on Fuzzy logic rules;
- CyclingView: This is defined as a visualization module service composed of a tool to allow the visualization of the (monthly) quality of cycle paths through maps.

Figure 7 demonstrates the integration details of all subsystems in the iBikeSafe-complaint BrazilCycling implementation.

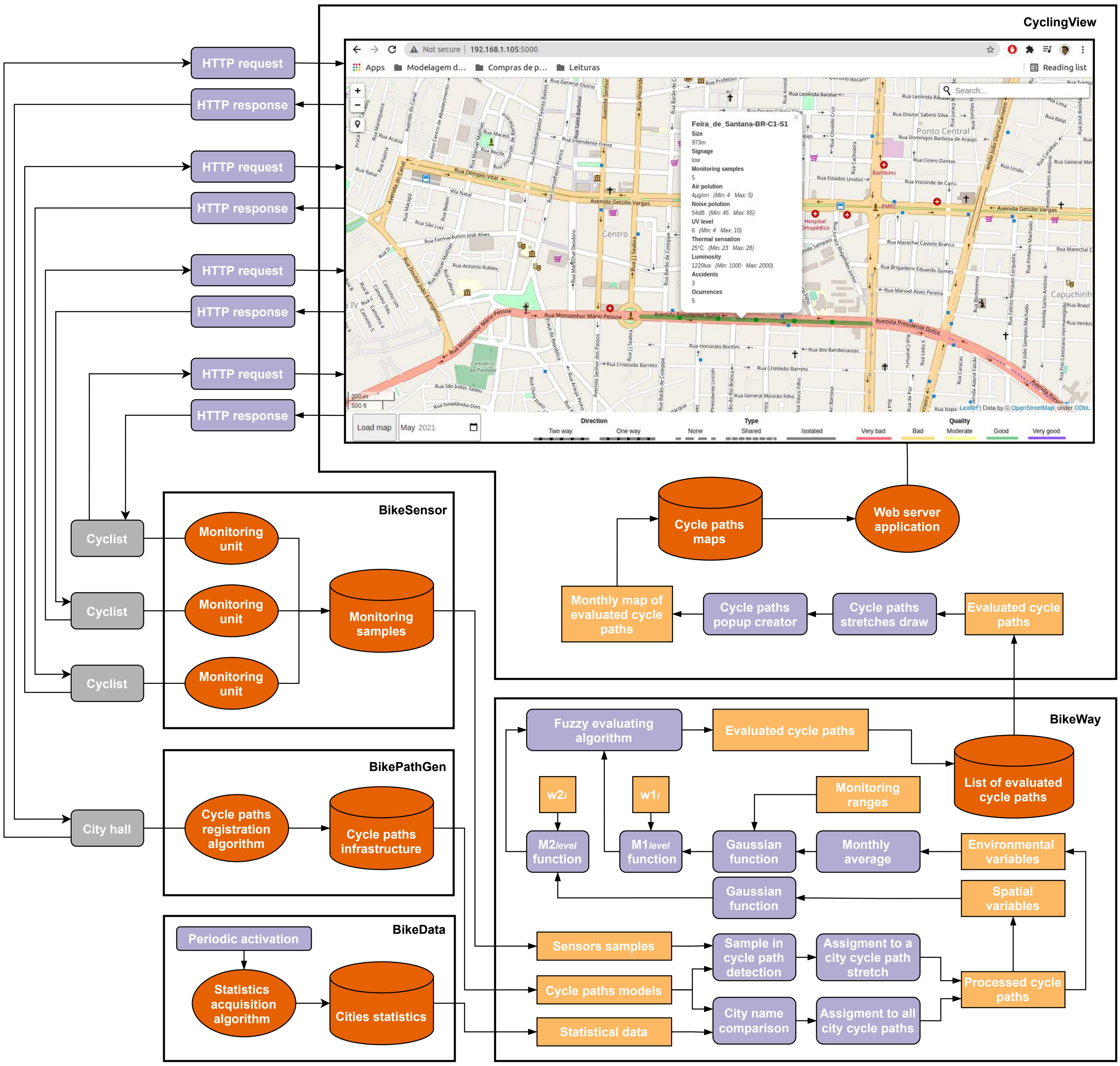

Figure 7. General diagram of the BrazilCycling implementation, exploiting the subsystems BikeSensor, BikeData, BikePath-Gen, BikeWay and CyclingView.

The following subsections provide an overview of each subsystem that composes the BrazilCycling implementation.

4.1. Monitoring Module: BikeSensor and BikeData

Composed of two similar services, the Monitoring module of the iBikeSafe approach is responsible for capturing information related to adverse cycling conditions, as discussed before. For the BrazilCycling implementation, the subsystems used to compose those services are known as BikeSensor and BikeData.

The BikeSensor consists of a system designed to collect environmental information such as air and noise pollution, temperature, humidity, ultraviolet radiation, and luminosity, exploiting for that Mobile Monitoring Stations (MMS) attached onto bikes. Each bike has an MMS attached to it, which periodically senses the environment and eventually transmits such sensed data to a Data Central Unit (DCU). Once the data collected by the MMS is sent to the DCU, it becomes accessible to various consumer applications, such as the cycle paths evaluation service expected to be provided by the iBikeSafe approach. Those consumer applications are referred to as BikeSensor Client (BSC) [15] in the BrazilCycling implementation.

Considering the BikeSensor central logical unit, the Mobile Monitoring Station is defined from a multi-sensor hardware framework to support the development of adaptable monitoring units for mobile applications, as defined in [16]. The definition of this framework makes the MMS fully adaptable to support any set of variable environmental monitoring sensors, which are identified from a basic configuration in a system file read at the beginning of the MMS firmware execution [16].

In addition to the sensor set dynamic configuration implemented by the MMS firmware, it is also responsible for running different processing states. The IDLE state puts the MMS into a standby state, making its power consumption low and saving battery power. When entered in the IDLE state, the MMS can change to the MONITORING state when the cyclist presses a specific button.

In the MONITORING state, the MMS performs the synchronous states presented in Figure 3, which allows the collection of georeferenced environmental data samples, as well as the writing of these samples in a file in the same way as presented in Listing 1. This way, the synchronous states are executed at a frequency F_s until the cyclist intervenes, which places the MMS in the IDLE state when pressing the monitoring button again.

The cyclist can press another button from the IDLE state, which moves the MMS firmware to the SETUP state, connecting it to a WiFi network via the WiFi Protected Setup (WPS) protocol. Since the MMS has unsent monitoring samples files and it is connected to the Internet, the MMS state machine changes to the UPLOADING state, triggering the execution of the asynchronous state presented in Figure 3, transmitting the files to the DCU.

Therefore, with the execution of these logical states by an MMS, it is possible to implement all the minimum requirements defined for the iBikeSafe sensing service. In addition, the architecture presented in Figure 2 was also satisfied, since the following parts represent the necessary components: Raspberry Pi Zero HW (open-source hardware platform + wireless network module + RTC module), 5V 2.5A regular 2600 mAh battery (power supply), SD class 10 card with 8GB (local storage module), GY-NEO6MV2 (GPS sensor) device and environmental sensors.

The BikeData system also has a well-defined structure that is presented in Figure 7. This system implements a web crawler that is monthly activated in order to execute the states presented in Figure 4, searching cities' statistical data (traffic accidents, robbery/theft, and urban violence), formatting and grouping it, predicting city statistics and exporting it to a database following the file format presented in Listing 2.

With the functioning of these two systems, the Monitoring module has been fully represented for this implementation of the iBikeSafe approach, generating data to be used in the Evaluation module.

4.2. Evaluation Module: BikeWay

BrazilCycling defines the BikeWay evaluation system as the Evaluation module service of the iBikeSafe approach. This system is responsible for combining environmental sensing and city statistics data in order to qualify cities' cycle paths using Fuzzy logic and following the steps presented in the Figure 5 [24].

The first step performed by the BikeWay system consists of importing data from the Monitoring module (BikeSensor and BikeData, for this implementation) and from the cycle path registration subsystem, which in this implementation is named as BikePathGen, a system capable of allowing public authorities to register their cities' cycle paths by marking points on a map available on a web site, as presented in Figure 7.

Once the BikePathGen registers the cycle paths, their mathematical models (defined as undirected graphs with vertices p_i represented by the geographic coordinates and the edges s_j represented by the cycle paths stretches) are exported to a database in city-named files with the content exemplified in Listing 3.

Listing 3: an example of a cities' cycle paths file.

```
{
  "statisticDataWeights": [0.3, 0.3, 0.3],
  "monitoringDataWeights": [0.2, 0.2, 0.2, 0.2, 0.2],
  "paths": [
    {
      "ID": "Feira_de_Santana-BR-C1",
      "constructionDate": "01/02/2021",
      "maintenanceDate": "01/03/2021",
      "inspectionDate": "01/03/2021",
      "creator": "gov",
      "stretches": [
        {
          "ID": "Feira_de_Santana-BR-C1-S1",
          "P0": [-12.259720085744956, -38.96384053644054],
          "P1": [-12.259990743034352,-38.95488161248777],
          "type": 1,
          "direction": 0,
          "signage": 1
        }
      ]
    }
  ]
}
```

With all the necessary data to evaluate the imported cycle paths, the BikeWay system executes an information pre-processing step. First, the cities' statistical data is assigned to all cycle paths present in the imported files from BikePathGen by comparing the cities' names, with the name pattern being equal to that followed by the statistical data collection service.

In addition, the BikeWay system verifies if all samples collected by the BikeSensor belong to one of the cycle paths registered by the BikePathGen. This verification is done by calculating the distance between a sensing sample in a particular city and the stretches s_j of all city's cycle paths. Since this distance is less than d, the sample is considered to belong to the cycle path stretch, with d is a configuration parameter usually defined as a few meters.

After pre-processing the information, each stretch of each registered cycle path has statistical data and a set of samples related to it, making it possible to apply the evaluation metric following the steps presented in Figure 7.

First, statistical data are grouped into a category named BW-Infrastructure, consisting of spatial variables. Meanwhile, the sensing data compose the BW-Environment group, categorized by environmental variables. Then, it is calculated the monthly average from the samples of each cycle path stretch. After grouping these variables, the system has monthly indexes for each variable in both groups. However, these variables have different value ranges, complicating the execution of the system's next steps. Thus, Gaussian functions were defined for each variable to translate their respective values to a limit from "0.0" (best) to "1.0" (worst) [24].

With the values translated to equal ranges, the BikeWay system advances to calculate the impact levels of each group on the cyclists' health and safety, which are: $M1_{level}$ (BW-Environment) and $M2_{level}$ (BW-Infrastructure). These levels are calculated through the weighted average of its variables that have the weights $w1_i$ and $w2_i$, presented in the Listing 3 as "monitoringDataWeights" and "statisticDataWeights".

After processing the levels of both groups, in the range from "0.0" to "1.0", these values are sent to the Fuzzy BikeWay classifier. In that, the groups levels of all cycle paths stretches are processed, resulting in a quality index based on five levels: very bad, bad, moderate, good and very good. With all cycle paths evaluated by their stretches, the last step to be performed by the BikeWay system for the monthly cycle paths evaluation is to export the data to the Visualization module. For this, files are generated for each city following the BikePathGen files name pattern and with the content exemplified in Listing 4.

Listing 4: An example of cities' evaluated cycle paths.

```
{
  "paths": [
    {
      "ID": "Feira_de_Santana-BR-C1",
      "constructionDate": "01/02/2021",
      "maintenanceDate": "01/03/2021",
      "inspectionDate": "01/03/2021",
      "creator": "gov",
      "stretches": [
        {
          "ID": "Feira_de_Santana-BR-C1-S1",
          "P0": [-12.259720085744956, -38.96384053644054],
          "P1": [-12.259990743034352,-38.95488161248777],
          "direction": 0,
          "signage": 1,
          "statisticData": [3, 5, 1],
          "monitoringDataAvg": [4.46, 54, 6.2, 25.2, 1220],
          "monitoringDataMin": [4, 45, 4, 23, 1000],
          "monitoringDataMax": [5.8, 65, 10, 28, 2000],
          "BikeWayQuality": "Good"
        }
      ]
    }
  ]
}
```

4.3. Visualization Module: CyclingView

Representing the visualization module service of the BrazilCycling implementation, the CyclingView will consist of a system divided into two software components: the map generator and the visualization web application. The map generator software is responsible for importing the data from the evaluation module, generating the map with cycle paths evaluated for a given month, and exporting it in a *mm-yyyy.html* file, following the data generator service depicted in Figure 6.

The map generated by the CyclingView service has all registered and evaluated cycle paths plotted with some characteristics that indicate their conditions related to quality, type, and direction, as detailed on the web page presented in Figure 7. In addition, that map allows the user to click on cycle path stretches, displaying a popup with general information about it.

After generating the monthly cycle path map, the CyclingView map generator exports the HTML file to a system folder, accessible by the visualization web application. This second software component is composed of a server to listen to the users' requests, who choose the evaluation months for the maps to be presented on the visualization web app.

Therefore, the BrazilCycling implementation of the iBikeSafe approach, comprising the BikeSensor, BikeData, BikePathGen, BikeWay, and CyclingView subsystems, stands as a practical solution for low-cost evaluation of the quality of cycle paths. However, due to the COVID-19 Pandemic scenario and the required social distances measures, it has become hard to perform large-scale adoption of the BrazilCycling implementation. In this sense, it was considered a case study for the BrazilCycling in a middle-size Brazilian city, initially validating the adoption of the iBikeSafe approach as a guide for quality evaluation of cycle paths in modern cities.

5. Evaluating the Quality of Cycle Paths in a Real City: A Case Study

After defining the BrazilCycling implementation, a Brazilian city was chosen to be used as a case study for this iBikeSafe-compliant implementation. Besides validating the proposed bike-based monitoring, evaluation, and visualization model, this case study aims to present practical details of how any implementation of the iBikeSafe approach could be used in an actual city. Therefore, for the conducted experiments and data analysis, the medium-size Brazilian city of Natal was chosen.

Being the sixteenth biggest capital in Brazil, this northeastern city located in the state of Rio Grande do Norte has an area of approximately 167 km^2 and a population of almost 900,000 inhabitants, according to the Brazilian Institute of Geography and Statistics (IBGE) [28]. In addition, this city has a cycling structure of 83.47 km with an expected increase of 15km until the end of 2021, which is a significant infrastructure compared to the vast majority of Brazilian cities.

Concerning the implemented cycle paths structure, 82.6% of the population approves the use of bikes as an alternative means of mobility, mainly in counter-proposal to public transport. In addition, a survey applied by municipal and state agencies to 800 city inhabitants estimates that 62.1% of the Natal population have adopted the use of bicycles as their primary means of transport since the beginning of the COVID-19 Pandemic [29].

This increasing popularization of the cycling practice in Natal, primarily due to the period that the coronavirus Pandemic has marked, is mainly due to the city's inhabitants search for the social distancing that public transport makes inevitable. However, it is vital to know if these approximately 26,000 cyclists who make about 58,000 trips/day have the proper conditions to practice cycling in terms of health, infrastructure and, safety. Thus, in this section, we apply the iBikeSafe-based BrazilCycling implementation to evaluate a set of cycle paths to understand their quality and use these data to compare with the information provided by cyclists about their perceptions of the city's cycling structure.

5.1. Registering an Existing Cycle Path

Considering the Brazilian city of Natal as the target scenario, a subregion of it was used as the input for the implemented system. Such subregion was defined as reference the University of Rio Grande do Norte (UFRN), a public institution primarily located in the central area of Natal. This University is the fourth-best University in its region, and one of the 25 top-ranked in Brazil [30]. It has five campuses, including the central campus, which is by far the largest of them. Its central campus gathers 47,000 students and 2300 faculty members, besides other employees and the external community circulating daily [31]. Thus, the cycle paths on the UFRN central campus will be the main focus of the performed analysis.

The UFRN central campus offers comfortable amenities, such as restaurants and cafes, bank agencies, bookstores, a multi-sport gym, art gallery, post office, among other facilities [31]. In addition, the campus is connected to the urban network of the city of Natal through a Ring Road circumscribing the campus, which was created to accommodate conventional transport, such as cars, motorcycles, and buses in the urban public transport system.

The University has initiated the construction of cycle lanes around and inside the campus to promote sustainable mobility among its users. As part of its campus expansion plan, it has built over 5 km of cycle lanes so far (represented by the red lines on Figure 8), which skirt the campus to the east and join with Ring Road. According to the Engineering Department head, cyclists have to share the lane (road) with other traffic users. In additional, the cycling infrastructure contributes to the connection between large areas of the campus, such as the university residence, classrooms, laboratories, multi-sport gymnasium, and university restaurants. According to [32], finding a way to provide a campus bike-sharing system is possible using the current infrastructure, but specific issues stand in the way of implementation. For example, there are long-distance paths shared with other vehicles, bringing safety concerns. Also, there are not enough trees along the campus tracks, potentially posing a disadvantage for cycling given the high levels of solar radiation in Natal due to its geographic position (near the Equator line).

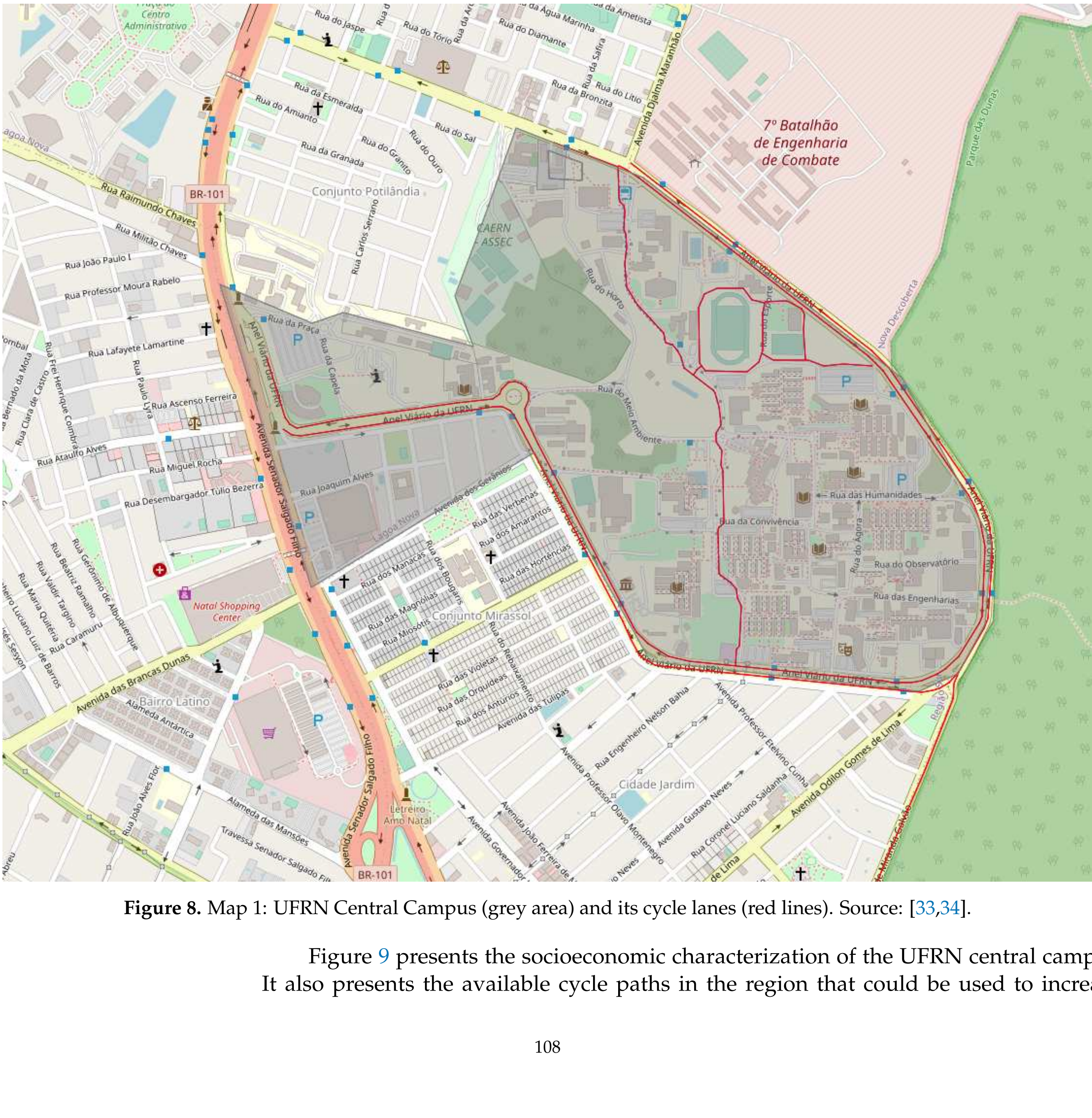

Figure 8. Map 1: UFRN Central Campus (grey area) and its cycle lanes (red lines). Source: [33,34].

Figure 9 presents the socioeconomic characterization of the UFRN central campus. It also presents the available cycle paths in the region that could be used to increase transportation for students and faculty. These data were obtained from the Institute of Applied Economic Research (IPEA), a Brazilian government agency that proposes innovative analyses, developing surveys on the economy to monitor, evaluate and give technical-scientific support in economic and social policies. Using census information, satellite images, and collaborative mapping, it is possible to calculate accessibility levels for a set of 20 municipalities.

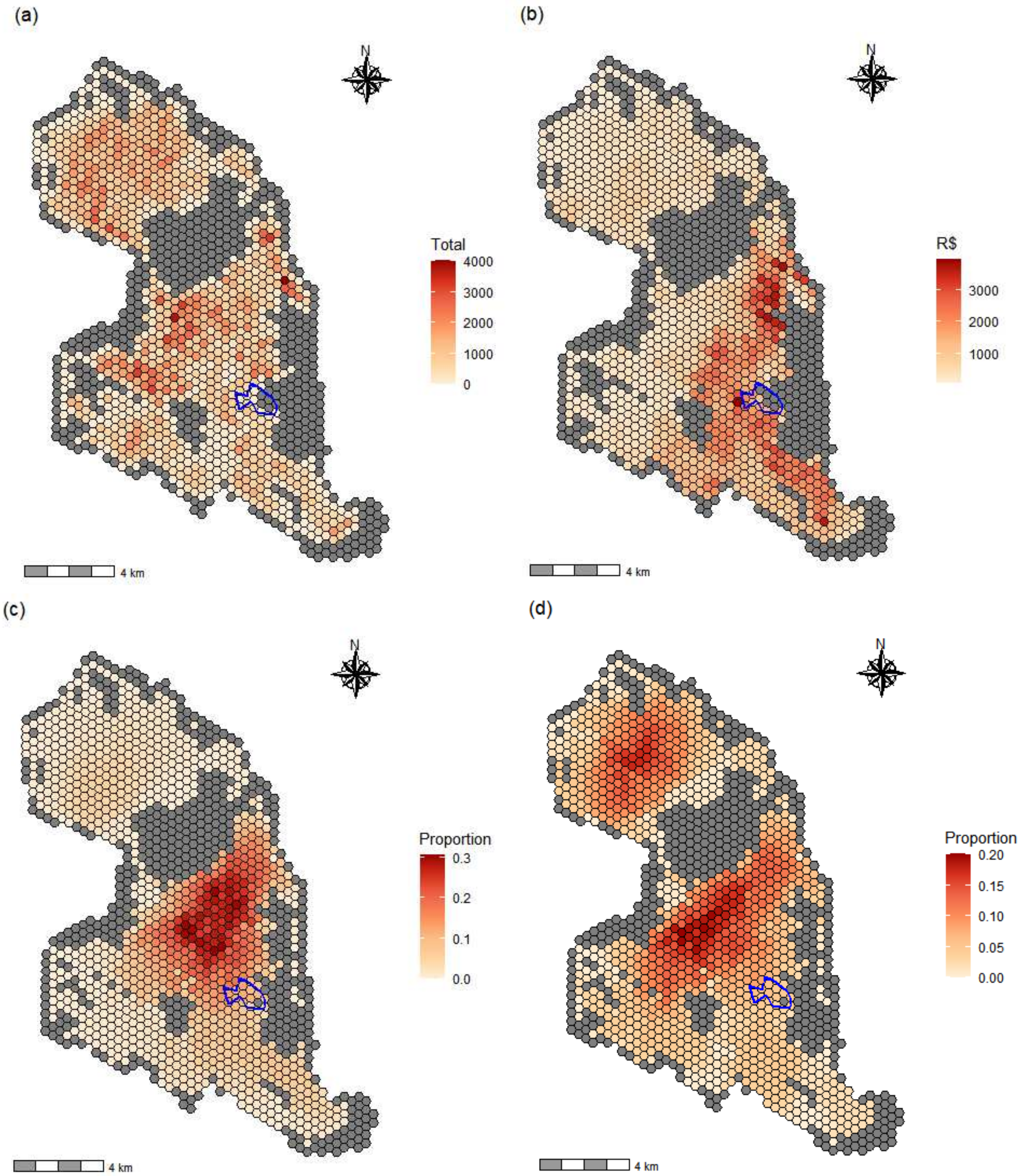

Figure 9. Socioeconomic characteristics and access to opportunities using bicycles: (**a**) Total population (**b**) Household income per capita (**c**) Accessible opportunities within a 15-min by cycling—employment (**d**) Accessible opportunities within a 15-min by cycling—public schools. In blue, the limits of the central campus of UFRN. Source: [35].

This study used the hexagonal mesh already available for the city of Natal. The hexagonal mesh is a digital model of the urban area that describes the space more efficiently than other models, like the irregular network grid or the planar grid. Four indicators were selected: (a) distribution of the total population and (b) the average household income per capita, both indicators coming from the 2010 Demographic Census, (c) proportion of formal jobs and (d) proportion of public primary schools, both accessible in trips of up to 15 min using bicycles. The central campus of UFRN is represented on the maps by the blue line. To note, hexagons that do not contain information for indicators are gray-colored.

According to Figure 9, the central campus is located in the South Zone of Natal, an area that has more remarkable economic development and a smaller population than other zones in the city. This is expressed in the distribution of households and the average income living in the South Zone and its surrounding areas. Therefore, expanding the cycle path network beyond the central campus of UFRN and covering other areas of that region can serve as a stimulus for developing this sustainable modal. According to a survey for the city of Natal, the South Zone represents the region of the city in which people use bicycles the least in their daily lives [29].

Associated with the lack of access to formal jobs, the proportion of these opportunities in trips of a maximum of 15 min tends to be more significant in the western portion of UFRN and precisely in the area where there is a discontinuity of the bike path that runs around the campus, and where a highway that has no lane exclusive for cyclists also connects the university to important commercial centers in the region. This presents the danger of traffic accidents involving cyclists trying to use the same roadways as commuters, as they are being forced to share the road with high-speed traffic. Concerning the percentage of public schools accessible by cyclists, it was lower and relatively homogeneous in the region surrounding the central campus of UFRN, especially in the West Zone of the city.

5.2. Attaching Mobile Monitoring Units to Bicycles

Under the recent initiative to implement and improve cycle lanes on the UFRN main campus, the BrazilCycling implementation can provide valuable data to cyclists. Furthermore, the implemented services can indeed be used to identify potential problems that can disturb cycling or risk the cyclists' health and safety. Hence, it is expected the implementation and proper configuration of the BikeSensor Mobile Monitoring Station (MMS) on bicycles, as well as the other resources defined in the previous section.

In the desired configuration, the MMS can capture data related to air pollution, noise pollution, ultraviolet radiation, thermal sensation (temperature and humidity), and luminosity that affects the cycle paths of the UFRN central campus. For this, the sensing units have the design presented in Figure 10, which has two light entrances on top for luminosity and UV radiation sensors data collection, and an air entrance on the back for temperature/humidity, air, and noise pollution sensors.

In addition to environmental data collection, the MMS proposed version in this scenario has three buttons that allow connecting the unit to the Internet, starting monitoring, and turning the module ON or OFF. These actions performed by the cyclist result in light signals presented by LEDs also depicted in the Figure 10, which inform that the sensing unit is connected to the Internet, collecting environmental monitoring data and turned ON or OFF, respectively.

Having 100 $\times$ 35 $\times$ 30 mm, this version of the MMS also features a micro USB input on its bottom for charging the battery present in the module. With these dimensions, this sensing unit could be easily attached to a regular bicycle in the position indicated in Figure 11.

Positioned as presented in Figure 11, the MMS can collect multiple data. With the application of these units on a large number of bikes, students and workers cycling on the campus would support extensive data collection of environmental data, potentially daily. However, although fully modeled and programmed, massive deployment of the MMS units could not be performed due to budget restrictions and the effects of the COVID-19

Pandemic, being left for future works. This way, data collection described in the following subsection mainly was obtained from open databases, still supporting the other services of the BrazilCycling implementation.

Figure 10. 3D model of the MMS version with the ability to collect data about air pollution, noise pollution, UV radiation, thermal sensation and luminosity.

Figure 11. Example of MMS implantation on a bicycle, when the BrazilCycling implementation is adopted for the UFRN central campus scenario.

5.3. Cycle Paths and Monitored Adverse Conditions

Considering the cycling structure of the UFRN central campus, and after retrieving and processing open data provided by the City Hall [36], the first step for data collection in order to evaluate those cycle paths was to create the models for the eight cycle paths present in that region. In a typical BrazilCycling implementation, those data would be registered by the City Hall through the BikePathGen subsystem, especially considering the burden of registering a large number of cycle paths. However, for the scope of this evaluation phase, the desired models were registered manually, being depicted in Figure 12.

From the cycling map already available for the city of Natal, it was possible to identify the bike paths in the region of the central campus of UFRN. This identification allowed it to be viewed using the Google Maps Street View tool, making it possible to verify the type of each cycle path and adding this significant metadata to the set of collected information from the cycle map (cycle path direction and administrator).

In addition to the cycle paths, the Google Maps service allowed the visualization of the car traffic level on the roads through its traffic visualization layer. Once all the desired data were collected empirically, the next step of registering the cycle paths consisted of capturing each point's coordinates that create the cycle paths through their stretches connected between two sequential points. This way, it was possible to collect information from the cycle paths presented in Table 5, generating graphs that represent the eight cycle paths on the UFRN central campus, as presented in Figure 12.

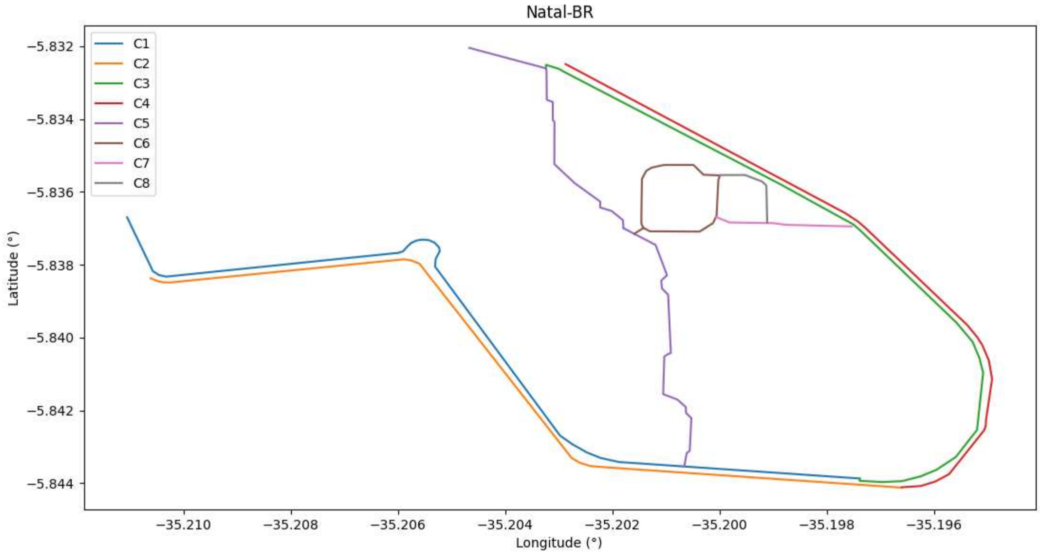

Figure 12. Cycle paths on the UFRN central campus, which were mathematically modeled according to the BikePathGen implementation.

Table 5. Characteristics of the UFRN central campus cycle paths.

Cycle Paths	Type	Administrator	Traffic Flow	N° Points	N° Stretches
C1	Shared	UFRN	Medium	22	21
C2	Shared	UFRN	Medium	12	11
C3	None	City hall	High	19	18
C4	None	City hall	High	16	15
C5	Shared	UFRN	Low	30	29
C6	Shared	UFRN	Low	19	18
C7	Shared	UFRN	Low	5	4
C8	Shared	UFRN	Low	5	4

With all the bike paths modeled and exported in the Natal-BR.json file, as exemplified in Listing 3, the way to collect environmental data was decided. For this, 117 geographic coordinates were collected related to different monitoring points, which were retrieved exclusively from each stretch of the eight registered cycle paths (Figure 13).

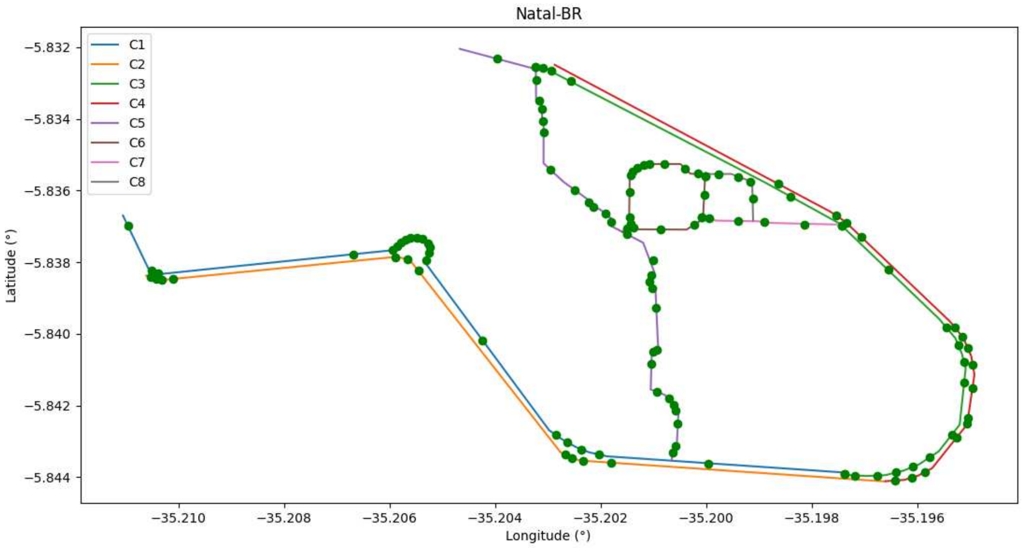

Figure 13. Simulated monitoring samples in each stretch of the UFRN Central Campus cycle paths.

From the empirically defined monitoring points, simulating the passage of bicycles with a MMS attached to them, it was possible to group the environmental variables data defined for this application in a period from January to December 2020. Collected through Accuweather, this specific period was defined in order to allow a more comprehensive analysis of the cycle paths conditions during the emergence of the COVID-19 Pandemic. Doing so, it was possible to divide that year into three phases: pre-pandemic (January and February), beginning of the Pandemic with severe restrictions (March and April), and relaxation of social distancing restrictions (May to December). As mentioned before, this monitoring phase was simulated instead of using an MMS physical implementation, although the same processing steps were considered when formatting and transmitting the sensed data.

The impact of environmental variables for each of the defined phases did not vary considerably because the Pandemic only affected the flow of cars near the cycle paths, with slight variation in air and noise pollution rates, which were not significant (Table 6). However, the statistical data collected through the Secretariat of Public Security and Social Defense of the state of Rio Grande do Norte had considerable variation along 2020 [37].

Composing those data, monthly information on accidents and urban violence (injurious homicide, police intervention, bodily injury followed by death, robbery/stealing, and femicide) that occurred in the city of Natal was considered. As Table 6 presents, accident rates are naturally high in the city. However, in the second phase of 2020, these rates had a considerable decrease, indicating an improvement in the cycle paths quality because this variable is critical since it brings immediate risk to the cyclist's life.

Table 6. Adverse conditions between January and December 2020 in the city of Natal-RN. Adverse conditions: $\mathbf{M}_{1.1}$—air pollution in μg/m^3, $\mathbf{M}_{1.2}$—noise pollution in dB, $\mathbf{M}_{1.3}$—UV radiation level, $\mathbf{M}_{1.4}$—thermal sensation in °C, $\mathbf{M}_{1.5}$—luminosity in lux, $\mathbf{M}_{2.1}$—number of accidents and $\mathbf{M}_{2.2}$—number of urban violence occurences.

Phase	Month	$\mathbf{M}_{1.1}$	$\mathbf{M}_{1.2}$	$\mathbf{M}_{1.3}$	$\mathbf{M}_{1.4}$	$\mathbf{M}_{1.5}$	$\mathbf{M}_{2.1}$	$\mathbf{M}_{2.2}$
Pre-pandemic	January	7.5	57	10	26.6	1000	26	444
	February	7.4	59	11	26.7	1100	19	430
Severe restrictions	March	7.2	54	10	26.7	2200	10	435
	April	6.8	53	9	26.4	1100	12	364
Relaxation of restrictions	May	6.9	50	9	26.1	1000	19	248
	June	6.3	55	8	25.2	1100	19	181
	July	6.2	51	7	24.6	1000	22	194
	August	5	52	8	24.7	900	22	235
	September	7.2	50	9	25.2	1100	26	261
	October	7.1	52	9	26	1200	19	330
	November	7	53	10	26.4	1300	20	304
	December	7.5	52	11	26.7	1200	27	292

Therefore, with all data from the monitoring module and the cycle path registration subsystem simulated for 2020, it became possible to evaluate the eight cycle paths at the UFRN central campus, providing processed data to be exploited by the CyclingView subsystem.

5.4. Cycle Paths Evaluation and Visualization

For the monthly generation of quality maps, the collected data were formatted according to the files exemplified in Listings 1–3, in order to provide data as input to the BrazilCycling evaluation system, the BikeWay. Thus, the data presented in Table 6 were processed in order to evaluate the cycle paths according to their quality within the group of five BikeWay levels, as presented in Table 7.

Table 7. BikeWay quality for the cycle paths in the UFRN central campus.

Phase	C1	C2	C3	C4	C5	C6	C7	C8
Pre-pandemic	B	B	VB	VB	M	M	M	M
Severe restrictions	G	G	B	B	G	G	G	G
Relaxation of restrictions	M	M	VB	VB	M	M	M	M

Being rated as very bad (VB), bad (B), moderate (M), good (G), or very good (VG), the considered cycle paths obtained roughly the same quality results for each month of 2020. From the analysis of these cycle paths qualities, which are a reflection of the variation in the city statistical data between the phases of fighting the COVID-19 Pandemic in the city of Natal, it was possible to perceive the following aspects:

1. C5 to C8 are the best-rated cycle paths overall. This is due to the fact that these cycle paths are located on the UFRN campus, they have shared paths, and they are located in an environment with low car traffic;
2. C1 and C2 have an average rating in relation to the others. They have shared lanes and they are located on an avenue with reasonable car traffic;
3. C3 and C4 are the worst evaluated because there are no actual cycle paths, causing cyclists to compete for space with the many cars present on these stretches due to high traffic;
4. The 2020's pre-pandemic phase was marked by very high rates of accidents and urban violence, which resulted in very bad to moderate ratings on all cycle paths;
5. When the Pandemic started and restrictions were imposed to prevent the propagation of the virus, a phase defined as "severe restrictions", there was a significant improvement in the perceived quality of shared cycle paths, which reached good quality due

to the low accidents rate. Meanwhile, the stretches with non-existent cycle paths were still considered as being bad because they posed an immediate risk to cyclists who were forced to pedal alongside cars;

6. After the relaxation of restrictions, there was again an increase in the accident rate, reducing the cycle paths perceived quality. However, environmental variables tended to soften due to the arrival of Autumn and Winter, causing shared cycle paths to reach a moderate level while non-existing cycle paths decreased from bad to very bad;
7. For every month, the urban violence rates were very high, and in this case, they did not influence the variation in the quality of the cycle paths.

According to the performed analysis, the most impacting factors about the chosen cycle paths in Natal are the structural conditions of the cycle paths and the high number of recurrent accidents in the city. In the survey "Cycling perception by people in Natal" (*Percepção dos Natalenses Quanto ao Uso da Bicicleta*) developed by the Federation of Commerce of Property, Services, and Tourism of Rio Grande do Norte with a population of 800 people, 53.1% of respondents said that drivers are a disincentive factor for cycling due to their poor education, which can directly reflect on the high rate of accidents.

In that survey, 51.9% of the participants stated that the quality of cycle paths could improve, as there are many places that force cyclists to compete for space with cars, such as the evaluated C3 and C4 cycle paths. Finally, another negative aspect mentioned by 55.6% of the survey participants is related to public safety, which, as seen in the data collected for 2020, has terrible statistics.

So, in order to guide those responsible for the construction and maintenance of cycle paths and/or the public authorities in order to improve these aspects, accurate implementation of BrazilCycling becomes feasible and very usual since the evaluations in the scope of this work have synergy with the cyclist's perception in the considered city. Thus, it is imperative to provide visualization tools for these cycle paths for feedback on their qualities for cyclists and public authorities. In this context, data from the eight monitored and evaluated cycle paths were provided to the CyclingView subsystem, which generated maps for all monitoring months (following a pattern per phase of 2020), as presented in Figure 14. As an essential remark, the color pattern presented in that figure follows the specifications in [24], which is based on a heatmap standard with worse qualities displayed closer to the red and best qualities displayed as blue marks.

Figure 14. Maps for each phase defined for 2020 with the registered cycle paths and their respective qualities. (**a**) Pre-pandemic phase (**b**) Severe restrictions phase (**c**) Relaxation of restrictions phase.

6. Conclusions

Adopting sustainable cycling initiatives is an fundamental challenge in modern cities, directly related to improving urban mobility services and promoting healthier habits. Although it has been a significant trend lately, with many cities struggling to improve their cycling infrastructure, innovative solutions should be created in different scopes to support better the transition from traditional mobility patterns to sustainable alternative transportation.

When overcoming several difficulties for sustainable cycling, the quality of the cycle paths is a significant characteristic to be considered. While some works have addressed the cycling quality of the available paths, for example, according to their pavement and signaling, there is an urgent need to better perceive the adverse conditions that bike paths may have on cyclists in a city, especially concerning their health and safety. Understating such negative impacts may be crucial to support smart cycling further.

The proposed iBikeSafe approach is an important step toward adopting of monitoring, evaluation, and visualization services to improve urban cycling since the perceived quality of cycling paths would be better known. In this sense, the proposed services and the interactions among them are important contributions to the area. Furthermore, besides the formal definitions of the iBikeSafe approach, the proposed iBikeSafe-complaint BrazilCycling implementation is another significant contribution, indicating how a comprehensive system comprising monitoring, evaluation, and visualization services could be implemented for accurate monitoring. In addition, however, although other implementations based on the iBikeSafe generic services could be implemented.

Finally, considering the BrazilCycling implementation, the presented simulated results for Natal, a medium-sized Brazilian city, are valuable as an important implementation and evaluation example, indicating how the proposed approach could be used in the real world. In this context, the achieved results were satisfactory, contributing to the overall validation of the proposals.

As future works, the monitoring module of the BrazilCycling implementation, notable to the MMS units, will be physically developed and attached to bicycles. The objective is to endow a large set of bikes with monitoring capabilities, which will provide monitoring samples to the overall quality evaluation of the cycle paths. This final phase will also be performed in Natal, supporting more accurate quality evaluations.

Author Contributions: Authors contributed equally to the development of this work. F.O. and D.G.C. surveyed recent works covering new contributions for smart cycling. F.O. and D.G.C. organized the text, coordinated the discussions and reviewed research directions. F.O., D.G.C., L.L. and I.S. structured the proposals and the implementation issues. L.L. and I.S. organized the experiments and practical evaluation of the approaches. All authors have read and agreed to the published version of the manuscript.

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Article

A Data-Driven Situational Awareness System for Enhanced Air Cargo Operations Emergency Control

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Abstract: Based on the constant need for safety and operational cost optimization, the air-cargo industry is continually evolving in the context of Industry 4.0. Used wisely, data can help the industry to provide critical resilience that will allow authorities to take proper measures/actions in response to unexpected disasters and secure societal protection. The "INTELLICONT" project combines state-of-the-art technologies blended with novel solutions to improve the loading/unloading time, the structural status awareness, and the safety and security of the air-cargo related operations (prior to, during, and after the flight), as well as to enhance their capabilities related to the execution of their duties. The suggested system is contextually aligned and harmonized with the existing international and EU regulations. In the present work, the remote monitoring and control system for intelligent aircraft cargo containers have been presented from the software perspective. The intelligent containers integrate three types of sensors, Structural Health Monitoring, fire suppression, and locking status indication. The focus has been given to the design and development of a Human Machine Interface (HMI) capable to visualize all related data for better and safer control of the aircraft cargo. It is shown that the system can contribute to making the air transportations safer, environmentally friendlier, faster and with the lowest possible cost.

Keywords: intelligent ULD; Structural health monitoring; fire suppression; locking status; human machine interface

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1. Introduction

While different definitions have been introduced by many authors from the concept of the smart city, its description by [1] as a large conglomeration of citizens, businesses, institutions, and agencies working towards a continually improving quality of life, is one of the most illustrative. Airports are a crucial part of every large city globally that provide the means for pleasure transportation [2] as well as business development [3]. Besides, while sea-based cargo transfer dominates the global trading industry, air cargo is crucial for time-critical, high-value, and perishable goods [4]. Its importance in the latter case was emphasized during the last two years because of the COVID-19 pandemic and the need for the timely transfer of vaccinations and paramedic supplies [5]. As a result, air cargo operations are a "living cell" of any efficient smart city concept.

Within the heart of air cargo operations lies the Unit Load Devices (ULDs). According to the International Air Transport Association (IATA) [6], an estimated one million aircraft ULD are operating in nearly all airports globally. ULDs are mainly primitive aluminum cage structures with minimal structural properties and substantial tar weight which penalizes the net loading capacity and fuel burn. They rely on permanent transportation components and crew intervention to be moved and secured in the cargo deck, which further increases aircraft weight, loading time, and operating cost. Moreover, being practically the only removable aircraft part that is handled by other than the operating crew members, ULDs have a strong impact on in-flight safety. After a series of cargo fire incidents, the

Federal Aviation Administration (FAA) recently presented a new regulation [7] on fire-resistant ULDs. A potential emergency, threatening to humans' lives and the environment during the air cargo life cycle, from a simple fire to a major stability accident, is strongly related to the timely and accurate actions of the involved team(s) of First Responders (FRs). As a result, modern ULDs should be able to restrain the loads and provide fire immunity and/or suppression capabilities with enhanced information to FR teams [8].

The majority of studies on the field have to do with the management and optimization of the operation of ULDs [9–12], mainly because there is a great impact on the delivery cost involved with cargo handling activities. In [13], a review of the most important efforts towards this direction is provided. Moreover, in [14], the authors provide an up-to-date list of key players within air cargo operations and briefly describe relevant issues from their different perspectives. While operational efficiency of air cargo transportation is of the utmost importance, unfortunately, incidents having cargo transfer as the core event are not rare. For air operations, the monitoring of the status of air cargo should be a topic of great interest due to the serious hazard of cargo which can lead to a safety-related alert. Battery presence is particularly dangerous since it turns what appears to be safe cargo into easily flammable cargo with a very detrimental effect on the carrier safety. Following [7], more than 100 incidents related to battery inflammation in cargo holds have been reported since 2019. More than half of them were related to the transfer of dangerous cargo, while 5% resulted in major operational destruction. Recent statistics [10] reveal a bleak picture of air cargo operations safety. As shown in Figure 1, almost 50% of accidents have to do with cargo, Low-Cost Carrier (LCC), and Full-Service Network Carrier (FSNC) operations.

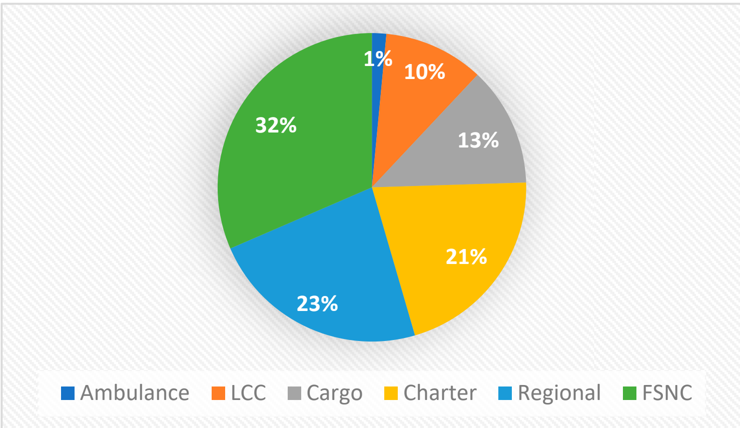

Figure 1. Percentage of safety accidents related to human error, for different air carrier operations. The majority of the accidents are related to air cargo operations.

The number of efforts focusing on the safety and monitoring of ULDs is significantly lower, although there are some examples of solutions developed for the remote monitoring and control of cargo handling [15], Structural Health Monitoring [16–18], and intelligent fire detection systems [19–21]. While important, none of the available solutions provide a complete solution for the remote monitoring and control of the container regarding its structure, status, location, handling fire and smoke warnings, and monitoring data. Working towards this direction, IATA, through its project called "Interactive Cargo" [22], aims to provide a regulatory regime to enable and ease the use of connected devices that interact with air cargo. The project involves a large number of stakeholders, but mainly focuses on air cargo tracking.

To address these issues, the "INTELLICONT" project integrates the best available technologies with novel solutions to Enhance Situational Awareness and support relevant crew and technical staff in the execution of their duties and involvement. In our previous work (under evaluation) we focused on the description of a novel intelligent Remote Monitoring System that is capable of receiving a feed from sensors in real-time and performing a preliminary analysis of sensor data and data from other sources (e.g., battery status). The objective of the current work is to describe the intelligent Human Machine Interface, which enables an adaptive smart working environment for air cargo operations crews, considering restrictions and needs of the harsh environment. Pillars of our architecture are (a) the novel visualization tool, (b) data fusion architecture, and (c) the standardized interconnection methods that will secure accurate predictions. To the best of the authors' knowledge, no similar system that involves different aspects of ULD safety has been presented.

The main innovation of our work is the development of a system capable: (i) of creating strategies and methods regarding the safety of passengers and FRs, easily integrated into the existing ULD systems and technologies; (ii) of creating a complex collaborative system for surveillance, detection, and monitoring of safety-related incidents and events; (iii) of creating situational awareness, future escalation projection, and early warning methods to prevent safety issues; (iv) of allowing easy engagement and smooth cooperation of different FR levels (crew, headquarters, authorities, emergency response teams) in an air cargo related crisis; (v) of modelling, classifying and preserving pieces of evidence and easily reporting a safety event.

The rest of the article is organized as follows. Section 2 briefly presents the general concept of the project. The functionality of the intelligent ULDs is introduced in Section 3. Section 4 describes how the ULD is connected with the HMI developed for the data visualization to the users. The structure of the HMI is presented in Section 5. In Section 6, the proof-of-concept testing procedure followed is described. Finally, the conclusions are summarized in Section 7.

2. General Architecture

The main goal of the "INTELLICONT" project is to develop, manufacture, and validate a new intelligent lightweight aircraft cargo container with integrated functions for restraining, transportation, and fire/smoke suppression, with sensing and wireless monitoring capabilities. The smart ULDs (Unit Load Devices) will be transferred upon a robotic platform and placed safely at the aircraft's cabin. Low-cost and low-energy sensors in the container with status (identification, location, locking state) detect critical events, fire/smoke, impacts, and accidental misuse during the loading and flight phases. The core of the system is the integrated Remote Monitoring System (RMS), which exploits recent advances in sensor network methodologies to assess the state of criticality, and to identify and monitor possible incidents. The general concept is presented in Figure 2.

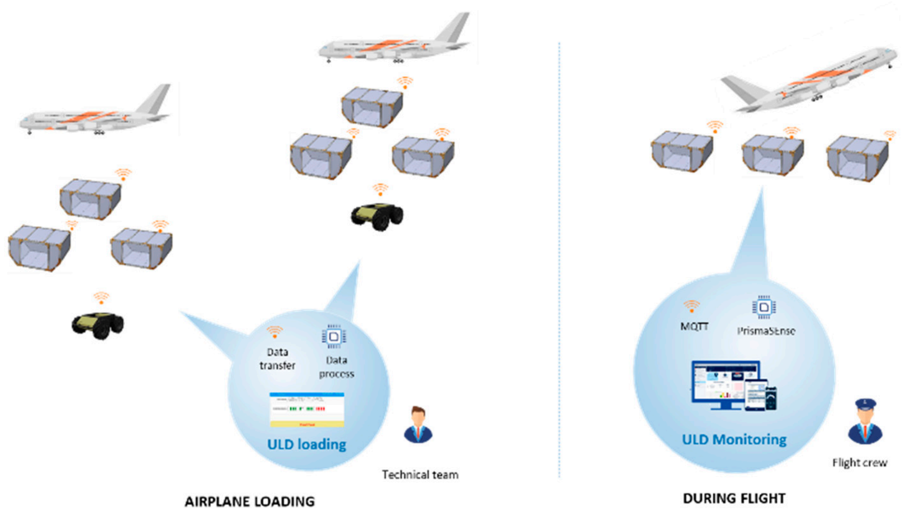

Figure 2. General Concept.

The platform's design was based on LAROS™ [23] and PrismaSense™ [24] systems, which were redesigned to meet the standards of the Aviation industry [8] using the wireless communication protocols (Wi-Fi) to transmit all collected & synchronized data to the HMI, where it can be stored, also ensuring data integrity and enhancing transparency in the case of future analysis and/or investigation, in a very efficient manner in terms of cost, speed, and safety. Transferred data can be further processed at the fleet level and combined with data coming from remote systems (FR teams, drones, satellites, weather forecasts, etc.). A hybrid data fusion architecture will enable the distribution of both processing power and storage capacity to different levels. In short, the data flow pipeline of the RMS System will be the following:

- Smart Collectors set up a secure wireless network inside the ULD to transmit the processed data to the HMI with a user-defined sampling rate and the ability to maintain and customize them remotely. The wireless protocol will be based on IEEE 802.15.4, with additional layers and data format to cover the requirements of the airport environment and increase the network quality of service, while secure transfer protocols ensure scalability of the solution;
- Data from collectors will further be transferred to the in-field HMI. All data are stored in data lakes for an extended period (up to one year, depending on the number of sensors and sampling rate). Being the upper layer of the onboard architecture at this level, two tasks will be performed: (a) the execution of ML and AI algorithms for early warning reasoning, (b) Real-Time Visualization via Augmented Reality alerting of all outcomes;
- Through HMI, data from the collector network on each of the ULDs are delivered to the robotic platforms. HMIs secure (a) the uninterrupted connectivity with dedicated collector networks, and (b) the collection of data that needs to be processed in real-time. HMIs on each air cargo loading/unloading operation establish a separate wireless network for data exchange between them;
- HMI periodically produces binary files and compresses them to reduce the size of the data to be sent via normal satellite broadband to the data center (Cloud Computing). The cloud could collect the processed data from a wide range of airplanes/ULDs (fleet wise) and handle them accordingly for the following fleet-level data analytics, data storage (Cloud level), and tracking/monitoring of incidents. Besides, third party data (e.g., weather, societal, satellite imaging disease dispersion), as well as data from in-field FR teams (drones, on-sea FR, nearby vessels), will be entered in the main database in the same format.

The smooth flow of information between the different components of the RMS system solution is performed through the design and development of user-friendly, fully parameterized, flexible software components. The status of each container (e.g., container number, position-locking state, structural condition), will be available in a Human Machine Interface (HMI) through a wireless communication network, such that problems would be detected, and proper measures would be taken, as shown in Figure 3. Figure 4 provides an overview of the decision-making flow (use case).

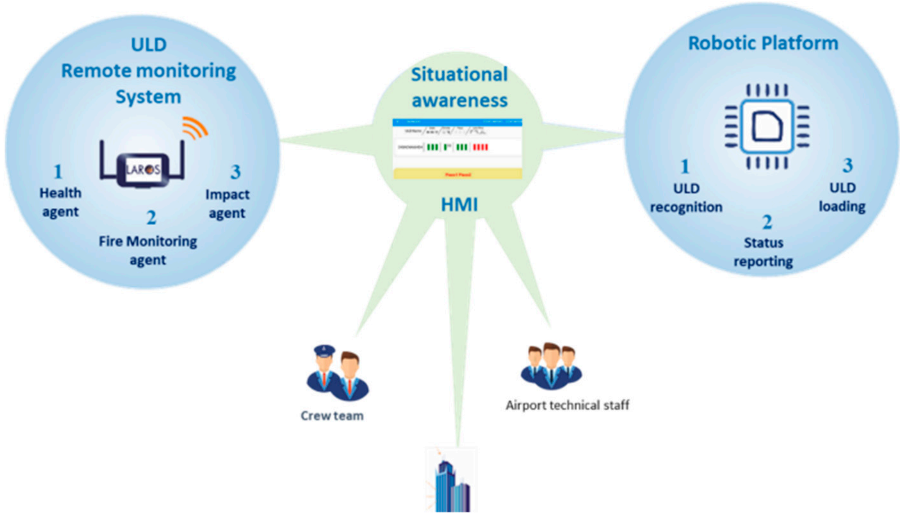

Figure 3. Remote Monitoring System architecture.

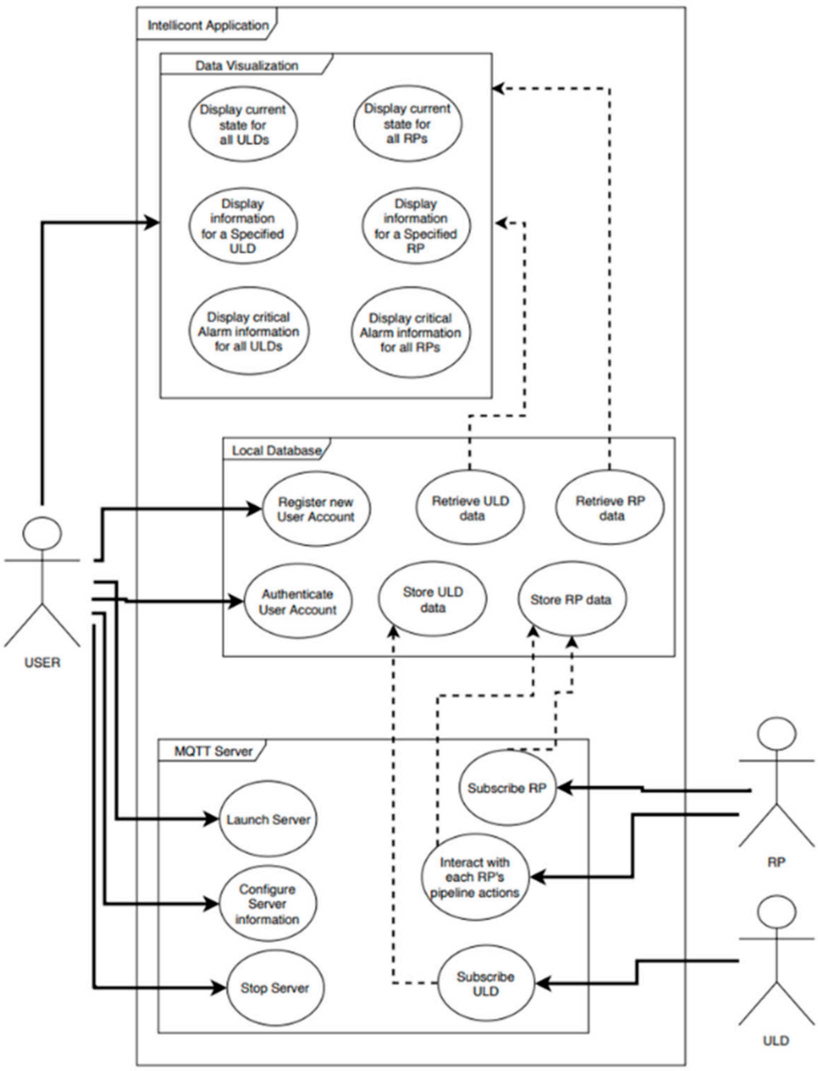

Figure 4. HMI application use cases illustration.

3. ULD Remote Monitoring System

Every sensor placed on the ULD is connected to the Main Board, which is responsible for collecting and processing data. The Main Board is powered by the Power Supply Board which provides the necessary voltage levels to the Main Board and the sensors (Table 1). The Main Board also includes a wireless communication module to transmit the sensors' data. Figure 5 illustrates the ULD Remote Monitoring System assembled.

Table 1. Remote Monitoring System technical specifications.

Component	Feature	Specification	Quantity/ULD
RMS Processing Unit	System clock Ultra-low power consumption Analog-to-Digital Converter (ADC)	16-bit RISC up to 20-MHz 295 µA/MHz at 8 MHz, 3.0 V 12-bit	1
Wireless Communication	Wi-Fi Communication rate	802.11 n (2.4 GHz) up to 150 Mbps	1
Structural Health Monitoring (SHM) sensor	Output voltage	100 mV to 100 V	3
Fire detection sensor	Siemens PCM1103-03	Temperature-humidity	1
ULD lock sensors	Contact switches Position sensors	30 operations/min (max) Sensitivity: 0.90 mV/Gauss	8 8

Figure 5. The Remote Monitoring and Control (RMC) system inside its Housing.

The ULD is designed to be at one of three states: Idle, Normal, and Lock. Regardless of the state, it will respond to every command sent by the HMI.

- Idle: data from sensors are collected, although nothing is reported. If a smoke alarm happens, it will be reported to HMI. The system can still receive commands.
- Normal: ULD will periodically report its measurements to the HMI, depending on its "report period" setting. It will also spontaneously send alarms to the HMI.
- Lock: designed for the loading–unloading phase. ULD sends every 100 ms lock feedback to the robotic platform through HMI.

The ULD's power supply is provided by two packs of batteries. A battery pack manager board is responsible for measuring the voltage of every cell of each battery every ten seconds. The charge percentage of each pack is calculated into a running average to smooth readings. At ULD Normal state, at the report, the charge percentage is sent to HMI. The switching between the two battery packs is done by a power source selector board. The first battery is always the first to deplete, after which comes the second. The convention used is that, at 0%, the pack does not provide power for the ULD to function properly while, at 100%, the battery pack is at its maximum charge capacity. The battery pack manager boards, the power source selector board, and the battery packs are shown in Figure 6.

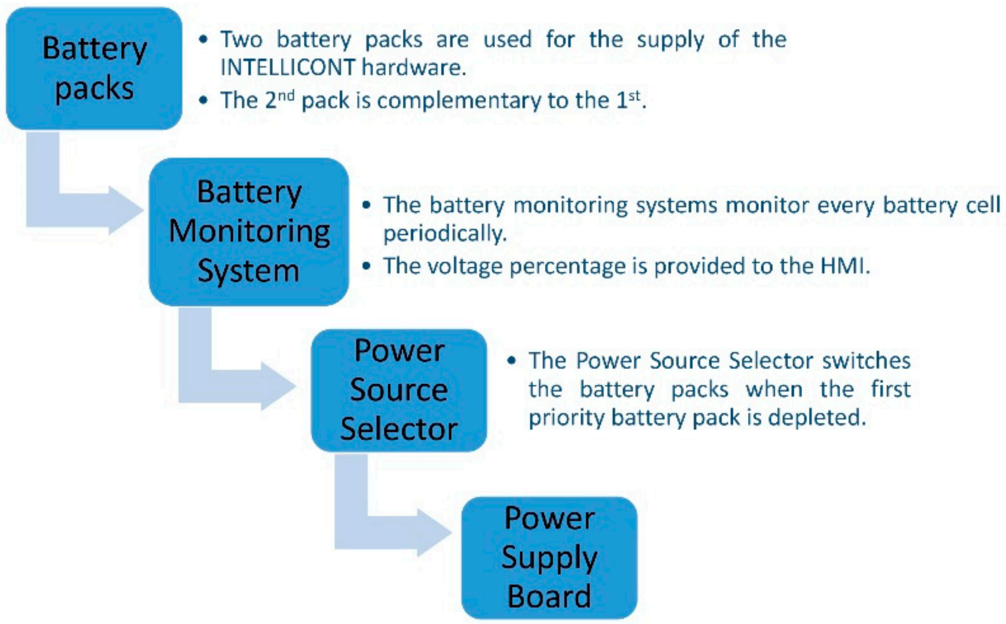

Figure 6. Battery supply and management system.

RMC system can control three basic operations:

3.1. Smoke/Fire Detection

The smoke detector, PMC1103-03 of Siemens, needs to receive a request for data, and then it replies via the Controller Area Network (CAN) bus. However, it will spontaneously send data if it detects conditions for a smoke alarm, i.e., high smoke optical signal combined with high temperature and low humidity. Besides, the smoke detector transmits its status according to the list below:

- Degraded mode: if any of the secondary parameters fail, the smoke detector enters degraded mode and relies on primary parameters only;
- Warning: internal monitoring of the smoke detector triggered on a minor fault criterion, recording the occurrence;
- Prefault: once the contamination of the detector reaches a fixed threshold, the smoke detector provides, through this flag, the necessity for maintenance;
- Standby: the smoke detector is operational, but not in operation;
- Alarm: the smoke detector has detected smoke signals or heat elevation signals that its algorithm identifies as a potential fire event and triggers the alarm;
- Fault: internal monitoring of the smoke detector triggered in major fault criteria, recording the occurrence.

3.2. Monitoring the Structural Health of the ULD

The piezoelectric elements (×3) provide an analog voltage. This is measured every 20 ms in 12-bit resolution into an exponential average of 80% for each element by the ULD microprocessor, except when reporting the data. When the ULD is powered on, a calibration procedure is executed and a calibration reference is created for each element, assuming the conditions cause relaxed values. After every measurement, the current value is set as the calibration difference and compared to the threshold for an alarm or not.

3.3. Supervision of the Locking Status of the ULD

The magnetic position elements (×8) provide an analog voltage. This is measured every 20 ms in 12-bit resolution for each element into an exponential average of 80% by the ULD microprocessor, except when reporting the data. The switch contact elements provide on–off data. This is measured at ULD Normal state right before the report message is sent to the HMI and at the ULD Lock state right before the lock feedback message is sent to the HMI (every 100 ms).

4. Communication Link

The ULD is designed to take measurements from sensors independently using settings ordered by the HMI wirelessly via Message Queuing Telemetry Transport (MQTT) protocol for when and how often to report that information. The ULD-internal timing of settings is supervised by RTOS mechanisms. The connectivity main frame of ULD can be seen in Figure 7.

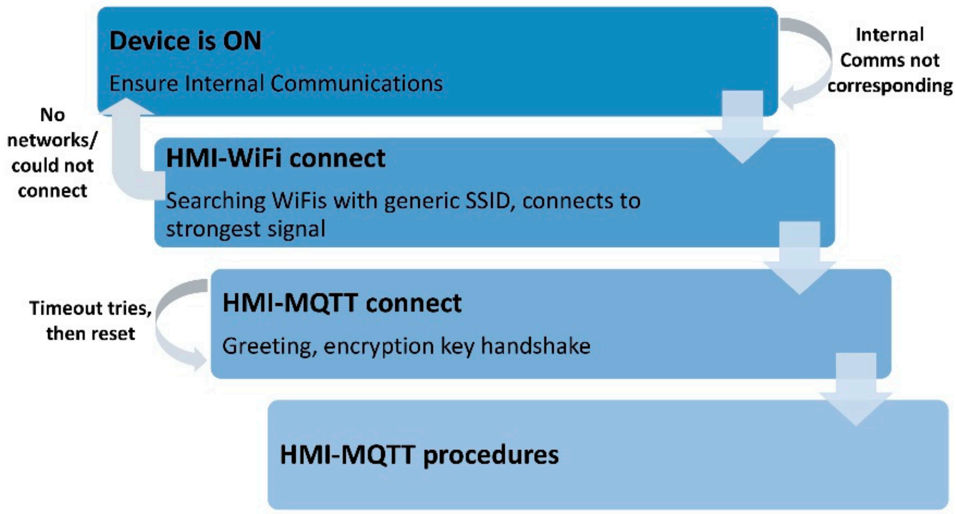

Figure 7. ULD connectivity block diagram.

It is a procedure that is fully automatic, with only one care of the installer agent: that the ULD and HMI are close enough for the Wi-Fi connection when the power is on. When the device (ULD) is given power, internal communications are ensured. If that is not ensured, the device resets. Otherwise, the device scans for Wi-Fi with Service Set Identifier (SSID) beginning with "INTELLICONT", which the HMI broadcasts, and connects to the one with the strongest signal. This means that there can be many installations with "INTELLICONT" HMI nearby, but the ULD will connect to the closest one. One should consider that this will happen when a ULD is powered on. Again, if no networks are found, or if the Wi-Fi connection cannot be established, the device resets. That functionality can be power consuming, thus it is recommended that the matter of when to power the ULD be cared for. Then, a connection to HMI's Message Queuing Telemetry Transport (MQTT) server with pre-configured static settings is tried a maximum number of times before a reset. If successfully connected to the MQTT server, the MQTT Ack - encryption key exchange happens between the ULD and HMI, as seen in the sequential diagram of Figure 8. After that, having secured the connection, the ULD awaits orders from the HMI to serve each of the HMI-ULD needed functionalities.

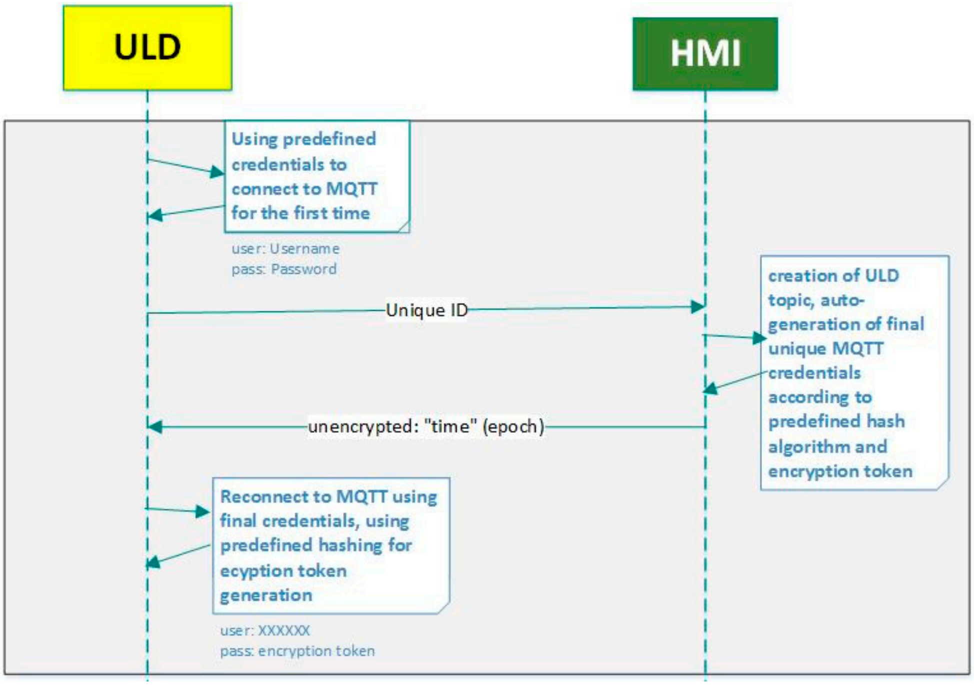

Figure 8. MQTT Ack - encryption key exchange.

5. Human Machine Interface

"INTELLICONT" is a cross-platform application for portable devices with the same functionalities in all platforms and small changes in UI. It requires the minimum OS versions to operate shown in Table 2.

Table 2. Operating Systems Supported Versions.

Operating System	Minimum Version	Target Version
Windows	Windows 10	Windows 10
Android	Android 5.0 (API Level 21)	Android 9.0 (API Level 28)

The "INTELLICONT" Application communicates with the ULDs and Robotic Platform via Wi-Fi. A hotspot needs to open in a portable device before the "INTELLICONT" application is opened. The page in Figure 9 contains the main operating menu for the HMI application. From here, the user can navigate to the ULD Dashboard for monitoring ULDs, to the Robotic Platform Dashboard for monitoring and control of the robotic platform for loading and unloading ULDs to air-cargo, to the MQTT Dashboard for information about MQTT Broker Internet Protocol (IP) address and port, and to Cabin Setup to setup air-cargo slots.

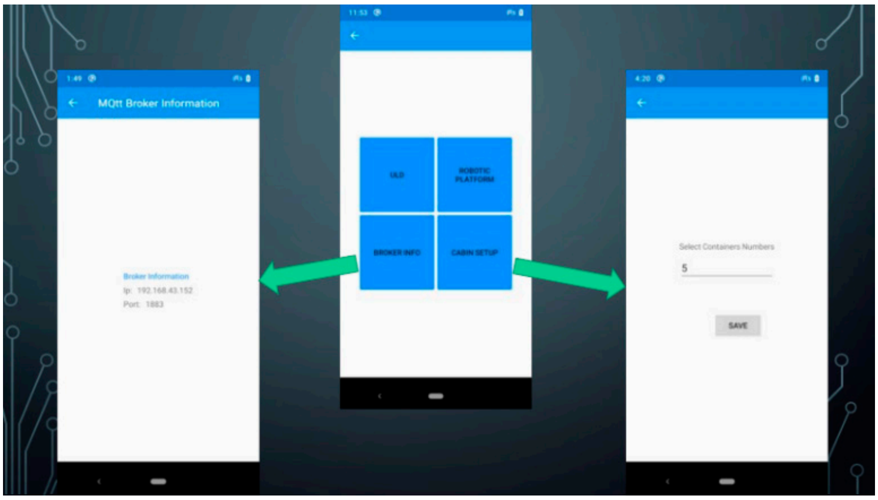

Figure 9. Main menu.

Figure 10 shows how the HMI is structured. The ULD Dashboard Page and the ULD Information and Raw Data Pages are described below.

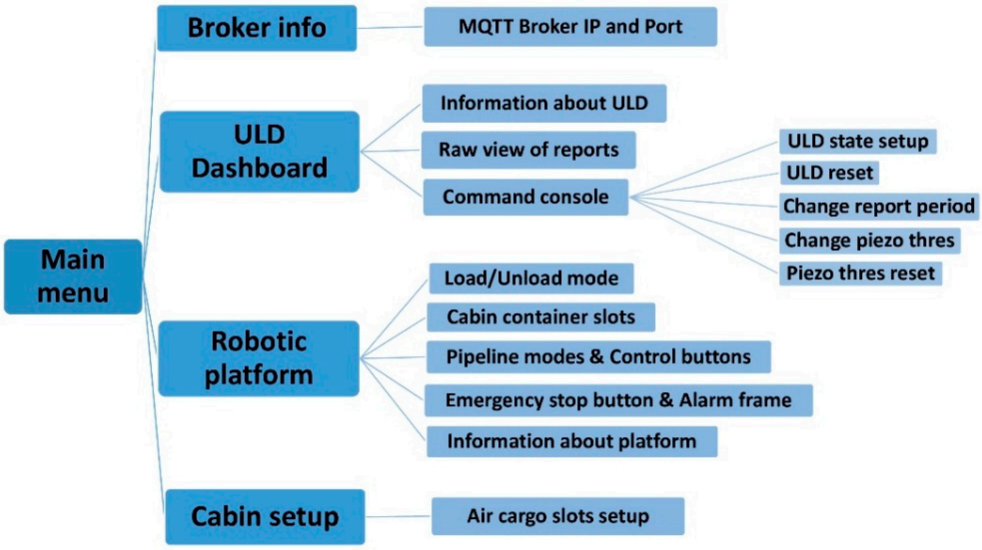

Figure 10. Flowchart of HMI design.

5.1. ULD Dashboard Page

In the ULD Dashboard Page (Figure 11), the user can see all registered ULD devices and their status indicators for batteries, Wi-Fi, smoke, piezo, magnetics, and alarms, and by selecting one the user can navigate to the ULD Information Page to see more detailed measurements. More specific presentation areas of the ULD Dashboard page with colored frames are:

- ULD Device Frame with ULD name, Batteries Status color indicators, Smoke Sensor Status and Temperature, Piezo Sensor threshold status color indicators, and Magnetic Sensors corner combination color indicators. When it is pressed, it navigates to the ULD Information Page for more analytic ULD measurements;
- Alarm Frame used to present real-time alarms from ULD devices;
- Start Report Button that changes all ULD states to Normal for obtaining measurement reports;
- Stop Report Button that changes all ULD states to Idle for stopping the obtention of measurement reports.

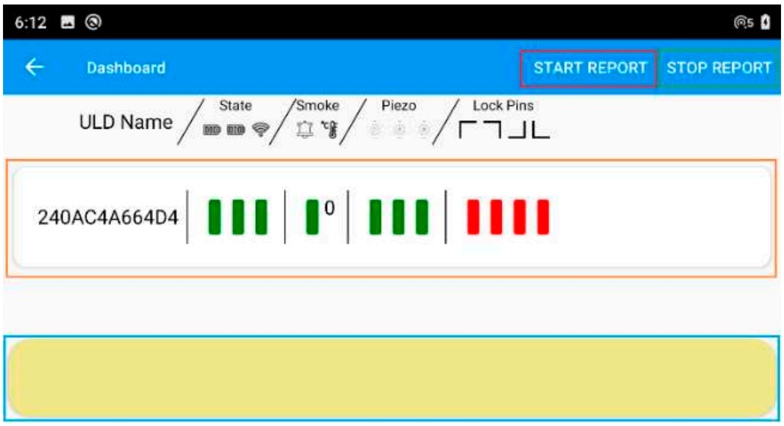

Figure 11. ULD Dashboard Page.

5.2. ULD Information and Raw Data Pages

In the ULD Information Page, there are the ULD measurement indicators shown in Figure 12, on the left in the color frames:

- The number of Measurement packages;
- The percentage level of the ULD's Batteries;
- Strength of Wi-Fi signal in dB;
- Smoke measurement that comes from the smoke detector sensor;
- Color indicators for eight Magnetic Sensors. If the value of the sensor is above 3200, then the indicator of the Magnetic is "Green". Otherwise it is "Red";
- Color indicators for three Piezo Sensors. If the value of the sensor is above a threshold, then the indicator of the piezo is "Red". Otherwise it is "Green";
- Color indicators for eight Digital Sensors. If the value of the sensor is 0, then the indicator of the sensor is "Green". Otherwise it is "Red";
- Package Date and Time;
- Piezo Sensors threshold and ULD report time in seconds.

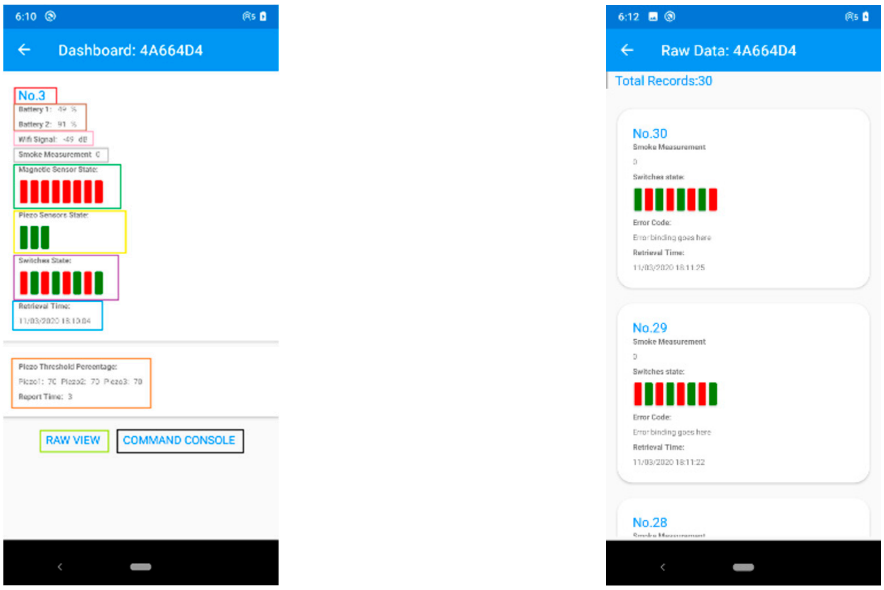

Figure 12. ULD Information (**left**) and Raw Data (**right**) Page.

The Raw Data Page contains all of the ULD measurement packages inside the Local Database with the same information as the ULD Information Page.

5.3. Robotic Platform Dashboard Page

In the Robotic Platform Dashboard Page (Figure 13), the user can see and interact with the active Robotic Platform by tapping each pipeline action and selecting the specific cabin container slots to load and unload ULDs and see real-time alarms and statuses from the Robotic Platform. More specifically, the Robotic Platform Dashboard Page areas with colored frames are:

- Cabin Container slots that can set up from Cabin Setup Page and have color indicators for states: (i) container slot activity completed, (ii) container slot waiting for action, (iii) container slot in progress, (iv) container slot selected for action, and (v) Container Slot Activity Error;
- Robotic Platform connecting ULD name and selection of Robotic Platform mode (Load/Unload);
- Robotic Platform Pipeline Modes buttons;
- Robotic platform Information: name, location, battery percentage, and signal strength in Db;
- Robotic Platform Message console with colored frame messages: (i) Prompt Messages that prompt for user action, (ii) Warning Messages (i.e., "Low Battery"," Weak Signal"), (iii) Error Messages Ongoing, task will be interrupted;
- Alarm Frame which is used to present real-time alarms from Robotic Platform Pipeline;
- Emergency Stop Button that, when tabbed, stops all actions from the Robotic Platform and releases two buttons fort the user: (i) Continue Button that continues the action of the Robotic Platform, (ii) Disable Button that disables the Robotic Platform after the user accepts the popup security notification;
- Robotic Platform Pipeline control buttons: (i) GoHome Button that moves the Robotic Platform to Home Position, (ii) Connect Button, connecting Robotic Platform to ULD, (iii) Load Button, loading ULD after a user selects a Container Slot for Loading Mode and Unload ULD from Selected Container Slot for Unloading Mode, (iv) Unlock Button, which sets connected ULD to "Lock" state to Unlocking ULD from Container Slot and then sets the ULD back to "Idle" state after unlocking is completed, (v) Lock Button sets the connected ULD to "Lock" state to locking ULD to selected Container Slot and then sets the ULD back to the "Idle" state after locking is completed;
- Robotic Platform Pipeline control buttons have colored states to indicate actions: (i) waiting for future actions, (ii) action in progress, (iii) action completed, and (iv) action Error.

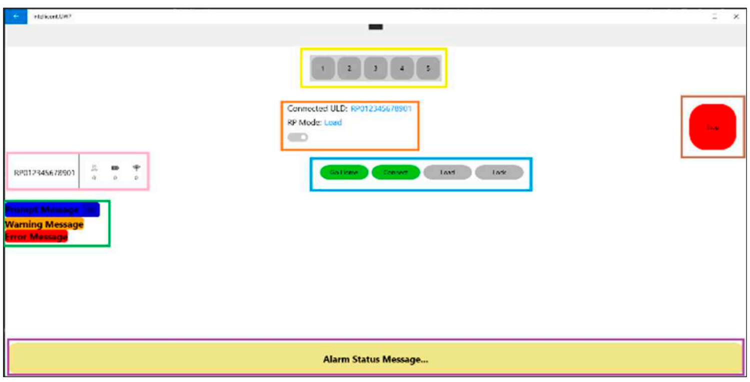

Figure 13. Robotic Platform Page.

6. Proof of Concept Testing

In the context of Proof-of-concept testing, all the hardware components of a ULD are fully operating and the application is connected to the ULD. The power supply is provided by two battery packs that switch when the pack voltage is under a threshold. The full "INTELLICONT" system is shown in Figure 14.

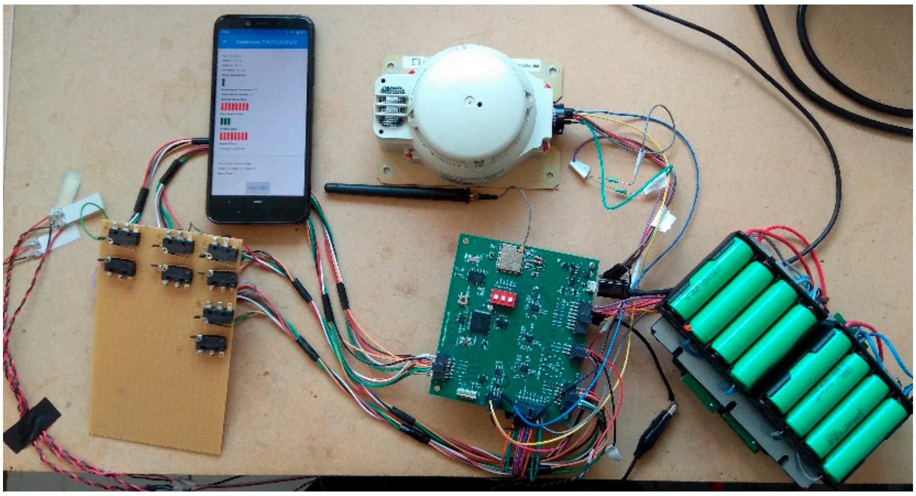

Figure 14. "INTELLICONT" full system.

This prototype system Proof Test Schedule provides a summary of the performed Proof tests for Hardware (HD) components, Software (SW) modules, and Data validation after "INTELLICONT" RMC installation in the ULD. Components to be evaluated are summarized in Table 3.

Table 3. ULD Components for Evaluation.

Product	Identifier	Description
Collector	RMC-C	Collector with different channels for sensor acquisition
Power Supply Unit (PSU)	RMC-PSU	Board for power management and distribution

The test plan followed can be briefly described as follows.

6.1. Hardware (HW) Component's Verification

These tests are intended to verify that the HW configuration complies with system specifications (operational, performance, etc.). The test includes a comparison of HW configuration onboard with that described in the relevant deliverable. The components selected, including the sensors and the circuit boards, are the same as the ones that are going to be installed in the containers during the system's pilot testing. The integrity and robustness of the measurements were assured by performing each series of measurements at least three times, according to the standard laboratory test practice. Each test is described in the corresponding paragraph.

6.1.1. Accuracy and Stability Testing

In the context of the Lab Scale Tests, the operation of boards and sensors operation has been checked repeatedly to define the durability and the stability of the RMC system. It is noted that accuracy tests were similar to the stability ones; however, the latter involved longer testing duration.

6.1.2. System Testing

This test involved the evaluation of the RMC operation according to its specifications. The evaluation procedure included testing the system under both normal and non-normal conditions so that the platform's operation and outputs could be tested during its normal operating conditions, as well as in the case of malfunction.

6.2. Software (SW) Module Testing

The software testing followed a similar but firmly different procedure. The purpose of SW tests was to ensure that the code runs correctly given the equations of the model and the initial requirements for operability and functionality. Three kinds of reliability tests were scheduled (static, dynamic, and passive), following standard software testing practice [25]. Besides, data integrity and user experience tests were performed as described below.

6.2.1. Static Testing

This kind of test involved Unit Tests and a series of proofreading tests, as well as data flow and static program analysis. Using different breakpoints, both the algorithmic flow of the code and the algorithmic rationality were evaluated. While, by the end of the development, a systematic static test set was performed, the process was initiated by the early stages of development (mainly with unit tests) and was performed in many iterative stages throughout the development lifecycle.

6.2.2. Dynamic Testing

This kind of test is commonly known as "debugging" and involves the in-depth analysis of the function of the software after it has been released or at the very late stages. In contrast to the static tests that mainly focus on software verification, these tests involve its validation. Besides, the performance of each software module is performed during these tests. In our case, the performance is crucial, especially during the loading stage where data need to be transferred from the ULD to the robotic platform in high transfer rate, thus special attention was given towards the test of this module.

6.2.3. Passive Testing

To test the function of the software in normal operational conditions, a series of log and error files were produced by the embedded code. The system provides different kinds of log files, from operational status and condition to time of function execution and completion flags. The main part of this test was performed in parallel to the field tests and the analysis of the involved files was performed off-line (after the completion of the tests).

6.2.4. Data Validation

These tests involve the comparison of characteristic obtained results with the same data obtained by visual inspection of the tester. This test involves (a) calculation of data packages loss and time shift, and (b) collection and transfer of data in periodic intervals between several Smart Collector devices and a remote server. All data integrity tests were performed via the HMI application. Testing proved that all values were successfully transferred to the end destination without loss or duplication and on the correct sampling rate. Deviation from the precise sample timing intervals occurred. This deviation was of the order of one (1) second, which is assumed to happen due to noise in the link budget.

6.2.5. User Acceptance

User Acceptance includes evaluation of Graphical Interface Design and Human Experience of the installation procedure, as well as customization effectiveness, and visualization quality and data export usefulness.

6.3. Fault Tree Analysis

One of the main features a system should adopt to be able to be approved for use in aviation is the in-depth fault tree analysis both for hardware and software components. According to the category, the system has to provide evidence that provisions for alternative paths, in case a major component fails, have been made. Figure 15 presents the faulty conditions that the platform was tested in. The activation of the auto-connect provision is timely when the system faces connection loss, malfunctioning sensors, or an under-voltage supply.

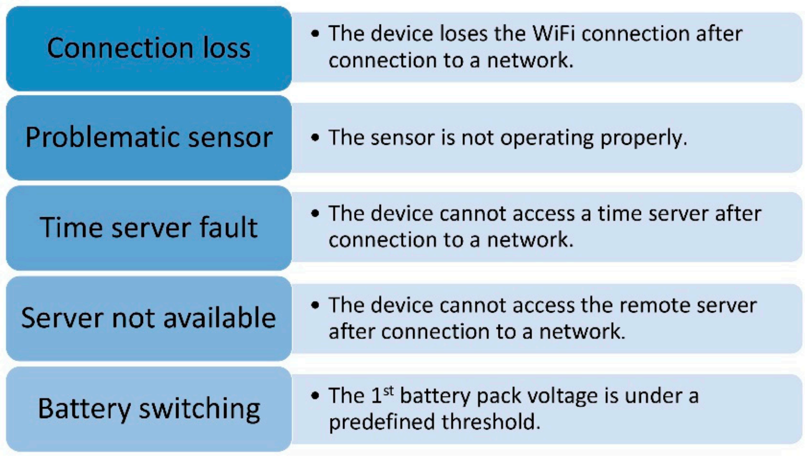

Figure 15. Faulty test conditions.

6.4. General Outcome of Laboratory Testing

Table 4 provides an overview of the testing amongst major perform very well following system-specific findings (if any) and suggestions for improvement. Limitations or restrictions faced during the testing shall also be briefly included.

Table 4. Overall Testing Outcome per Component.

Product	Identifier	Comments
Testing System	Pass	The prototype complies with system specifications
SW Module	Pass	N/A
Data Quality	Pass	Corrections in HW and SW performed before the final release
User Acceptance	Pass	Minor changes performed before the final release
Testing System in Non-normal conditions	Pass	The system responds satisfactorily in faulty conditions

7. Concluding Remarks

Key figures for accidents reported by IATA [7] reveal the importance of safety during operations involving air cargo. Safe and accurate ULD operations, after all, have been proven to be crucial during emergencies (e.g., the COVID-19 pandemic), where both accuracy and proper cargo handling are of vital importance [6]. In our view, the proposed HMI platform will contribute to reaching the expected safety assurance because it provides a holistic intervention that not only addresses the FR needs of the target use cases, but also produces a mindset change in the involved stakeholders (e.g., Operation Departments, line managers, crew, airport authorities, etc.), which combine in a synergic way: digital technology innovations, advanced data processing techniques and decision support, and organizational changes in business processes.

Major risks for the safety of the FR involved in air cargo operations are the ones involved with continuous tracking capabilities of container ID, locking status, fire/smoke warnings, and logs of impact events. One additional risk, vital to the safety of the FR (especially the medical teams), is the one involved with the early warning capability for incidents and the real-time assessment of the condition of the incident, especially when rules such as social distancing are not possible all the time.

Towards reducing these risks, a Remote Monitoring and Control system was developed. The RMS has a profound impact on the adoption of several innovative technologies in the aviation sector. These include sensing, monitoring, data fusion, and distributed computing. To reduce these risks and enhance health and safety working conditions, a Decision Support Platform has been developed and described during this work, which aims to pave the way towards a more sophisticated policy-making process and standardization. Furthermore, the HMI platform will benefit operators in increasing efficiency, reducing downtime and costs, and ensuring the safe operation of their assets.

The next step would be the analysis of data collected from field and pilot tests. In addition, the platform will be redesigned to be fully customizable to the role and activity of each FR member, as well as with responsible Artificial Intelligence (e.g., [26]) and Augmented Reality (AR) components that will run on smart glasses. The aim is to extend first responder capability to "percept" crucial information, including visualized Air Cargo Standard Operational Procedures and Emergency Response Plans/Check Lists, and make more risk-informed decisions during on-field operations.

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Article

Dynamic Restaurants Quality Mapping Using Online User Reviews

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Abstract: Millions of users post comments to TripAdvisor daily, together with a numeric evaluation of their experience using a rating scale of between 1 and 5 stars. At the same time, inspectors dispatched by national and local authorities visit restaurant premises regularly to audit hygiene standards, safe food practices, and overall cleanliness. The purpose of our study is to analyze the use of online-generated reviews (OGRs) as a tool to complement official restaurant inspection procedures. Our case study-based approach, with the help of a Python-based scraping library, consists of collecting OGR data from TripAdvisor and comparing them to extant restaurants' health inspection reports. Our findings reveal that a correlation does exist between OGRs and national health system scorings. In other words, OGRs were found to provide valid indicators of restaurant quality based on inspection ratings and can thus contribute to the prevention of foodborne illness among citizens in real time. The originality of the paper resides in the use of big data and social network data as a an easily accessible, zero-cost, and complementary tool in disease prevention systems. Incorporated in restaurant management dashboards, it will aid in determining what action plans are necessary to improve quality and customer experience on the premises.

Keywords: OGRs; health; smart city; food safety; big data

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1. Introduction

E-commerce sites such as TripAdvisor and Yelp have increased exponentially over the last decade or so. They are continuously innovating in order to facilitate consumer decision-making through a system of user evaluation of products and/or services (in the case of restaurants: food, service, atmosphere, etc.). Meanwhile, national health departments have limited resources to dispatch inspectors, leaving out many restaurants or being unable to carry out visits with required frequency, for example, to verify if the quality has improved [1]. From a smart cities perspective, local authorities faced with inadequate resources are, in effect, urban decision-makers stymied in their progress towards achieving smarter cities and improved living standards [2]. Consequently, there is a veritable need for implementation of systems to support strategic decision-making, with the aim of adopting smart city health initiatives in mind [3].

Cities are generating a lot of data that could be availed of for improvement of services provided to citizens. Millions of users generate online data about service experience when visiting a restaurant, a bar, or a cinema. These online-generated reviews (OGRs) written by the customers themselves are an important part of e-commerce website design, as they reflect the customer experience [4]. For the companies listed, it is crucial, since reviews naturally have an influence on visitor behavior [5] and are, as to be expected, directly linked to financial performance [6].

The academic field covering OGR computing is very large since text, visual data, and image tags can reveal important information [7]. Many authors have argued the potential positive effects of OGRs for health protection [1,8,9]. They claim OGRs could fill this gap, even if the idiosyncratic nature of data collection brings specific challenges [10,11]. Understanding of this information, therefore, remains rather poor, despite the importance of OGRs in decision-making about buying a product [12], listening to music [13], voting for a presidential election [14–18], or choosing a restaurant [19–21]. Consequently, the present study extends incipient research into the question of how to put OGRs to good use for restaurant inspection purposes, protecting citizens' health in the process. The research objective is to evaluate how OGRs might be efficiently used to predict restaurant health condition distribution at the city scale and reveal unknown health risks. Our methodology consists of, with the help of a Python-based scraping library, collecting a set of data and comparing it to related restaurant health inspection reports. Our results reveal that there is a correlation between the health inspectors' data and OGRs garnered from TripAdvisor. In other words, OGRs can dynamically indicate restaurant quality.

The originality of the paper resides in the use of big data as an easily accessible, zero-cost, complementary tool in disease prevention systems. Incorporated in restaurant management dashboards, OGR data can aid in determining actions necessary to improve overall quality and customer experience on the premises. The remainder of this manuscript is organized as follows. The next section briefly sketches out the current state of affairs and reviews previous studies that have used OGRs to resolve urban issues. This section is followed by a mapping out of the methodology employed to analyze OGRs and yields the results. The results are presented in Section 3 and discussed thereafter in Section 4. Finally, the paper concludes in Section 5 with theoretical and managerial implications, as well as directions for future research.

2. Literature Review

In the last decade or so, studies have also begun to look at how big data can be integrated as a complementary tool in restaurant hygiene inspections. The importance of this field of activity in terms of maintenance and improvement of living standards can hardly be overstated, not least because one of its ultimate objectives is health protection, for example through reducing risk of food poisoning and encouraging better sanitary conditions. Research carried out in California has shown that implementation (by local authorities) of stricter measures for public disclosure of inspection results can lead to reduced hospitalization rates linked to suspected foodborne illnesses [22,23]. Enforcing requirements to post inspection grades at a given establishment has also been shown to affect business revenue considerably [24], since obviously many patrons will be deterred from frequenting a restaurant with a publicly visible poor score.

The present research topic explores links between online-generated reviews (OGRs) and restaurant inspection scores. The use of online reviews (of products, hotels, restaurants, etc.) tends to have the effect of reducing uncertainty for customers prior to making decisions [25]. Since one of the key factors in the decision to patronize a restaurant is consumer perception of its hygiene standards [26], exploring the links between restaurant OGRs and hygiene inspection scores is a logical step forward in putting these vast datasets to purposeful ends in terms of minimizing health risks.

While research linking user reviews to health inspections is still in its incipient stages, the sparse studies that do exist show simple and linear regression between the two variables, and thus are convincing as to the utility of such investigation. For instance, a 2019 US-based study, drawing on datasets from the social networking site Yelp, confirmed the unequivocal impact of health inspection results on online restaurant reviews [9]. That is, as one might expect, "critical health inspection results lead to a decrease in star ratings" ([9], p. 1370). The study also found that severe health inspection results trigger quality improvements, and, importantly, that restaurants with poorer overall ratings are more likely to see a rise in fake reviews, presumably in an attempt to mitigate the obvious negative effects of such results. More importantly, an earlier study by Kang et al. [1] reported a significant correlation between reviews on social media (also using Yelp) and prediction of actual restaurant inspection scores, reporting "over 82% accuracy in discriminating severe offenders from places with no violation" ([9], pp. 1443–1444). In focusing on restaurants with severe violations, the authors also report finding a number of clear lexical cues in reviews which correlated with the inspection results [1].

These studies open up vast potential for uses of big data as a complementary tool in the field of restaurant inspection, a field which has many challenges to contend with. For instance, research to date has yielded mixed results in terms of the capacity of inspections to predict outbreaks of foodborne illnesses [5]. Not only that, but doubt has been cast over consumer ability to correctly interpret inspection information [27], and issues arise around environmental health officers' subjective categorization of violations. These issues aside, local governments and health departments of course have limited resources. Kang et al. [1] even report that no inspection records were available for over 50% of restaurants found on Yelp at the time of their study in Seattle, suggesting limited coverage. Hence, assistance in targeting establishments at risk of committing food safety infractions are highly likely to be an aid in effectively deploying available resources. We would also posit that making better use of big data, in particular OGRs, for such purposes may act as a further incentive for dining establishments to promote a safe food environment, also potentially bolstering consumer confidence in existing health inspection procedures.

The current study contributes to this early line of research, looking to restaurant inspection scores in the context of Manhattan, New York, and OGRs posted in the same jurisdiction by users of TripAdvisor, a leading global online platform for reviews on restaurants. To the best of our knowledge, neither of these variables have been explored in similar research. Since studies on the topic to date have focused on American cities, we deem New York a good choice of location in extending this line of research. In addition, its high concentration of restaurants has yielded 1045 restaurant inspection results, alongside 50,618 OGRs for our data analysis. In addition, the sheer volume of tourists to New York precludes possible bias that may arise from overconcentration of any one cultural group, by ruling out culturally relative judgements of cleanliness, hygiene standards, or otherwise.

3. Materials and Methods

Using the case of Manhattan in New York City, our methodology draws on two compiled datasets entailing restaurant health inspection results and online restaurant reviews posted to TripAdvisor for corresponding restaurants. To address our research question, we employed a four-step approach.

3.1. First Step—Analysis of the Restaurant Health Inspection Report

Restaurant health inspections are carried out by local government health departments to ascertain the compliance of restaurants with food safety conditions and requirements. The inspection entails various aspects such as food handling, food temperature, and conditions of infrastructure hygiene. Vermin control is also carried out. In the event of infraction, the restaurant is penalized with a poor inspection rating. Systems for these ratings and disclosure thereof differs according to jurisdiction. In New York, they are made publicly visible to customers by being displayed in restaurant windows [1]. Even if they are also available online, clients must search in an Excel sheet of >100,000 lines, which renders the task laborious https://health.data.ny.gov/Health/Food-Service-Establishment-Last-Inspection/cnih-y5dw (accessed on 31 July 2021). From the dataset, we extracted two variables for our study: (a) the health inspection date and (b) the health inspection score, which is the sum of violation points for inspection demerits of a given restaurant. It is important to note that the higher the health score is, the worse the conditions of the particular restaurant are. This system evaluation works in the opposite way to the TripAdvisor's rating by number of stars.

3.2. Second Step—Analyzing the TripAdvisor Data

Restaurants listed on TripAdvisor (www.tripadvisor.com accessed on 30 May 2021) accumulate OGRs composed of the following elements: textual review, review posting time, and OGR scorings. With the help of a Python-based scraping library, we were able to retrieve this data. The algorithm and our repository are available at the GitHub.com website https://github.com/SebasGarcia08/reviews-summarization (accessed on 31 July 2021). GitHub.com hosts projects which can be accessed and managed using the standard Git command-line interface and allows users to browse repositories on the site. It also provides social networking-like functions such as feeds, follows, and wikis. As a recent upgrade, it offers a social network feature which shows when developers work on a future version (coined as fork) and which fork or branch inside this fork is the newest.

We calculated two review scores for each restaurant as per Formulas (1) and (2) below. One formula takes into account reviews between today and the date of health inspection (Formula (2)) and the second takes into account reviews before this date and after 1 March (Formula (1)). To obtain the requisite information on quality, we calculated the mean star scoring evolution when at least one review exists within 30 days before and after the inspection date.

Mean star scoring is calculated according to Formulas (1)–(3) below:

$$\text{OGR\_extract\_before}(\text{restaurant} = x) = \frac{\sum_{March1st,2018}^{lastHealthinspectiondate} OGR(x)}{n} \tag{1}$$

$$\text{OGR\_extract\_after}\ (\text{restaurant} = x) = \frac{\sum_{lastHealthinspectiondate}^{today} OGR(x)}{m} \tag{2}$$

where n and m are the number of OGRs between the respective periods.

Finally, we calculate:

$$\text{OGR\_extract\_var}\ (x) = \text{OGR\_extract\_before}\ (x) - \text{OGR\_extract\_after}\ (x) \tag{3}$$

3.3. Third Step—Developing a Relationship Model Joining the Two Datasets

The two datasets have in common the names and addresses of restaurants. The address is important since Manhattan has different chains of restaurants (e.g., Hard Rock Cafe, Domino's, etc.) which have the same name and can thus be confused. However, official health inspection reports do not include the restaurant URLs necessary to download OGRs. Consequently, we assigned a group of 21 students (working on a smart city project at Ramon Llull University (Spain)—bachelor's level) a sampling of the report and asked them to manually input the TripAdvisor URLs. The result was a list of URLs that was compatible for use with our Python script.

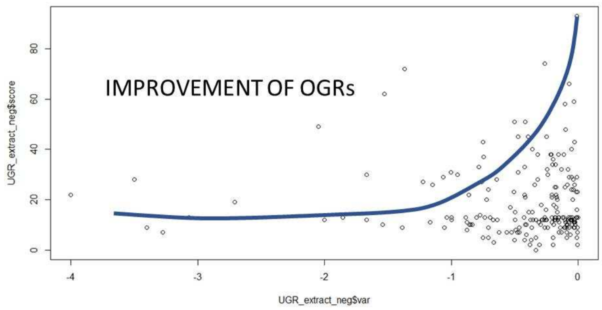
3.4. Fourth Step—Analyzing a Possible Correlation Inside the Final Dataset

Our dataset covers 1045 restaurants' health inspections posted from 1 March 2018 to 1 March 2021. We compared the two sets of data, the one retrieved from TripAdvisor, and the other from the national health system. It covers 50,618 restaurant OGRs which are also divided into two parts: prior to the inspection date and after it. Before processing the OGRs to make our calculations, we conducted a preprocessing of the data, defining and calculating the reviewers' popularity through two dimensions: the average number of friends and their general rating behavior, i.e., the average number of stars they award restaurants on the platform. Accordingly, a small number of users' OGRs were eliminated. Namely, those that were awarding excessive positive scoring in order to whitewash restaurant quality (positive fake news) or very negative ones (negative fake news) were removed. The correction based on this preprocessing yielded a refined, and only very slightly reduced dataset.

To address the research question, we then analyzed the possible correlation between the variation of the star rating observed (variable: "OGR_extract_var") and the health inspection results (variable: the "health score"). The variation considered is a subtraction between the period before and after the health inspection date.

4. Results

The results of our study ("health score" versus "OGRs_extract_var") are presented in Figure 1a,b. Figure 1b represents negative evolution, i.e., there is a deterioration of the OGRs, while Figure 1a shows when the evolution is positive. For Figure 1b, we observe a logarithmic correlation, while in Figure 1a we observe an exponential correlation, with significance degrees of 0.002185 and $<2.2 \times 16^{-10}$ *p*-values, respectively. We interpret these results as follows. If TripAdvisor reviews worsen ("OGR_extract_var" with positive values), we conclude that the restaurant's owner has reacted with a corrective action plan. The latter increases restaurant quality and compliance with food safety regulations, and the consecutive health score results lower (which is, we recall, synonymous with the lower irregularities in these reports).



Trip Advisor OGR (before inspection) < Trip Advisor OGR (after inspection)

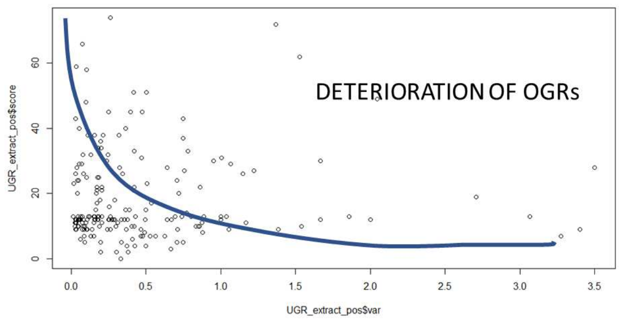
Coefficients:

	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	-3.651e-01	2.441e-02	-14.96	< 2e-16 ***
exp(score)	-6.106e-32	1.970e-32	-3.10	0.00219 **

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Multiple R-squared: 0.04131, Adjusted R-squared: 0.03701
F-statistic: 9.609 on 1 and 223 DF, p-value: 0.002185

(**a**)



Trip Advisor OGR (before inspection) > Trip Advisor (after inspection)

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.173829	0.024501	7.095	2.4e-11 ***
exp(var)	0.130296	0.005342	24.389	< 2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Multiple R-squared: 0.755, Adjusted R-squared: 0.7538
F-statistic: 594.8 on 1 and 193 DF, p-value: < 2.2e-16

(**b**)

Figure 1. (**a**): Zone of improvement according to TripAdvisor OGR evolution. (**b**): Zone of deterioration according to TripAdvisor OGR evolution.

On the contrary, if TripAdvisor reviews improve, i.e., "OGR_extract_var" with negative values (Figure 1a), the New York Health report score improves also, and the number of infractions and health score of consecutive inspection are therefore low. This result suggests that an improvement observed by visitors leads to a better inspection grading. Finally, when the OGRs scoring average shows little change during the periods before and after the inspection ("OGR_extract_var" with values close to 0), the health inspection scoring worsens on average. We posit that this is because an absence of (negative) OGRs on restaurant quality is likely to lead to lack of improvement-oriented action by owners and/or management, i.e., akin to a laissez-faire approach, manifesting in deterioration of the food quality and hygiene conditions.

In sum, our findings reveal a U-shaped behavior or correlation between health inspection ratings and OGR scorings. To improve visualization of the results, we decided to use the Quantum GIS (QGIS) software platform, a free and open-source desktop geographic information system (GIS) application, to map the OGR and health inspection results. QGIS allows users to create maps composed of either raster or vector layers and based on the geolocalization of all the restaurants. The results are shown in Figure 2 and illustrate, firstly, how OGRs can be used to identify patterns/clusters of health risks related to distribution of restaurant health conditions on a city scale. Secondly, they reveal a clear visual overlap between OGRs and health inspection results. The correlation rate is 0.82. This outcome confirms, at a macro level, the benefits of OGRs and their potential beneficial uses for heath protection [28–30].

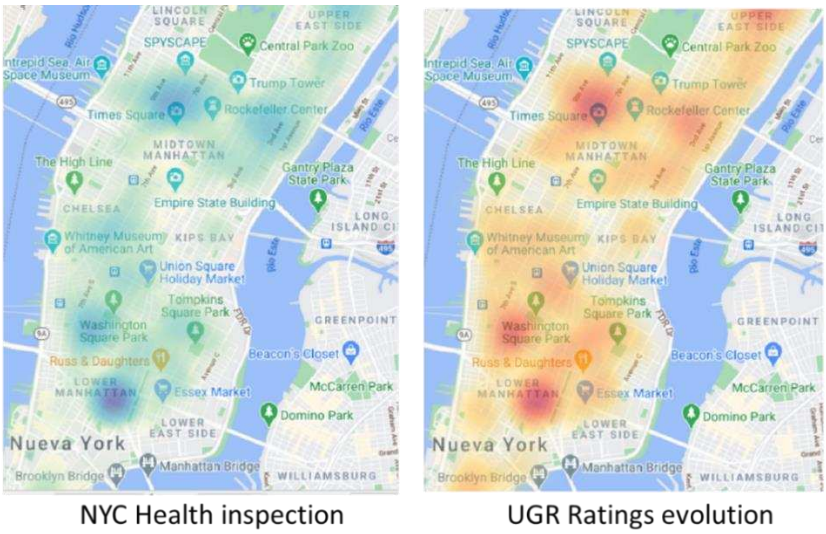


Figure 2. Visualization of the NYC health inspection and UGR ratings evolution.

5. Discussion

OGRs can be categorized in terms of quantitative (e.g., average number of stars, review wordcount) and qualitative characteristics (e.g., general opinion, sentimental polarity of the experience, predictive lexical cues) [1,25,28,30,31]. The quantitative characteristics of OGRs are heuristic cues displayed close to the product or service proposed that inform about customer experience and/or (dis)satisfaction [19,32]. Recent papers have shown a simple and linear regression between OGRs and health inspections [1,9]. Our results shed further light on these findings. They show the relation is more complex and has a U-shaped behavior. Our study, in fact, demonstrates a negative causality between OGRs and health system scores. In other words, negative variation of OGRs can predict a possible diminution of the official health system scoring. Our correlation corroborates findings which confirm the direct influence of health inspections on restaurant reviews [9].

Moreover, since the OGRs are posted daily to websites such as TripAdvisor, our findings highlight the real-time and dynamic role that customers' reviews could play in the area of health inspection. Therefore, thinking more broadly, i.e., citywide, our results indicate that the OGRs could be a good assistance for cities which have a department of health with limited resources hindering frequency of inspections and/or follow up of hygiene or cleanliness issues. They can potentially serve as a new contribution to smart city health systems and form part of a decision support toolset to aid urban managers in adopting and implementing health initiatives [3]. Moreover, when these health issues are localized in a specific zone, such as in the Lower Manhattan area (Figure 2), they can be leveraged to look for factors external to the restaurant. By using appropriate techniques and bridging the vocabulary gap between health seekers and healthcare knowledge [10], an influence zone can be determined [33,34] and the objective of plague or disease propagation prevention achieved.

The penetration rate of smart phones is currently reaching 121% in developed countries, whereas in developing countries it is already 90% and continues to rise [35]. Therefore, the proliferation of these devices represents an important opportunity to generate OGRs and improve health conditions. Regarding the possible generalization of our findings, our methodology is based on a case study. This type of approach is fruitful for studying complex phenomena and is increasingly common in business research, where case studies have been used to analyze diverse phenomena [1,36]. They are highly recommended for the analysis of social networks [36], such as TripAdvisor in our case. Case studies are also appropriate in the early phases of theory development when key variables and their relationships are to be explored and the revision of the literature shows incipient understanding of the phenomenon at hand [14,17,37].

6. Conclusions

Much potential for smarter cities resides in the opportunity to analyze freely available, large quantities of user reviews generated upon visiting a restaurant or employing an urban service. These online-generated reviews (OGRs) reflect customer experiences [4] and are an important decision aid in customers' purchase decision-making processes [9]. By collecting and analyzing OGRs in tandem with health inspection scores, our study aims to demonstrate that restaurant health inspection results can be reflected by OGRs. In other words, OGRs can be seen as a proxy for predicting the likely outcome of the next health inspection of a given restaurant. The practical implications are twofold. Correctly processed by the owner of the company listed, OGRs constitute valuable information to guide implementation of corrective actions and thus lead to an increase in restaurant quality and safe food handling. For local governments constrained by limited resources, they can be used to predict health risks and orientate the prioritization of restaurants for official inspection. The theoretical implications constitute new evidence that data analytics could be an additional and valuable source of information to support such decision-making processes. Uncovering the multiple ways in which big data, social, and unstructured data can potentially improve the management of cities makes for novel scientific contribution [18,38–40].

The present study, however, has some limitations which can be addressed by future research. First, our results should be confirmed by performing similar research in other cities to verify their scalability. The validation of different cases could then support the development of an urban prediction model and a comprehensive theoretical decision support system. Second, a further study could carry out a fine-grained analysis of OGRs to identify characteristics that could influence visitors' perceptions, such as reviewers' nationality. Indeed, the standards of quality, cleanliness, or service attention vary from one country to another, and could be considered. Finally, this research focuses on the quantitative aspects of OGRs, taking into account the star average scoring. Future research should seek to also include the analysis of qualitative information present in the OGRs which, when summarized and categorized, could also be of assistance to the health inspectors by anticipating valuable information about the restaurants they will want to audit [41].

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smart cities MDPI

Communication

Determinants of Smart City Commitment among Citizens from a Middle City in Argentina

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Abstract: This paper aims to examine the determinants of smart-city commitment across individuals from Bahía Blanca, Argentina. Literature has identified different factors explaining citizens' commitment to smart cities, such as education, age, labor condition, and other more subjective factors, such as trust and awareness about the smart-city concept. A mediator factor of smart commitment is e-readiness or digital readiness, that is, the level of preparedness to properly exploit internet opportunities such as e-government and e-commerce. To achieve this goal, we used a survey conducted on 97 citizens (followers of the Moderniza Bahía Facebook) from the city of Bahía Blanca, Argentina. By estimating a structural equation model, we found that higher levels of ICT use are associated with higher levels of smart-city commitment and that higher awareness of the smart-city concept is related to higher levels of smart-city commitment. Sociodemographic factors such as age and labor condition also explain ICT use.

Keywords: smart cities; ICT use; sociodemographic factors; e-readiness

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1. Introduction

Smart cities are a new style of a city designed to encourage healthy economic activities with the help of information and communication technology (ICT) while improving quality of life and providing sustainable growth. We are witnessing a more interconnected and challenging context that imposes the need to find better solutions for information sharing and transfer among multiple actors involved in shared environments, such as urban cities [1].

Under this smart-city scenario, information and communication technology infrastructures are critical tools to improve and support social and urban growth, promoting citizens' participation and governmental efficiency. From the citizen perspective, the adoption of ICT is critical for the performance of smart cities and smart activities. Smart-city services offer citizens a better living environment and raise their quality of life [2–4]. There are many examples of smart-city services such as end-to-end applications that focus on common concerns such as mobility, public services and safety. Recently, the crucial role of these smart-city services has been evidenced because of the pandemic crisis [5].

Since urban services are used by citizens, it is of main importance to take account of their opinions and perceptions for correct management of the services [6]. Nowadays, cities do not have a deep enough understanding of their citizens to actively and effectively engage them [7] (p. 12). Scholars have highlighted that little research has focused on examining the citizens' commitment to smart cities such as smart practices or activities [8]. The authors believe there is a gap between the recent political approach that focuses on citizens' "engagement" or "participation" in smart cities and research related to this issue. In fact, the smart city differs from the digital city in the focus given to the relationships among the actors and entities involved and their contribution to the success of all [9]. However, some recent empirical literature has explained the factors that motivate citizens' engagement in smart cities [6,10,11]).

The framework of this study is in line with the diffusion of innovation theory and incorporates the claims of the unified theory of acceptance and use of technology (UTAUT) [12]. Based on the UTAUT, citizens (users) with different socioeconomic characteristics act differently regarding the usage of technology for performing smart activities. While most of the empirical literature on smart cities focuses on the supply side, which is the role of firms providing smart services, government policies for building smart cities and urban planning, among others, there is scarce research on the demand side from the citizens' perspective. This gap is especially pronounced in the context of developing countries.

Empirical literature on smart-city commitment in cities of developing countries is still scarce [13,14]. Thus, this paper contributes to the expansion of research on this subject. Building on this reflection, this study provides some understanding of the factors that are related to the success or failure of citizens' engagement with smart-city initiatives through an explorative study on the smart-city landscape. Does ICT use mediate the relationship between smart-city commitment and sociodemographic factors? In order to accomplish this goal, a structural equation model (SEM) was estimated by employing an online survey of a group of citizens from Bahía Blanca.

We examined the city of Bahía Blanca because it is one of the most transparent cities in Argentina. Based on the Open Data Index (ODI) of the Open Knowledge Foundation, the city is ranked fourth at the top of the ranking. During the last years, the city has changed the relationship between local government and citizens through the adoption of innovative actions and projects, a more transparent government, the opening of data, the implementation of practices to promote citizens' engagement and the adoption of new technologies [15].

Bahía Blanca is a city of about 400 thousand inhabitants located in the southwest of Buenos Aires Province, Argentina. Bahía Blanca is also one of the Argentinean cities awarded for the program "Pais Digital". Based on the latest data on ICT diffusion at the household level, Bahía Blanca is one of five urban places in Argentina with the highest percentage of households using the Internet [16]. In Argentina, 69.4% of individuals use the Internet (two out of three people use the Internet), but only 16.1% of inhabitants have a fixed broadband subscription. On the other hand, active mobile broadband subscription is higher than fixed broadband reaching 67% [17].

Better exploitation of Internet opportunities depends on the education level of the population and their digital skills. In this aspect, data based on EPH (Household Permanent Survey) 2016 show that 34% of people older than 25 hold a tertiary or university level complete in the Bahía Blanca Cerri conglomerate. Moreover, 60% of people older than 20 have at least the secondary school level complete.

The paper is structured as follows. First, we describe the theoretical framework related to smart cities necessary to establish the hypotheses of the study. Secondly, the methodology and data are explained. Thirdly, we show the results obtained by estimating the structural model, and finally, results and conclusions are provided.

2. Theoretical Framework

During the last years, some research has emerged on the importance of building smart cities. Although the concept is not new and there are plenty of definitions, we can distinguish two different approaches. On the one hand, a technological view centers on the ICT role as a means to deepen and strengthen access to public information and to make city services more efficient [9,18–21]. On the other hand, a wider approach is related to notions of sustainable economic growth, quality of life, participatory governance and the reduction of CO2 emissions that place the citizen at the center of analysis [19,22–26]. According to this view, "the spirit of e-governance in a smart city should be citizen-centric and citizen-driven [22] (p. 12)". Most definitions of smart cities in this approach coincide in five features or characteristics: smart economy, smart governance, smart mobility, smart environment and smart people.

At the same time, the evaluation of citizens' perceptions with respect to urban innovations has become relevant [27,28]. Macke [27] focused on a wider definition of smart cities and evaluated the perception of the quality of life of Curitiba, Brazil. From a theoretical perspective, the diffusion of innovation theory (DOI) [29] offers a model to explain the social and technological factors that affect the acceptance of innovative information technology (IT). This theory is broadly employed for comparison of initial adoption and continued use in a variety of technologies [30]. Later on, Moore and Benbasat [31] proposed the innovation diffusion theory (IDT), which is an extension of the DOI theory, but it also includes in ICT adoption a moderating factor termed "personal innovativeness". This term represents an individual's propensity to innovate [30]. If users are more novelty-seeking, they will accept more innovative technologies. IDT focuses on the technological aspects and then incorporates the users' behavior and social factors associated with the innovative technology.

Recent empirical evidence has analyzed the determinants of citizens' engagement in smart-city initiatives. For instance, Novo Vázquez and Vicente [32] analyzed the factors that outline citizens' e-participation in smart cities. The authors found that political engagement, ICT usage and socioeconomic factors, such as age, educational attainment and labor situation, explain participation.

In addition, Cardullo and Kitchin [11] analyzed the role and context of citizens in smart cities by examining smart-city initiatives in Dublin, Ireland, which they titled "the scaffold of smart citizen participation". On the other hand, Polese et al. [10] offered an empirical investigation from a sociological and psychological perspective on the perception of citizen services in the city of Brno, the Czech Republic. The study centered on the smart-cities issue as an example of complex service systems (CSSs) and showed how actors' perceptions (cognitive and psychological dimensions) can influence opportunities and willingness for value co-creation and collaboration.

Similarly, Caputo et al. [33,34] analyzed the role of individual perceptions in the evaluation of services and in the definition of possible collaborative behaviors, with specific reference to the domain of the smart city. On the other hand, Yeh [6] examined citizens from Taiwanese cities that had participated in smart-cities campaigns. Citizens will use smart-cities services if they are innovative, high-quality and secure (in terms of privacy).

Moreover, dimensions utilized to evaluate the performance of cities range from the most technological ones to aspects related to citizen participation and engagement. Most smart-city indexes (i.e., Smart City Index, IESE Cities in Motion) are based on six dimensions: economy, people, governance, mobility, environment and life. Each of these dimensions is decomposed into elements or factors and each factor into a set of indicators [35].

2.1. SC Activities or SC Commitment

Since the increasing focus of smart cities on citizens, there is a need to enable citizen engagement by fostering participation, collaboration and community empowerment [36]. In this study, we supposed that citizens' engagement with the smart city should be reflected in the accomplishment of many smart activities such as e-government, e-commerce and care for the environment, among other dimensions.

The smart economy dimension is critical to measure the economic "health" of a smart city [37]. This aspect is related, directly or indirectly, to smart and ICT infrastructure for connectivity. In addition, it refers to "soft" capabilities such as smart health and smart funding [37]. Businessmen are usually the first adopters and drivers of ICT in the economy. In this paper, we focus on the citizens' ICT adoption for buying and selling online. By participating in e-commerce, citizens help to foster a competitive economy, where competition and competitiveness take place [38].

The smart people dimension stresses that human and social capital is an important tool to develop smart cities. Prosperity in any smart city involves investment in human capital and related infrastructure [39]. This explains why knowledge workers are frequently apt to concentrate around cities [4]. Technological devices and digital resources are useful tools to enhance people's lives if and only if their users are ready and prepared to properly utilize them [21,40,41]. In smart-city frames, the demand for smart learning has increased steadily due to the integration of digital technologies and the Internet into learning [42].

The smart governance dimension characterizes the efficiency and qualification of the state intervention to solve citizens' requests. Governance is associated with e-government practices, mainly citizens' engagement [43]. In many countries, e-government initiatives are common because they imply more citizen-centric governance [44]. E-government conveys new ideas such as transparency, accountability and citizen participation in the evaluation of government performance under this knowledge-society approach [45,46]. Moreover, processes of political and electronic participation are a baseline in the development of smart cities [47,48]. Citizens perform smart practices if they realize the potential economic and environmental gains of living smart [49]. On the other hand, Granier and Kudos [8] explained the case of Japanese citizens and found that smart communities' goal is to encourage citizens to participate in the co-production of public services but not involve them in governance.

The smart environment dimension implies citizens developing sustainable and scalable practices such as classification and/or recycling of waste, using less energy and purchasing second-hand goods, among other environmentally friendly practices [37]. While the built environment (including both buildings and supporting infrastructure) will need to support the rapid increase of population and urbanization, cities will have to adapt to address climate change and its associated impacts. Many studies show that citizens from smart cities have a strong commitment to the development of sustainable and scalable practices such as trash recycling and efficient use of energy resources, among others [8,41,50–52].

From an environmental perspective, Sovacool [53] suggested that citizens' participation increases democracy, especially if citizens perceive they are represented in environmental decision making. In addition, public engagement and learning lead to behavior change related to environmental issues [54,55]. Bull and Azennoud [54] offered an example of citizen engagement in Hampshire, USA, where a discussion of an adequate waste strategy was performed to engage the public in decision management of household waste in the city.

Finally, smart mobility also plays a key role in promoting the development of smart cities. In metropolitan large areas, mobility is considered one of the most challenging topics to confront. It comprises both environmental and economic factors and needs both high technologies and smart people. Smart mobility is mostly embedded in ICT to support optimum traffic and to collect citizens' opinions regarding livability in cities or quality of local public transport services [56].

2.2. ICT Use and SC Activities

Technology trends in smart cities such as mobile broadband connectivity, open data, urban interfaces and cloud computing, among others, are progressing at a rapid pace. ICT plays a key role in smart cities by connecting infrastructures, government and citizens [7]. Paskaleva [21] highlighted that a smart city is based on the "use" of advantages offered by information and communication technology.

By using ICT, public services can be offered online, public information can be easily accessed and citizens can organize among themselves to share interests and concerns. Moreover, ICT use can facilitate and promote citizens' decision making and involvement in public life [32].

ICT has an increasing impact on different aspects of citizens' quality of life [6,57–60]. For instance, the adoption of ICT applications in e-government is a prerequisite for the emergence of smart cities [14]. By using e-government, citizens can communicate with governments from different levels (national, federal, regional, local), and, by being involved in public-sector governance, they improve its efficiency and effectiveness. In this vein, Lytras and Serban [61] established that one of the most critical applications of smart cities in contemporary societies is e-government. However, "although smart city services are driven by advanced information technologies, their success is highly dependent on user engagement, which is historically problematic [49] (p. 845)".

Socioeconomic demographics differences can give rise to a digital infrastructure gap between cities in emerging economies, such as India, asking for smart-city policies implementation [62]. However, in some countries such as India, most technologically advanced cities such as Ahmedabad had only 10.3% of its households with Internet access in the year 2011 [62]. Therefore, ICT access has not yet been considered a basic infrastructure for building smart cities in some less developed countries.

ICT use depends not only on connectivity (Internet access) and access to digital devices such as computers, tablets and mobile phones, among others, but also on ICT skills. This relationship between access and use is due to the existence of complementarities in ICT diffusion [63]. Personal computers have a stronger impact on Internet diffusion in developing countries than in developed countries. Usually, unequal access to resources and rights is correlated with both ICT appropriation and ICT intensity use. Then, we can state the first hypothesis:

Hypothesis 1 (H1). *ICT use positively affects citizens' performance of SC activities.*

2.3. Awareness of the SC Concept and SC Activities

Studies based on the IDT have shown that the perceived characteristics of innovation can have a significant effect on adopters' behaviors toward the acceptance and usage of innovative ICT solutions [64], e-government systems [65–67] and SC services [6]. Similarly, awareness of the smart-city concept is a main factor to explain smart citizens' behavior. However, Neirotti et al. [48] found a negative relationship between awareness and SC activities through a sample of 70 international cities. A possible explanation is that the most polluted cities are located in developing countries in which complete awareness of the SC concept has not yet been established.

Hypothesis 2 (H2). *The awareness of the SC concept positively affects citizens' performance of SC activities.*

2.4. Trust and SC Activities

Trust is generally understood as the willingness of one person to count on the behaviors of others, especially when this person is in a vulnerable situation. Trust always supposes the person is ready to accept a certain degree of risk and to become vulnerable to a trusted party [68]. This approval of risk is based on the expectation that the trusted party will perform actions that are important or beneficial to the vulnerable party [69].

If citizens trust in ICT-based SC services, they will positively accept and use the ICT-based SC services [6]. However, Novo Vázquez and Vicente [32] did not find trust in governments to be a significant factor explaining e-participation, which is one of the dimensions of smart cities (smart governance). Therefore, we can pose hypothesis 3.

Hypothesis 3 (H3). *Citizens' trust in e-government positively affects citizens' performance of SC activities.*

2.5. Sociodemographic Factors and SC Activities

Demographic characteristics affect the use of a given product or service [70], probably because the needs of citizens vary according to their educational level, gender and age. However, results on the impact of demographic factors on usage are not conclusive. Yeh [6] showed that Taiwanese citizens' attitudes and behaviors toward ICT-based SC services are not affected by their demographic characteristics in terms of age, gender and education reinforcing the public nature of services, which are oriented toward the whole community. On the other hand, Novo Vázquez and Vicente [32] observed that socioeconomic factors such as age, educational attainment and labor situation are significant factors explaining citizens' e-participation, while gender is not significant.

Citizens' education is one of the main determinants of people's digitalization level [71]. The educational condition is a significant predictor of ICT use. An educated individual can access cognitive resources, digital skills and, more importantly, social and knowledge resources. Some studies have claimed that education affects the probability of using the Internet [72] and the diffusion of the Internet [73,74]. In particular, Hargittai [74] observed that education significantly enhanced the penetration level of Internet hosts across countries. In addition, Kiiski and Pohjola [73] showed that mean years of schooling is a significant factor explaining the growth of Internet hosts per capita. On the other hand, Chinn and Fairlie [75] did not observe a significant correlation between the variables.

Hence, education can indirectly determine the development of SC activities. In this line, Belanche, Casaló and Orús [52] showed that citizens' educational level positively affects urban services usage since the more educated the people, the higher the environmental consciousness will be. The higher the educational level (human capital), the greater the probability of using ICT will be. People that are more educated have better access to information about SC benefits and how to perform intelligent activities. Hence, the development of SC activities will be higher.

Hypothesis 4 (H4). *The more educated the people, the higher the ICT use will be, and therefore, the higher the citizens' performance of SC activities might be.*

Gender is also considered an important factor to predict the use and acceptance of technology-related applications or systems. Decision-making processes are different between men and women [76–78]. Tarhini, Hone and Liu [77] found that gender was not significant in influencing the relationship between perceived ease of use and behavioral intention of students' e-learning. Moreover, Al-Shafi and Weerakkody [79] observed that gender significantly moderates the effect of the determinants on behavior intention to use the wireless Internet park service in Qatar. In particular, males were positively associated with higher intention to use. On the contrary, Mensah [76] did not find gender to be a significant demographic factor in explaining the willingness to use e-government services.

Hypothesis 5 (H5). *Men are more likely to use ICT than women are; therefore, they are more likely to perform more SC activities than women are.*

On the other hand, older people perceive lower potential profits from innovating than younger people because they attribute a higher discount rate to future profits. While young people are more likely to have ICT access [80], older people usually use the Internet to a lesser extent [71,81]. There are differential effects regarding the affect–creativity association, depending on employees' age [82]. Therefore, age is a proxy of personal innovativeness and can be employed as a preliminary factor to understand the characteristics of adopters [30] and the level of acceptance/usage of ICT-based SC services [6].

Hypothesis 6 (H6). *Older people are less likely to use ICT and, therefore, to perform SC activities mediated by ICT such as e-commerce and e-government, among others.*

Finally, income is an important determinant of ICT adoption as it indicates the households' budget constraints [72,80,81]. One of the users' characteristics that affect the intra-country digital divide is related to income [83]. The greater the household income, the higher the probability of using the Internet is [84]. The lack of income does not allow citizens to take part in the ICT demand. Therefore, unemployed or people with a transitory job are less likely to use ICT.

Hypothesis 7 (H7). *Citizens with a permanent job are more likely to use ICT and, therefore, to perform SC activities.*

Based on this research background, the model examines the causal relationship between smart-city activities and sociodemographic factors by describing the mediating role of ICT use. Hence, citizens' gender, age, education level and labor condition are the control variables of the proposed framework by explaining directly ICT use and indirectly SC activities. Figure 1 offers a graphical representation to explain the model.

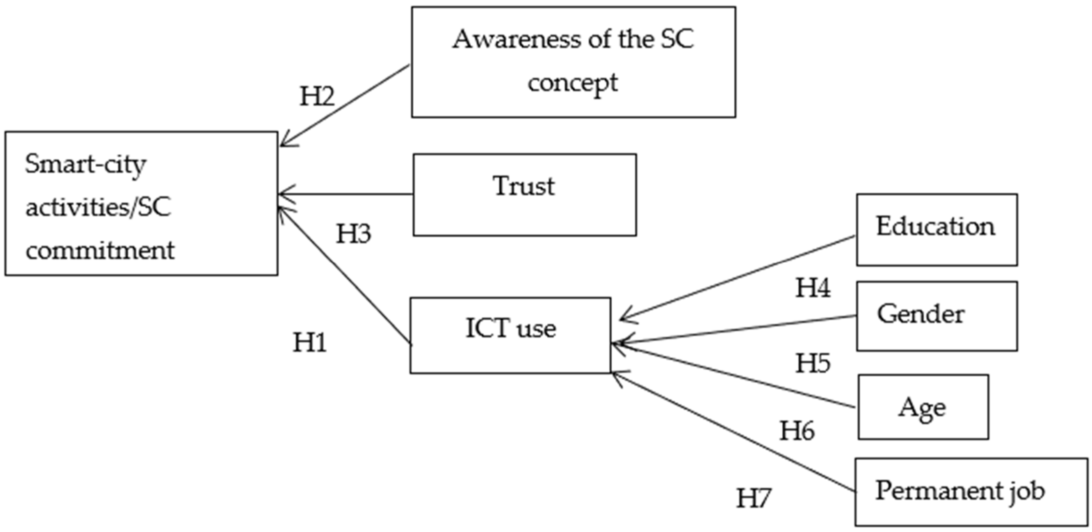

Figure 1. The model to be estimated Source: Own elaboration.

3. Methodology

Bahía Blanca is a city of around 400 thousand inhabitants situated in the southwest of Buenos Aires Province, Argentina. According to the National Survey on ICT for the year 2011 [85], 53.8% of urban inhabitants had fixed Internet access and 43.9% had a personal computer in Bahía Blanca. These percentages were higher than the national level of Internet access (38.8 %).

Since it would have been costly to obtain a representative sample of the whole population of the city, we decided to limit the population under study to the followers of the Facebook fan page "Moderniza Bahía". Nowadays, this page has the name of Lab Bahía, a place to promote citizen participation and collective intelligence to bring innovative solutions to local problems. The lab is part of the local government initiative, and it is very active in terms of open government and open data. The number of followers is stable, with around 17 thousand followers. The type of interaction is mainly unidirectional. A couple of recent publications with many comments and shares have concerned the transformation of the city park "Parque de Mayo" and building of the app "Organiza tu salida" to manage walking around because of COVID-19.

We used data obtained from an online survey conducted between April and May 2019, which was supported by the Secretary of Modernization of Bahía Blanca Town Hall. During these two months, we collected data from 97 citizens. The original sample (N = 99) included two invalid cases of individuals who did not live in the city. As a result, there were too many missing data in those cases. These two cases were not included in the analysis. Besides, the sample is biased and does not represent the overall population of Bahía Blanca. Therefore, results obtained are only representative of follower citizens of that social media website.

The questionnaire was based on several literature sources on e-government and smart cities [86–88]. It collected information about the citizens' profile (age, education, labor condition and ICT use), smart cities and e-government. Questions were closed, and most of them were Likert-scaled.

The size of the sample was 97; we collected 97 valid observations during the two-month period of diffusion of the survey. The sample size was enough for a finite population sampling (lower than or equal to 100,000) [89]. The sample responded to the following formula:

$$n = \frac{Z^2 * N * P(1-P)}{(N-1) * K^2 + Z^2 * P(1-P)} \quad (1)$$

where N is total population. In this case, followers of Moderniza Bahía Facebook, N = 16,400 by April 2019.

Z is the value obtained from significance levels. If population distribution is normal at a significance level of 95%, z value is 1.96. In this case, with a significance level of 90%, the corresponding z is 1.645, and so on.

K is the error or maximum difference between the sample proportion and the population proportion to be accepted based on the significance level proposed. For a significance level of 95%, k is 0.05; similarly, for a significance level of 90%, k is 0.1, as in this case.

P is the population fraction of interest, a parameter that indicates the percentage of population interested in smart cities. It can be obtained from a pilot survey, but if it is an unknown parameter, as in this case, it is suggested to use the most unfavorable value of 50%.

For each question, respondents were asked to declare their opinion using a five-point Likert scale [90] in which 1 = "strongly disagree" and 5 = "strongly agree".

In a brief characterization of the sample, we found that 69% were female (the majority of the sample) and 56% were young people between 22 and 40 years old (followed by 37.6% of adults between 41 and 60). On average, the education level of the sample was high, with 38.2% with a university degree and 20.6% with postgraduate studies. On the other hand, 79% had a permanent job. Almost the whole sample had Internet access at home and used mobile phones. The profile of the participants was congruent with the literature on the subject: citizens who regularly use the Internet and are familiar with the digital world, mainly use smartphones and are already aware of the smart-city concept and related terms [91–93].

In terms of the smart-city concept, 42.3% had heard about the concept but did not know enough, and only 2% had worked or implemented smart-city initiatives. Moreover, 25% of the sample did not connect with the local government through the website. Thus, 25% were not using e-government, and only 6% of the sample achieved a transactional level (download, share or re-use databases). On the other hand, 67% connected to Internet to buy and sell products online (e-commerce), and 41% of the sample had recycled or classified waste.

We studied the relationship between smart-city activities and ICT use by estimating a structural equation model (SEM). Although there are different statistical packages, we utilized STATA 14 to perform the estimations. STATA software only uses CB-SEM [94].

In this frame, SEMs are of two different types with regard to the statistical approach (non-parametric or parametric testing), the objective of the study (exploratory or confirmatory) and, especially, the algorithm employed (generalized least squares (GLS) or maximum likelihood estimator (MLE)) (Esposito, 2009). These differences lead to variance-based structural equation modeling (VB-SEM) and covariance-based structural equation modeling (CB-SEM), respectively.

This paper uses a CB-SEM model, which is SEM based on the covariance matrix. CB-SEM goal is to test and confirm the theory by using data (exploratory model). The difference between the theoretical covariance matrix and the estimated covariance matrix (based on data) is minimized to estimate the parameters. Indicators of goodness of fit arise due to the difference between the empirical and theoretical covariance matrix [95].

Iacobucci [96] conducted a simulation study to examine the effect of sample size on goodness-of-fit measures. The study observed that sample size should be more than 50 (the fit measures are better when sample size increases). In addition, maximum likelihood estimation performed better because it was relatively robust to the multivariate normality assumption. ML has been found to be relatively robust in case of violations of the multivariate normality assumption [97,98]. However, since there are no outliers in the sample under study, we did not expect non-normality to be a problem and we relied on the goodness of fit of the model. Moreover, "if the variables are reliable and the effects are strong and the model is not overly complex, smaller samples will suffice (Bearden, Sharma & Teel 1982; Bollen, 1990) " [96] (p. 91).

On the other hand, there are PLS (partial least squares) models that are SEMs based on the variance matrix (VB-SEM). However, PLS-SEM objective is to build theory based on the emerging relationships (in the same way as multiple regression analysis). Thus, it is a more exploratory model. PLS-SEM emerges from the discrepancy between the observed values and/or the dependent latent variables and the values estimated by the model [95]. Hence, measures or indicators of the predictive capacity of the model using PLS-SEM are of main importance to determine the quality or goodness of fit of the model, such as reliability and explained variance, among others, which is not needed in CB-SEM models [99]. Figure 1 shows the causal relationships to be tested.

Variables

The structural model is compound of two structural equations since there are two endogenous variables: SC activities and ICT use.

SC activities: SC activities is a variable (non-observable) obtained by using a factorial analysis among a set of indicators (Table 1).

Table 1. Communalities from factor analysis among SC activities. Source: own elaboration.

Smart-City Dimension	SC Activities	Initial	First Extraction	Second Extraction
Smart environment	Reduction of private transports (car, moto)	1.000	0.597	0.607
	Use of public transport	1.000	0.698	0.699
	Use of bike lanes	1.000	0.391	
	Recycle or classify waste	1.000	0.606	0.760
	Rational water consumption	1.000	0.723	0.742
Smart government	Interaction with local government through internet (e-government)	1.000	0.515	0.497
Smart economy	Electronic commerce (sale-buy through internet)	1.000	0.495	0.509
Smart mobility	Use of SAMPEM Parking (parking app)	1.000	0.562	0.586
Smart people	Home-banking or financial transaction online (i.e.,: pay taxes)	1.000	0.738	0.739
	E-learning	1.000	0.617	0.652

To develop a construct or variable for measuring SC activities of citizens from Bahía Blanca, a set of items was included based on a thorough review of the smart-city literature and mainly on the project's questionnaire. Citizens were asked to provide information about the kind of smart activities performed, from reduction of public transport to e-learning.

For instance, the survey explicitly asked if they performed any of the following activities to turn Bahía Banca into a smarter city (multiple choice): Reduction of private transports (car, moto); Use of public transport; Use of bike lanes; Recycle or classify waste; Rational water consumption; Interaction with local government through internet (e-government); Electronic commerce (sale-buy through internet); Use of SAMPEM Parking (parking app); Home-banking or financial transaction online (i.e.: pay taxes); and E-learning.

Both the Kaiser–Meyer–Olkin measure of sampling adequacy and Bartlett's test of sphericity indicate that the factor analysis may be useful with the data. The KMO measure of sampling was nearly 0.6; if the value were less than 0.50, the results of the factor analysis probably would not be very useful. On the other hand, the *p*-value related to Bartlett's test of sphericity was zero, indicating that these variables were related and therefore suitable for structure detection.

Table 1 shows communalities from each SC activity acquired by performing a component principal analysis. We observed that the item or variable "Use of bike lane" was not relevant for explaining the variance (since communality from the first extraction was lower than 0.4). Then, we made the second extraction to define the significant items. After that, by using the components extracted, we built the SC activities index. Table 2 reports the first four factors that explained nearly 64 percent of the variance.

Table 2. Total variance explained.

Components	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	% Accumulated	Total	% of Variance	% Accumulated	Total	% of Variance	% Acummulated
1	2.021	22.459	22.459	2.021	22.459	22.459	1.919	21.321	21.321
2	1.521	16.903	39.362	1.521	16.903	39.362	1.609	17.874	39.195
3	1.222	13.579	52.941	1.222	13.579	52.941	1.166	12.956	52.152
4	1.026	11.403	64.343	1.026	11.403	64.343	1.097	12.192	64.343
5	0.847	9.417	73.760						
6	0.754	8.375	82.135						
7	0.662	7.358	89.493						
8	0.530	5.890	95.383						
9	0.415	4.617	100.000						

Extraction method: principal components analysis.

To construct the SC activities index, we computed the weighted sum of the four components. Each weight represented the proportion of variance of each component related to total variance. The average value of the SC activities index reached 0.51.

ICT use: This variable represents an independent explanatory factor of SC activities. The hypothesis was that the higher the ICT use, the higher the propensity of developing SC activities such as e-commerce and e-government would be.

ICT use is also an endogenous variable in the model, which is mainly explained by demographic factors. We used the same methodology as the SC activities index to build the variable ICT use. ICT use is a variable obtained from a factorial analysis among a set of ICT-use indicators. People were asked to provide information about the places used for connecting to the Internet as well as the devices employed. The higher the number of places and devices used for connecting to the Internet, the higher the intensity of using Internet will be.

Since we built ICT use as an exogenous variable by using factor analysis, we showed the suitability of the data for structure detection. Both the Kaiser–Meyer–Olkin measure of sampling adequacy (nearly 0.52) and Bartlett's test of sphericity (p-value 0.000) indicated that the factor analysis may be useful with the data. Tables 3 and 4 show information needed for this task.

Table 3. Communalities from factor analysis in ICT use. Source: own elaboration.

	Initial	First Extraction	Second Extraction
Internet access at home	1.000	0.862	0.868
Internet access at work	1.000	0.581	0.702
Internet access in educational places	1.000	0.572	0.571
Internet access in commercial places	1.000	0.625	0.670
Internet access in public places	1.000	0.701	0.736
Use computer to connect Internet	1.000	0.656	0.689
Use mobile phones to connect Internet	1.000	0.870	0.872
Use tablet to connect Internet	1.000	0.363	
Use TV to connect Internet	1.000	0.449	0.468
Use e-Reader to connect Internet	1.000	0.487	0.478

Table 4. Total variance explained. Source: own elaboration.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Accumulated%	Total	% of Variance	Accumulated%	Total	% of Variance	Accumulated%
1	1.948	21.646	21.646	1.948	21.646	21.646	1.714	19.048	19.048
2	1.684	18.715	40.362	1.684	18.715	40.362	1.651	18.347	37.395
3	1.302	14.469	54.830	1.302	14.469	54.830	1.382	15.357	52.752
4	1.120	12.446	67.277	1.120	12.446	67.277	1.307	14.524	67.277
5	0.936	10.398	77.675						
6	0.751	8.339	86.014						
7	0.571	6.340	92.354						
8	0.434	4.824	97.178						
9	0.254	2.822	100.000						

Extraction method: principal components analysis.

Independent variables of SC activities:

Web-Trust: Trust in the web is an important factor of the willingness of citizens to use e-commerce and e-government, among other SC activities. Web trust refers to trust in the municipality's website; it is an ordinal Likert-scaled variable that ranges from 1 (totally disagree) to 5 (totally agree).

SC-Awareness: It is related to how much local citizens are aware of the smart-city concept. The survey asked each citizen if they were acquainted with the smart-city concept. It is an ordinal variable that ranges from "have never heard about that" to "I have heard about it but I do not know much", "I know the concept, what it means and how cities are implementing it", "I am researching about smart cities ideas" and, lastly, "I am planning or implementing one or more smart cities projects".

Independent variables of ICT use:

Age: Age is a scalar and continuous variable. Each participant was asked to report his or her age in the survey.

Education: High_education is a binary variable that takes value of 1 if the individual has reached a tertiary or university degree and zero otherwise (if the maximum education level is lower than tertiary).

Income: Permanent_job is a binary variable that takes the value of 1 if the individual works in a permanent job and zero otherwise. The survey did not collect information on income. However, labor condition can be a proxy of income. We supposed that citizens without a permanent job were in a more vulnerable condition to support connectivity and, therefore, to use ICT than the rest (people with transitory or informal jobs or unemployed people).

Gender: A binary variable that takes value of one if the individual is a man and zero if she is a woman.

4. Results

This SEM does not include a measurement model since there are no latent variables. Due to the limited number of observations, we did not add latent variables but included non-observable variables (such as ICT use and SC activities) by using factorial analysis.

In this section, we test the goodness of fit of the structural model (Table 5). The chi-square test is a test of exact fit that confirms that the structural equation model estimated can explain the theoretical model. Chi-square values near zero show adequate goodness of fit. Based on this model, the chi-square is 6.4 with a p-value of 0.38. As a result, the hypothesis of a perfect correspondence between the estimated matrix and the observations matrix cannot be rejected.

Table 5. Goodness of fit of the structural model. Source: own elaboration based on Stata 14.

Statistic	Value	Description
Likelihood Ratio		
Chi square_ms(6)	6.405	model vs. saturated
p > chi square	0.379	
Chi square_bs(13)	23.281	baseline vs. saturated
p > chi square	0.028	
Population Error		
RMSEA	0.027	root mean square error of approximation
90% CI, lowerbound	0.000	
upperbound	0.139	
Pclose	0.623	RMSEA probability <= 0.05
Size of residuals SRMR	0.038	standardized root mean square residual

On the other hand, we analyzed the root mean square error of approximation (RMSEA) to provide a more sensible approach than the chi-square test. The model fit is good if the RMSEA is lower than 0.05 and does not surpass the lower bound of the 90 percent confidence interval [100]. We could determine that the model fits well because the RMSEA reached a value of zero.

Moreover, there is an overall measure of bad fit known as the root mean square residual index (RMR). This indicator is based on the fitted residuals that are scale-dependent [101]. Therefore, the standard RMR (SRMR) is a more accurate indicator. If the SRMR is lower than 0.05, it indicates a good fit of the model [97].

Once the goodness of fit of the model was determined, we examined the structural model results (Table 6). Based on Table 6, ICT use positively affects SC activities (β = 0.286) (hypothesis 1). Higher levels of ICT use show that citizens are more digitalized and probably have better digital skills than the rest. As the ICT use is greater, citizens can perform smart-city activities. People with lower ICT use will not be able to develop all kinds of smart cities. For instance, citizens without smartphones are less likely to use parking apps or use e-commerce.

Table 6. Structural models. Notes: ns means not significant; ** significant at 5% level. Source: own elaboration.

Variable	Structural Equation SC Activities	Structural Equation ICT Use
ICT use	0.2865806 **	
Trust	0.0063282 ns	
Awareness	0.0492644 **	
Education		−0.0204209 ns
Labor_condition		0.075872 **
Age		−0.0029159 **
Gender		0.0039698 ns

In addition, awareness of the smart-city concept is a significant predictor of performing smart-city activities (hypothesis 2, β = 0.049). The more aware people are of the smart-city concept, the more likely they are to perform smart activities. This result confirms previous literature on the subject [6,48]. Furthermore, trust in the website does not affect SC activities (hypothesis 3). Trust does not significantly explain SC activities. Therefore, we cannot confirm that citizens with a higher level of trust in the website are more likely to buy products and contact local governments. This finding follows Novo Vázquez and Vicente [32] but contradicts most of the literature [6,68].

On the other hand, labor condition and age are two significant factors of ICT use. Citizens with a permanent occupation show greater ICT use than the rest. In addition, the younger the citizen, the more likely they are to use ICT. This result follows previous studies [6,82]. Hence, young citizens with a permanent job will indirectly perform smart activities.

Moreover, the education level is not a significant factor of ICT use, contrary to the literature review provided [52,73,74]. This result is not surprising considering the sample selection bias. It is likely that respondents of an online survey have more digital skills and education than the whole population. On the other hand, gender is also not a significant factor of ICT use or SC activities.

5. Conclusions

The main contribution of this paper is offering some insights into citizens' engagement with smart cities in a city of a developing country, Argentina. In particular, the paper examines the determinants of smart-city activities across individuals from Bahía Blanca, Argentina. Although there is some empirical literature on this subject in developed countries, much less research has been conducted in the developing world where infrastructure and technological conditions are different. The paper also provides some insights useful for city stakeholders and policy makers to properly design smart-city policies and strategies for citizen engagement.

Based on the results obtained, citizens with different sociodemographic characteristics use ICT differently, and as a result, they perform smart activities in a different way, which supports the theoretical framework based on the UTAUT [12]. With respect to practical implications, local governments should focus their attention on performing ex ante promotion of ICT use and bringing awareness to the smart-city concept. Leading to smart cities implies reducing the digital gap in terms of ICT use. Local policies conducted to universalize Wi-Fi and Internet connectivity are not sufficient to amplify ICT use. In addition, a strategy of increasing ICT use would be useful to encourage smart-city activities or initiatives especially those related to environmental issues. Results show the environmental dimension has more weight among smart-city activities in Bahía Blanca. However, some activities are more developed in terms of the smart-city concept than others. For instance, use of public transport is more ICT-assisted than the rest. There is an app that shows real-time bus route and schedule information. On the contrary, there is a lack of digital technologies for a more effective waste management regime.

Moreover, since the smart-city concept is citizen-centric, a strategy to collect citizens' opinions and surveys about the degree of awareness of the smart-city concept should be promoted. In this vein, social media occupies a central role as a tool of communication and interaction between citizens (especially young citizens and those having a permanent job) and local government. Furthermore, this policy to increase smart-city awareness seems to be more efficient than motivating citizens to trust the web which resulted in a non-significant factor for encouraging SC activities. Public authorities should coordinate and cooperate with civic associations to raise trust and facilitate the understanding of smart-city initiatives and projects. This policy follows the international successful experience of global cities such as London, where citizens drive change in the same way as technocrats, businesses or policy makers.

Some limitations of the model are the omission of some variables such as citizens' political interests or political engagement, a sample size that is not large enough and sample selection bias since the survey was conducted on followers of the municipality's social media. Therefore, the results represent that population and not all citizens of Bahía Blanca. With respect to sample size, there is a consensus that larger samples are better than smaller ones. However, in the context of CB-SEM with a simple model to be estimated, non-measurement constructs (latent variables) and no presence of outliers, we are not concerned about the distribution of data. However, a larger sample would be desirable in case the population fraction of interest (the p parameter in the sample size formula) was larger than 50%. Finally, it would be useful to reproduce the survey with other citizen profiles, for instance, conducting a survey on citizens without Internet access or use.

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smart cities

Article

Intrusion Detection in Critical Infrastructures: A Literature Review

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Abstract: Over the years, the digitization of all aspects of life in modern societies is considered an acquired advantage. However, like the terrestrial world, the digital world is not perfect and many dangers and threats are present. In the present work, we conduct a systematic review on the methods of network detection and cyber attacks that can take place in a critical infrastructure. As is shown, the implementation of a system that learns from the system behavior (machine learning), on multiple levels and spots any diversity, is one of the most effective solutions.

Keywords: critical infrastructures; intrusion detection systems; digitization

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1. Introduction

Nowadays, the tremendous development of technology has resulted in the permeation of it in all sectors of industries and infrastructures. This phenomenon is inevitable because modern societies have increased demands of resources to function properly [1]. Due to the extensive use of technology, production can be increased and society's demands handled [2]. These infrastructures are called critical infrastructures due to the significant roles that they play. However, the adoption of technologies in the function of critical infrastructures allows several attacks to exploit the vulnerabilities of the critical infrastructures [3]. The scientific community tries to detect the vulnerabilities, possible threats, and attacks in critical infrastructures to develop security systems that prevent those attacks. One of the most well-known and commonly applied types of attack is the intrusion attack.

Today, countries have to support the increased resources that societies need to remain functional and protect their economies from crises. For this reason, countries rely on infrastructures (assets, industries, and systems) to handle and provide the required resources such as energy, communications, transportation, etc. We characterize as critical infrastructures the group of infrastructures that handle important resources such as power grids, water treatment plants, health services, and any other service which relates to the maintenance of the national economy, health, and security. The most crucial of the critical infrastructures are energy, water, transportation, and communications [4] since these infrastructures handle resources for the majority of operations of modern societies. Moreover, all critical infrastructures are interconnected and interdependent between them and with the sectors of the economy. This strong association between the critical infrastructure sectors means that damage in one service of a sector or even worse the loss of one sector will undoubtedly affect, to the same or a greater degree, the other critical infrastructures.

The large necessity of countries to satisfy the aforementioned requirements caused a rapid inflow of technology in the critical infrastructures to control their operations and maximize their performances. However, these computer systems have vulnerabilities and there are threats to their security. The high rate of cyber attacks in critical infrastructures such as the well-known Stuxnet malware, whose goal was to damage a nuclear power plant in Iran [5], confirms the necessity to develop algorithms, techniques, and software to counteract such attacks.

This research focuses on intrusion detection in critical infrastructures. More specifically, we refer to some of the most common attacks that can be used by the attacker to take the control of a system or cause damage to it. Furthermore, this research contains a description of techniques and models which have been implemented in several intrusion detection systems. The contributions and novelty of the article are:

- We present some of the most used and well-known attacks which could harm a critical infrastructure and cause serious problems and damages;
- We present a short analysis of machine learning and deep learning models and methods which are used in intrusion detection systems, as shown in the literature;
- We conduct several experiments by generating DoS (Denial of Service Attacks) attacks in order to measure packet loss and response delay;
- We evaluate the efficiency of several machine learning techniques against several attacks by using a publicly available dataset;
- We discuss our findings and propose several future research directions.

The rest of this research is organized as follows: In Section 2, we present the related work with critical infrastructures' vulnerabilities and threats, types of attacks, e.g., phishing, SQL injection, etc. Section 3 presents some of the most used intrusion attack methods along with the proposed IDS models from the literature that use either machine or deep learning. In Section 4, we evaluate common DOS attacks using our experimental small network section and we also present the accuracy of common ML techniques against a dataset that includes a wide variety of intrusions simulated in a military network environment. Finally, Section 5.2 includes the conclusions that we draw from this research.

2. Related Work

Critical infrastructures are a significant sector of every country and, for this reason, it is crucial to know which are the threats and vulnerabilities in such systems and possible attacks in order to find a way to prevent and confront them. The research effort presented in [6] gives emphasis on the recent SCADA systems vulnerabilities and recommends ways for the improvement of the security in crucial components of SCADA systems in industrial infrastructures. Additionally, the authors of [7] present the main threats in critical infrastructures, security measures for these threats, and an overview of the categories of cyberattack techniques. In [8], the vulnerabilities and the threats in critical infrastructures are presented, and possible solutions are recommended. In [9], the authors present a review of the existing sniffing attacks, variations of these attacks, and prevention and detection techniques. Moreover, in [10], the authors presented a review of SQL injection attacks. The next paper introduces a survey of phishing attacks [11]. The research article in [12] investigates brute force attacks which aim to find the configurations of an IoT network.

The development of several types of systems to ensure the security of critical infrastructures is the result of the need to deal with the threats and attacks in critical infrastructures such as nuclear power plants [13]. Scholars have proposed a number of technical measures that include technological tools to prevent [14,15], defend [16], detect [17], mitigate [18], and respond to cyber attacks. One way to check if a system is being attacked or an intruder has gained access to it is to detect abnormal behavior. The authors of [19] present the similarities, differences, and limitations of the most used tools for fault diagnosis and cybersecurity. In [20], the authors present a real-time anomaly-based Intrusion Detection System (IDS), which has the goal to detect attacks in industrial process levels of critical infrastructures. In [21], the authors present a survey of data mining techniques adopted to detect anomalies in data or reveal if a system attacked. The authors of [22] introduce a new method for intrusion detection that relies on an incremental clustering algorithm and adopts the DBSCAN algorithm. The authors of [23] propose a new algorithm for attack detection based on an autoencoder. In [24], the authors present a new algorithm to prevent users from phishing. Again, the DBSCAN algorithm is adopted, but in combination with a technique named RD-TIA [25], which clusters the data based on their features as phishing or legitimate, in an effort to increase the accuracy of the algorithm. An extended version of an isolation forest was introduced by the authors of [26] for fault detection in hydroelectric plants. Furthermore, in [27], a deep learning approach using a Long Short Term Memory (LSTM) architecture and Recurrent Neural Network (RNN) aims to create an intrusion detection system. Additionally, ref. [28] studies the comparison between the naïve Bayes classifier and hidden Markov model. Both models are applied to detect spam emails. In [29], a detailed analysis is presented for seven deep learning models such as Convolutional Neural Networks (CNNs), recurrent neural networks, etc., and their performances for intrusion detection are tested. The authors of [30] evaluate some of the most well-known machine learning models for intrusion detection. Finally, the research [31] presents an evaluation of the performance of restricted Boltzmann machines when they were applied to detect intruders in an anomalous network intrusion detection system.

3. Intrusion Attack Methods

Critical infrastructures, as mentioned before, have a crucial role in the functioning of society. Hence, countries try to improve their efficiency and at the same time reduce the time and production cost. However, some of the improvements that the countries apply to achieve this goal have created vulnerabilities in critical infrastructure systems. Hence, these vulnerabilities allow attackers to overcome the security of those systems and gain access to systems with privileges that are not permitted to have. Below, we give a short description of intrusion attack methods.

Brute-force attack: This is one of the most well-known attacks. The operation of this attack type is simple and relies on the computing power of the attacker's computer system. Specifically, the attacker tries to find the correct combination of username and password using an exhaustive search of passwords and usernames. Usually, these attacks use tools to find the proper letters and symbols that constitute the password and the username. An attack that belongs to this category is a Dictionary attack which tries to find the correct username and password searching through a dictionary with common words and phrases that could be the password or username.

Buffer overload: This kind of attack has as goal to overwrite the data that exists in memory to gain control of the system. More specifically, the attacker gives as input to a program—more data than the buffer can handle. As a result, the data overcome the buffer boundary and the additional data stored in adjacent memory locations. The attackers use this attack in order to cause a Denial of Service (DoS) situation or in cases where the memory is well-defined can find the part of memory where the executable code of the system is stored and replace it with their own executable code. In the second case, the attacker can take the control of the system and intervene in the program operation.

Phishing: Phishing is a fraud type attack [32] that tries to delude the users by impersonating someone else, e.g., a company, which the user (victim) trusts. Often in these attacks, the attackers send an email that seems to be legitimate but it is not. The email that the user receives contains a malware file or insecure link. Hence, the attacker hopes the user (victim) will open the attachment file or link and the malware will be installed on the victim's computer. The previous process has the result that the attacker has access to sensitive data such as passwords, usernames, etc. Some of the most common types of phishing listed below are referred to in [33]:

- Clone phishing;
- Spear phishing;
- Social networking on mobile;
- Gaming phishing;
- DNS base phishing;
- Live chat;
- Whaling;
- Filter evasion.

SQL injection: In this type of intrusion attack, the attacker sets an SQL statement as an input in the application's input box in order to gain access to the database. The success of the attack results in the intruder gaining the permission to execute malicious code and harm the database or, even worse, retrieve sensitive data. The risks associated with SQL injection attacks and classification of SQL injection attack types are presented in detail.

Sniffer attack: Frequently, applications transmit packages over the transmission channel to exchange information with each other. A Sniffer attack is a process where the attacker captures, decodes, inspects and interprets the data in these packages. The context of these packages is usually passwords, usernames, etc.—i.e., important data. There are two types of Sniffer attacks, active and passive. In an active Sniffer attack, the attacker interacts with network traffic and the victim can detect if someone spies him and steal packages. On the other hand, in a passive Sniffer attack the victim does not has the ability to realize if someone performs a Sniffer attack because the attacker does not interact with network traffic.

Trojan horses: Trojan horses are programs that contain the attacker's malware file in order to camouflage the malware from the victim's systems defenses. In particular, the attackers use these programs attached to an email or in free downloaded files and programs to insert their malicious code in the victim's computer or to performs any other attack they want. Frequently, trojan horses are used by attackers as backdoors to gain access to a system.

4. Intrusion Detection Systems

Models and algorithms in intrusion detection systems: In this chapter, we present some of the most well-known algorithms and models which can be applied into an implementation of an intrusion detection system (IDS), since the existence of anomalies in data may denote that an intruder has access to our computer system. The models presented below belong to the areas of machine and deep learning.

4.1. Machine Learning Models

K-Means: K-Means is one of the most popular and used unsupervised algorithms. This algorithm tries to minimize the distance of points in a cluster with their centers. The K-Means takes as input a dataset of n data points, i.e., $D = d_0, d_1, \ldots, d_n$ and the number of clusters (K) that we want to cluster the data need to be predefined. The steps of the K-Means algorithm are enumerated as follow:

- From the dataset, D are randomly chosen K data points to be the centers of the K clusters;
- Every data point in D are assigned in the cluster whose centers is nearest to the examined data point;
- After the completion of step 2, we recalculate the center of each cluster only based on the data point which belongs to the cluster;
- When the new cluster's centers are the same as the cluster's centers of previous iteration, the algorithm output the clusters. Otherwise, we iterate from step 2.

The K-Means algorithm is a simple and efficient method for intrusion detection systems because it has the ability to cluster and classify tremendous volumes of high-dimensional numerical data.

Naive Bayes classifier: The naive Bayes classifier is based on Bayes' theorem. The algorithm uses the Bayes theorem which has the ability to calculate the probability of an event occurring when we know the probability of another event that has already occurred. This probability can be calculated using the formula $P(c \mid x) = (P(x \mid c) * P(c))/(P(x))$.

In the above equation, $P(c \mid x)$ is the probability of the target class (C) given predictor (x, attributes), P(C) is the prior probability of target class (C), $P(x \mid c)$ is the likelihood which is the probability of the predictor given class and P(x) is the prior probability of the predictor. More specifically, the posterior probability is calculated constructing a frequency table for each attribute against the target class. Then, the frequency tables are transformed to likelihood tables and used in combination with Equation 1 to calculate the posterior probability for each class. The class with the highest posterior probability is the outcome of prediction. The goal is to predict the correct class for a new instance.

K-nearest neighbors classifier: This algorithm is based on distance/similarity between two data. Specifically, the algorithm classifies a given data x using the following steps: (i) calculate the distance/similarity to all the data based on a function; (ii) sort the outcome of the function in ascending order; (iii) select the top K data of the ascending order; (iv) classify the given data x in the majority class of the top k nearest data. The most common approach of KNN uses the Euclidean distance between the data to detect the top K nearest neighbors.

DBSCAN: The DBSCAN (Density-Based Spatial Clustering of Applications with Noise) is one of the most widely used algorithms for performing clustering. DBSCAN processes the data based on the density that they have and for this reason it belongs in the category of density-based algorithms. The goal of DBSCAN is to assign the examined data points to subsets, i.e., clusters, and detect possible anomalies in the dataset. Assume a set of n points $P = p_0, p_1, \ldots, p_(n-1)$ and each data point p_i,i ϵ [0,n) belongs to some d-dimensional space R $\wedge$ d with d ϵ N. Hence, the DBSCAN, in order to cluster the points that belong in P, uses two parameters: The first is ϵ, which is the radius of the neighborhood around a data point (calculated by a distance metric) that determines the data points that are very close to a data point under consideration. The second parameter is the minimum number of points minPts that p_i has to be connected in its neighborhood to be characterized as a core point.

Decision trees: Decision trees are used for classification processes. A decision tree is designed upside down with the root at the top. It consists of the root node, the interval nodes, and leaves, and all these components are connected with branches. The root node is the beginning of the tree, each interval node represents an attribute/feature, and every leaf represents a class in which the data will be classified. The general step for the creation of a decision tree can be summarized in the following steps: (i) beginning from the root node, which contains the complete dataset, we defined as D; (ii) find the best attribute/feature in the dataset based on an Attribute Selection Measure (ASM); (iii) divide the D into subsets that contain possible values for the best attributes/features; (iv) construct the internal node, which contains the best attribute; (v) the algorithm repeats steps three and four recursively to construct new internal nodes using each time the subsets were created from the third step. The algorithm stops when it cannot further classify the data, abd the last node is the leaf node which contains the classes of the data. The paper [34] contains an anomaly-based intrusion detection system using a CART decision tree.

SVM: Support vector machine is a supervised machine learning classification algorithm which is usually used in IDS systems. SVM is mostly used for binary classification problems and has as goal to find the appropriate hyperplane to maximize the distance between two classes. A hyperplane is a threshold which separates the data into two classes in the best way. In a two-dimensional space, we can image the hyperplane as a line which separates the data into two groups/classes. Hence, SVM makes sure to select the appropriate hyperplane. The data points which are closest to the hyperplane are called support vectors. SVM is used in both linear separable cases and linear non-separable cases. In linear separable cases, SVM plots the data in a n-dimensional space where each feature of data corresponds to one dimension and tries to find the hyperplane that maximizes the distance between the two classes. On the other hand, in linear non-separable cases, SVM introduces two concepts: soft margin and kernel tricks. SVM uses the soft margin approach in an effort to balance the trade-off between the maximization of distance between the classes and the misclassification. Alternatively, SVM adopts kernel trick, where the kernel maps the data into a new higher-dimensional space so that the original non-linear data can be separated.

Isolation forest: This algorithm is used to identify the anomaly data creating decision trees over random attributes. The idea behind the algorithm is that if a forest of random decision trees produces shorter path lengths for some points, then these points are highly likely to be anomalies. The algorithm starts with the training phase, i.e., the construction of the isolation trees. In the first step, a subset of training dataset is selected. The second step of the construction is to randomly choose an attribute r and a random value of this attribute between its min and max values; this value is called the split value. In the third step, a data point is selected and if it has a value smaller than the "split value" for the attribute r, then that point is sent to the left branch. Otherwise, the point is sent to the right branch. The second and the third steps are repeated recursively over the subset until a complete data point isolation, or a predetermined tree depth limit is reached. After the training phase is completed, the testing phase begins. In this phase, every examined data x has to pass over all isolation trees to obtain its path length h(x). The anomaly score for the x is calculated as follows:

$$s(x,n) = 2^{-E(h(x))/c(n)} \tag{1}$$

where

$$E(h(x)) = \Sigma_{i=1}^{t} h_i(x)/t \tag{2}$$

is the average path length of x over t isolation trees and $c(n)$ is the average path length of unsuccessful search in Binary Search Tree.

$$c(n) = 2H(n-1) - (2(n-1)/n)$$

with

$$H(i) = ln(i) + \gamma$$

where γ is the Euler's constant. Generally, if the score is close to 1, then the examined data point is considered as an anomaly. Otherwise, if the anomaly score is smaller than 0.5, it is considered as a normal datum.

4.2. Deep Learning Models

Autoencoders: Autoencoders belong to unsupervised learning algorithms. An autoencoder in its simplest form consists of three components, an encoder, code, and decoder. An encoder is a feed-forward, fully connected neural network which has a goal to compress the input data vector into a latent space representation and encode it in a reduced dimension. The code contains the reduced data vector and sets it as input to the decoder. The decoder has the same structure but inversed, i.e., the first layer of the decoder has the same size as the last layer of the decoder. The operation of an autoencoder starts with the transformation of the input data vector into lower dimensions (encoder). The output of the encoder is stored in the code. After that, the autoencoder tries to reconstruct the initial input from the compressed data vector (decoder). There are many types of autoencoders. There are many types of autoencoders. Below we refer to some of the most used autoencoders types: convolutional autoencoders, variational autoencoders, denoising autoencoders and deep autoencoders.

RNN: Recurrent neural networks (RNNs) are a type of artificial neural network used in cases of processing sequential and time-series data. RNNs take as input a sequence of data and, from them, produce a sequence of outputs. The difference between the classical neural networks and the RNNs is depicted with the presence of a "hidden" state vector which represents the context based on prior input(s)/output(s). This means that the output depends on two parameters; the current input and the sequence of previous inputs. A simple implementation of RNN can be mathematically formulated by the following equations:

$$h_t = \sigma^{(h)}(W^{(h)} h_{t-1} + W^{(x)} x_t) \tag{3}$$

$$y_t = \sigma^{(y)}(W^{(y)} h_t) \tag{4}$$

In these equations, x_t represents the input for the current timestamp t, h_t and h_{t-1} represent the hidden state vector for the current and previous timestamps, respectively. Additionally, the dense matrices are defined by $W^{(h)}, W^{(x)}, W^{(y)}$ and the activation functions are represented by $\sigma^{(h)}, \sigma^{(y)}$. One important characteristic is that the RNNs have the same weight parameter within each layer of the network in contrast with traditional neural networks.

LSTM: Long short-term memory networks are a type of recurrent neural network (RNN) which have the ability to overcome the long-term dependency issue of recurrent networks. Many times, information from previous timestamps have important effects on the output of a model. Due to the ability of LSTMs to remember information for long time, LSTMs are a common choice for time-series models. A classical LSTM consists of four neural network layers. Each LSTM module contains a forget gate, an input gate, an output gate and a cell state. The basic component is the cell state which passes through the repeating modules. The forget gate decides how much of the memory from the previous module should be maintained. The input gate takes into consideration the input at current timestamp, the output of the previous output and combines them with an output activation function. The output gate decides based on the information from the input at current timestamp, the previous output and an output activation function the new output.

1D convolutional neural networks (CNN): CNNs are a deep learning model of feed-forward neural-networks. The most common version of CNNs is 2D CNNs which are applied in image processing. However, in intrusion detection systems they can be more effective than 1D CNNs due to the way they process the data. More specifically, 2D CNNs kernel move horizontally across the data whereas 1D CNNs move vertically. The architecture of CNNs contains two types of layers CNN-layers and MLP-layers. In CNN layers, the 1D convolutions and sub-sampling functions are applied. The list of hyper-parameters below forms the configuration of a 1D CNN.

- Number of hidden CNN and MLP layers;
- Kernel size in each CNN layer;
- Subsampling factor in each CNN layer;
- The chosen pooling and activation functions.

The paper [35] include a survey in 1D convolutional neural networks and present the applications in which they can be applied.

5. Evaluation of Attacks and Detection Mechanisms

The purpose of our section is to generate DoS (Denial of Service) attacks as well as deploy countermeasures against them. Both the attacks and their results will be presented in detail along with some detection mechanisms.

5.1. Attacks

Denial of service attacks aim to deny machine or network resources to certain users by interrupting the services of the host that are connected to the Internet. Such attacks are usually carried out by flooding a machine with unnecessary requests, overloading it, thus preventing the fulfillment of real requests. The scripts are located in Github Source Code (https://github.com/DeStC3/DosAttacksAndCountermeasures, accessed on 25 August 2021).

DDoS attacks are similar, except that incoming requests to the victim now come from multiple sources (distributed), making DDoS attacks more efficient, as it is almost impossible to block all target destinations of the attack.

All of these attacks are usually a derivative of some specialized tools available on many Linux operating systems, or programming language packs that take advantage of the basic principles of network structures and their principles used in an OS to easily generate scripts/attacks. In the simplest variations of these, the technique is usually to send a large volume of packets to the target, while in more complex ones, botnets or tools such as MyDoom or Slowloris can be used, along with sending packets of various protocols.

UDP Flood: A UDP Flood attack floods the target with a large number of User Datagram (Protocol) protocol packages. The general goal is to find random ports of the system, with the result that it repeatedly tries to check the application listening to this port; when none is found, then it sends back, in response, an ICMP package with the information "Destination Unreachable". Obviously in large volumes, network resources start to run out of downloads and send, possibly leading to denial of access. Our version of a UDP Flood follows this simple standard, creating a udp packet and then sending it to the target for a specific period of time. Here, we assume that we already know the IP of the target as well as which ports are open in its system.

SYN Flood: SYN Flood exploits a known vulnerability in the TCP connection sequence, the three way handshake, where a SYN request to start a TCP connection must receive an SYN-ACK response from the host and then send back an ACK response. In such an attack, the request sender sends many SYN requests, but either does not respond to SYN-ACK with its own ACK, or sends requests from fake IPs. In any case, the host system waits for the response to each request, freezing resources until it can not create new connections, leading to denial of service.

To create our own attack, we used Python's scapy package, which is widely used in such cases. Initially, fake IPs are created for a number of packets, as well as TCP packets that are sent. Due to problems using the scapy classes, the addresses and packet data were based on the template, but were inserted directly into the shipment function as it was the only suggested solution that bypassed the object creation problem.

ICMP Attack: Similar to UDP attacks, ICMPs send a large number of echo requests without expecting a response. They are able to consume incoming and outgoing bandwidth, as the system is forced to constantly send back reply packets, delaying it considerably. Our ICMP attack module creates and sends packets, the number of which is user-defined and determines the duration of the attack at a rate of about 10 to 1 (10 packs per second).

Ping of Death: An attack of this type typically involves sending malicious or malicious pings to a computer. The maximum size of an IP packet is about 64 bytes, including the header. However, the data link layer sets some upper limits on size, usually the maximum frame size. So, sometimes a large package is split into smaller fragments when sent, while the recipient reassembles them into a whole, which can create a buffer overflow on the memory pieces assigned to the package by creating denial of service for regular data packets. and allowing malware to be installed. For this attack, which runs on a number of packets, a false IP address is created each time it is used to create the packet before it is sent to the recipient.

5.2. Evaluation Results

The attacks were carried out on two machines which are in the same network, connected to two different router devices. For convenience, the target machine has its firewall turned off while the only processes running in the background are those that monitor the system network devices (nload, netstat, tcpdump) and the process that measures the device network response (ping in the address google.com). At the same time, the fact that the router/modem devices that provide the internet connection have their own firewalls that are locked to the active one by the provider must be taken into account. When the system is in a healthy state, the response time for the ping google.com command is 68–69 ms depending on the execution time with no data loss.

The results of the attacks vary, depending on the type of each (see Figures 1 and 2). The Ping of Death and SYN Flood attacks proved to be stronger, with the former creating a very large percentage of packet loss (80%), which makes sense considering its model as well as the size of the packages shipped, while SYN creates the longer network response delays (up to 500 ms) due to the commitment of network resources to validate the handshake for each TCP packet.

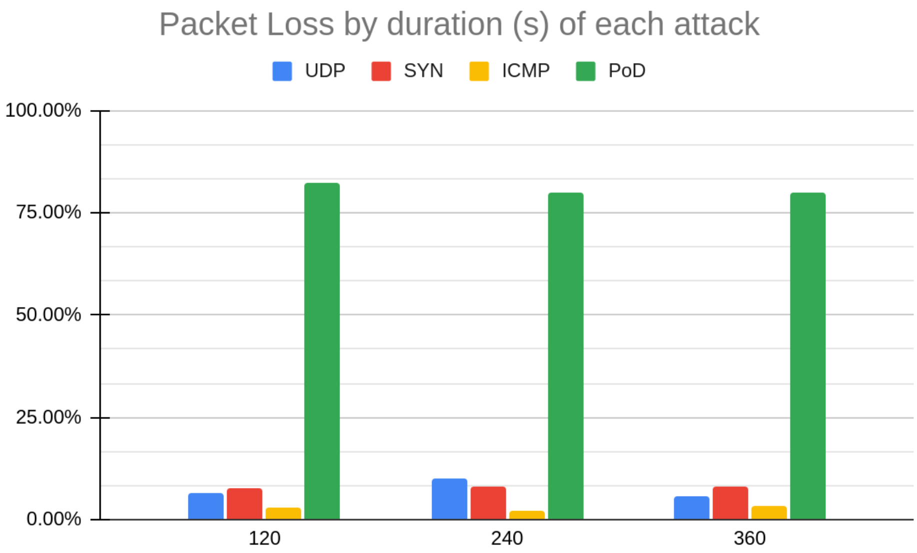

Figure 1. Packet loss during attacks.

The UDP and ICMP attacks proved to be less effective, a phenomenon based on the simplistic model they follow. Of course, the ICMP attack crisis must also be based on the settings of the target machine. A conventional machine (PC) has very few ports listening to the ICMP protocol and more TCP/UDP so most packets do not reach the target effectively. Of course, if the target was a configured mail-server, obviously the configured ports listening in the mail protocol would be higher in number and the attack would be more efficient.

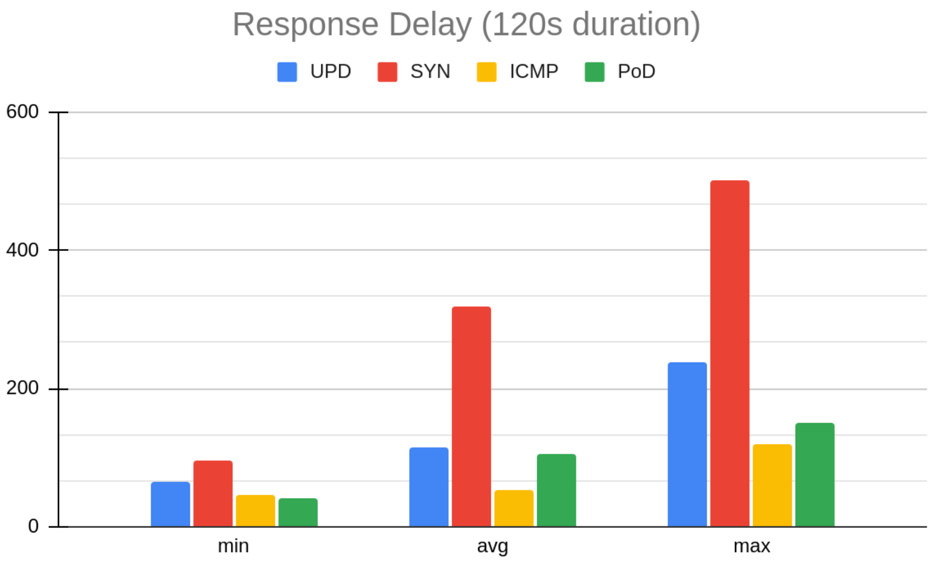

Figure 2. Response delay during attacks.

5.3. Intrusion Detection Systems

Finally, we decided to test several ML methods against several attacks since usually the implementation of an IDS system follows a more dynamic approach using different machine learning models. By choosing a dataset that contains a number of malicious and normal connections to a network, we can train a system so that by inputting a link with the same number of arguments as the dataset, it can decide and inform the administrator of a network for malicious connections and packets. We decided to implement an IDS which will use machine learning to detect suspicious links and test it on the KDD CUP 1999 Dataset (http://kdd.ics.uci.edu/databases/kddcup99/kddcup99.html, accessed on 25 August 2021) We used several algorithms (Gaussian naïve Bayes, decision tree, random forest, support vector classifier, logistic regression, gradient descent) and the findings are shown in Figure 3.

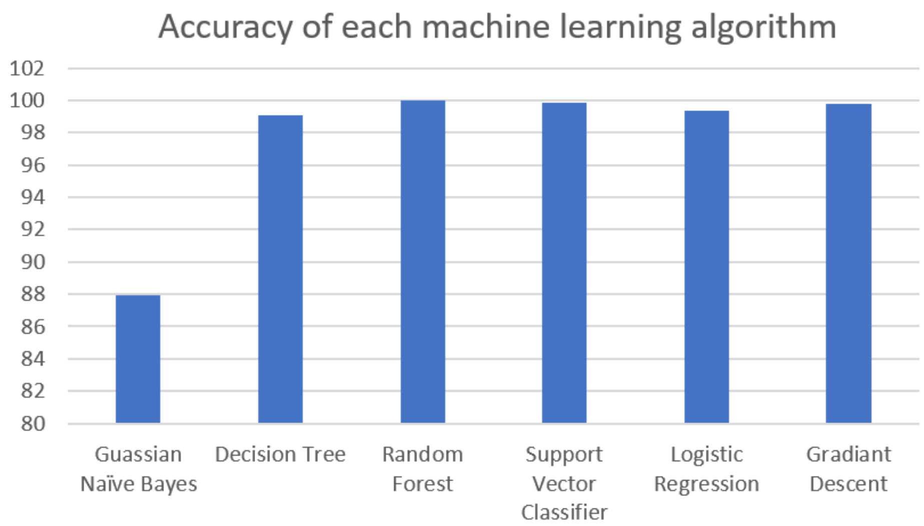

Figure 3. Detection accuracy.

6. Conclusions—Discussion

Over recent years, the need for shielding critical infrastructure has become more and more and more urgent. The security of the product or service produced, through one almost completely automated process, and the elimination of labor opportunity accidents caused by cyber attacks and at the same time their full cooperation with automations and automated processes that take place during the production process perform timely and valid detections of cyber attacks on and cyber intrusion into a critical infrastructure, which is a rather difficult achievement. The most modern studies discuss the application of intelligent algorithms using artificial intelligence (AI), which will be modeled on a set of rules set out in by the managers or the system itself and will evolve through productive processes using machine learning (ML). To date, it has not been established whether theory can meet practice in real conditions of an infrastructure that manages vital products or services and whether, during the production process, different suppliers of devices, as well as sensors of low technical specifications and computing power, are used.

In this research, we investigated intrusion detection in critical infrastructures. Intrusion detection systems are the first line of defense against intrusion attacks. More specifically, we referred to the definition of critical infrastructures and the significant role that they have for a country. Additionally, we mentioned some of the most used and well-known attacks which could harm a critical infrastructure and cause serious problems and damages to it and by extension to the sectors of a country such as the economy, etc. Furthermore, we present a short analysis of machine learning and deep learning models and methods which are used in intrusion detection systems, as shown in the literature. We comprehended the important role of the security of critical infrastructures from cyber attacks and other threats. However there are many challenges in the security of critical infrastructure and generally in cybersecurity. A significant part of the implemented solutions does not focus on unsolved important problems, such as the development of lightweight intrusion detection systems that are able to work in devices with limited power supply, false alarm control, the reduction in false positives and false negatives number and DoS attacks. Moreover, dynamic IDSs that can cope with altering conditions of the system must be further examined and analyzed [36]. Another important future direction in intrusion detection systems is the application of deep learning approaches in combination with a proper dataset to produce valid results.

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smart cities

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Data Co-Operatives through Data Sovereignty

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Abstract: Against the widespread assumption that data are the oil of the 21st century, this article offers an alternative conceptual framework, interpretation, and pathway around data and smart city nexus to subvert surveillance capitalism in light of emerging and further promising practical cases. This article illustrates an open debate in data governance and the data justice field related to current trends and challenges in smart cities, resulting in a new approach advocated for and recently coined by the UN-Habitat programme 'People-Centred Smart Cities'. Particularly, this feature article sheds light on two intertwined notions that articulate the technopolitical dimension of the 'People-Centred Smart Cities' approach: data co-operatives and data sovereignty. Data co-operatives are emerging as a way to share and own data through peer-to-peer (p2p) repositories and data sovereignty is being claimed as a digital right for communities/citizens. Consequently, this feature article aims to open up new research avenues around 'People-Centred Smart Cities' approach: First, it elucidates how data co-operatives through data sovereignty could be articulated as long as co-developed with communities connected to the long history and analysis of the various forms of co-operatives (technopolitical dimension). Second, it prospectively anticipates the city–regional dimension encompassing data colonialism and data devolution.

Keywords: data co-operatives; data sovereignty; data colonialism; data devolution; smart cities; people-centred smart cities; platform co-operatives; COVID-19; blockchain; foundational economy

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1. Introduction: Data Are Not the Oil of the Twenty-First Century

There is a widespread assumption that data are the oil of the twenty-first century [1]. This phrase is the cliche du jour of the tech-smart city industry, which has turned out to be a viral idea shared by marketers, tech companies, governments, regulators, and mainstream media commentators [2–4]. This metaphor portrays public data as passive and untapped resources that have value only when they are extracted [5]. As such, this framing completely removes the individual agency created. Data are created in real time, as individuals click and swipe around the internet [6]. Consequently, what is absent in this mainstream metaphor is essentially that data sharing should be based on trust and social capital that emerged in communities from peer-to-peer interactions. This metaphor, therefore, might work in an economic sense, but it fails to describe what data are as material assets: Data are not oil; they are people. This contrasts with the imperative that data should inevitably be monetised as a one-size-fits-all, business-as-usual solution. By contrast, according to Sadowski et al. [7] (p. 169), 'everyone should decide how their digital data are used—not just tech companies'.

Hence, stemming from the counterinterpretation of the metaphor 'oil equals data', this article suggests an alternative pathway in light of several emerging and promising practical cases to revert surveillance capitalism in smart cities [8]. It illustrates an open debate in data governance and data justice field related to current trends and challenges in smart cities.

Particularly, this feature article sheds light on two intertwined technopolitical notions that are paving the way towards the new UN-Habitat approach called 'People-Centred Smart Cities': data co-operatives and data sovereignty.

It must be acknowledged that these concepts may have been separately already emerging in current discussions about smart cities. Nonetheless, it is equally true that these current debates on trends and challenges about the so-called technocratic smart city approach still need people-centred or citizen-centric overarching, transitional, and experimental frameworks to further democratise citizenship and subvert the path-dependency of surveillance capitalism and sensory power in post-COVID-19 contemporary societies [9]. Smart infrastructures have propelled an industry of smart technology producers to pursue a technological solutionism that often dismisses the multi-layered implications of the platform economy and society, and more importantly, the side effects of datafication over citizens amid the pandemic.

Consequently, this article explores the following research question: How can the potential emerging alternative around data co-operatives be described in parallel with data sovereignty in the post-COVID-19 era, given that both technopolitical notions are intertwined and also explicitly presented as key principles of the new 'People-Centred Smart Cities' approach, coined by UN-Habitat to subvert the negative side-effects on social exclusion and the digital and data divide stemming from existing and hegemonic surveillance capitalism and sensory power [8,9]. The article introduces these two intertwined technopolitical notions alongside the new 'People-Centred Smart Cities' approach as a way to open up new research avenues related to the prevailing nexus between smart cities and data [10].

By describing these intertwined relationships between data co-operatives [11], data sovereignty [12], and the 'People-Centred Smart Cities' approach [13], this article—as shown in Figure 1—addresses several technopolitical discussions by providing a systematic angle and offering a thorough literature review about each of these notions to prove that outlined statements remain valid and relevant [14]. At the end of the article, the city–regional dimension is prospectively anticipated as the next step to be considered in the future development of the 'People-Centred Smart Cities' approach [15]. The article thus aims to offer a framework to describe the present (technopolitical dimension) and anticipate the potential prospective advancements (city–regional dimension) around 'People-Centred Smart Cities' [16].

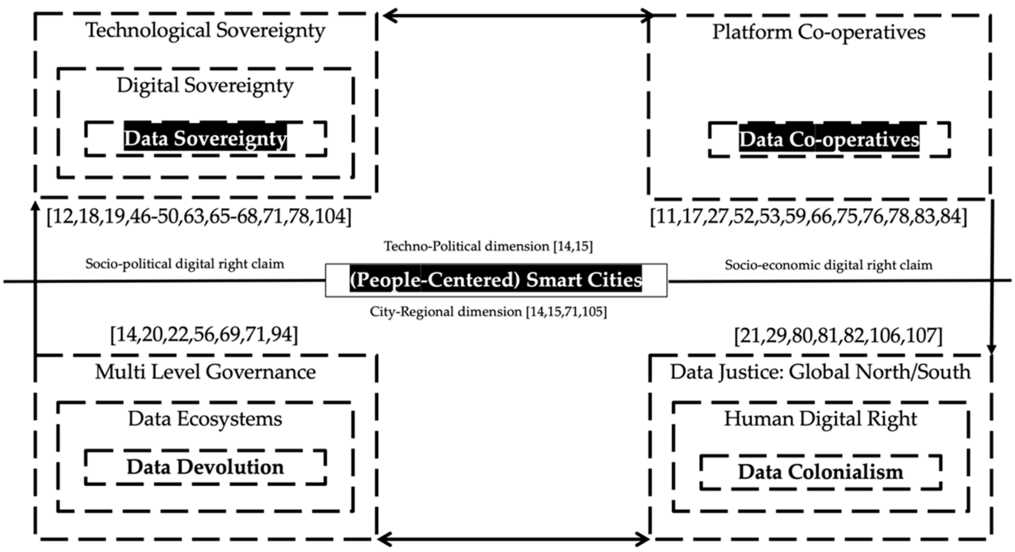

Figure 1. Framework, structure, and literature review: technopolitical dimension of the 'People-Centred Smart Cities' consisting of data co-operatives through data sovereignty.

The article is structured as follows: (i) the Introduction Section presented the rationale and research question; (ii) Section 2 will introduce a discussion around data co-operatives being understood as p2p data-sharing and ownership organisational forms [17]; (iii) Section 3 will describe the main challenges with implementing data sovereignty in a wide range of city–regional contexts that could already claim to have a plethora of digital rights for communities and citizens [18,19]; (iv) Section 4, consequently, blends the data co-operatives (second section) and data sovereignty (third section) in relation to the new formulation coined by UN-Habitat in 2018 as 'People-Centred Smart Cities' by providing a transitional framework to subvert surveillance capitalism; (v) lastly, Section 5 elucidates its main contribution, the novelty of its standpoint, its existing limitations, its inspirational intention, and potential future research avenues to elaborate on the city–regional dimension of the 'People-Centred Smart Cities' approach: data devolution [20] and data colonialism [21].

2. Data Co-Operatives: Socioeconomic Digital Right Claim through P2P Data Sharing and Ownership

Big data—extremely large data sets that may be analysed computationally—originated with the increasingly advanced data collection capabilities of the internet, social networks, the Internet of Things (IoT), artificial intelligence (AI), and sensors [22]. However, this AI-driven algorithmic phenomenon has led to new consequences, such as hyper targeting through data analytics, facial recognition, and individual profiling, received by many with both helplessness and threat, resulting in not-so-desirable outcomes, such as massive manipulation and control via the surveillance capitalism push in the US and the Social Credit Systems in China [23].

In contrast, these societal concerns raised a debate in Europe that crystalised into the General Data Protection Regulation (GDPR) coming into force since May 2018 [24], becoming thereafter a fully fledged inspiration for several data regulations worldwide, including the California Consumer Privacy Act (CCPA) [25]. Yet, while the discussion around data governance has spurred fruitful debates [26], we must confess more nuanced and humble cases, grounded in practice, are required to pave the way. At present, most alternative initiatives stemming from platform co-operatives [27] are based on services provided by Amazon Web Services (AWS), which has revealed the insurmountable hindrances related to how hard is to bypass data extractivism [28–30].

Criticism of platforms that do not adhere to democratic principles has led to the emergence of an alternative proposition, known as platform cooperativism: worker-owned cooperatives based on open-source technologies, which respect ethical working conditions and redistribute to the users the value they have created [31,32].

Amidst post-pandemic uncertainties, COVID-19, and now its Delta variant, have hit pandemic-stricken citizens dramatically worldwide, creating a general risk-driven environment encompassing a wide array of economic vulnerabilities and also exposing them to pervasive digital risks, such as bio-surveillance, misinformation, and e-democracy algorithmic threats. It has become clear how deeply data practices are connected to democracy.

Recently, in this similar vein, Ada Lovelace Institute found a 'data divide' of inequalities in access, knowledge, and awareness of digital health technologies used in the pandemic, such as symptom-tracking apps, contact-tracing apps, and consumer-facing mental and physical health apps [33]. The long-researched 'digital divide' risks transforming into the 'data divide', as data-driven technologies developed in response to the coronavirus pandemic, such as vaccine passports, benefit, represent, and respond to the needs of some people and some groups more than others [34]. Hence, a much more inclusive approach to developing data and data-driven systems is required.

Moreover, we are now witnessing the side effects of an uneven global vaccination and its aftermath [35]. First, the paradox of vaccines passports (supposedly a tool meant to unite the world after lockdown) could now instead end up balkanising it into closed systems where only certain apps are accepted, only certain vaccine brands are welcome, only some documentation is accessible to cross any border and enter a country [36]. Second, the global race for doses has also affected which countries receive which vaccines, resulting in extreme protectionism also known as 'vaccine nationalism' [37,38]. Additionally, third, despite the fact that biometric technologies from facial recognition to digital fingerprinting have proliferated through society in recent years, the benefits they offer are clearly counterbalanced by numerous ethical and societal concerns [39].

The quantity of data, and the resulting power, held by a small number of players (so-called GAFAM: Google, Amazon, Facebook, Apple, and Microsoft) has already created a counterreaction in the European continent [40]. The European Strategy for Data [41] and the Data Governance Act [42] attempt to provide an alternative driven by data sovereignty (whatever it might mean in both European Union as well as worldwide, and particularly in the Global South regarding data colonialism) [21,43]. Recent years have seen an emergence of this notion to claim data ownership in debates on the development, implementation, and adjustment of new data-driven technologies and their infrastructures. Despite its unclear territorial and technopolitical jurisdiction, data sovereignty is exemplified through national data sovereignty in cloud computing, indigenous data sovereignty [44–46], and (more intensively now) patient data sovereignty claims. At the end of the day, the concentration of power around data has been counter reacted by claims stemming from national and political interests, indigenous population's digital rights, and users–consumers–workers–citizens' digital rights [47–50].

In the European continent, data sovereignty has adopted a legal form of data altruism and donation, meaning that individuals can choose the way their data can be stored [51]. However, it remains to be seen how this data sovereignty enables citizen organisations helping us move from the current paradigm of individuals giving up data to large big tech entities to a system based on collective data rights and accountability, complete with legal standards and fiduciary representation. Therefore, this article argues that these co-operative forms known as 'data co-operatives' are a subcategory of the widespread phenomenon called 'platform co-operatives' [17,31,32].

Data co-operatives are member-owned data management storages (e.g., credit unions) with fiduciary obligations to members, where all data usage is for the benefit of members and done only with their consent; it is driven by privacy preservation. Data co-operatives focus on data interactions among citizens and not essentially on the core social value behind them [52,53].

Hence, arguably, the current pandemic and democracy are pervasively related to data governance issues, exposing citizens' vulnerability in a potential surveillance state [54]. However, how can job quality (or worker power) be ensured for all platform workers while also creating further democratic socioeconomic platformised alternatives to revert algorithmic and data politics (data oligopolies) extractivist, business-as-usual hegemonic paradigm [55]? At this stage, consequently, we may also ask whether it is possible to alter existing data governance extractivist models to incentivise the emergence of platform co-operatives [56,57] and data co-operatives [58,59], thereby protecting pandemic citizens' labour and digital rights [60].

Never before has the crucial role that co-operative organisational forms—currently reignited and reinforced through updated reformist paradigms such as the foundational economy paradigm—play in sustaining the social fabric of communities, societies, and economies become so visible to a broad public [31], nor has the need for such organisational forms ever been more evident. Worldwide, in the post-COVID-19 era, neighbourhoods, associations, co-operatives, and civic groups have self-organised to help guarantee access to life-saving resources such as food, health services, IT equipment, clothes, shelter, and psychological support to those in need [61,62]. One such case is the data co-operatives that are being increasingly studied broadly in the academic literature and policy implementations as a base to provide solid research; for example, the recent article published in the journal Sustainability [17] by the author of this article shows a deep examination of more than 159 platform and data co-operatives. The present article stems from that empirical examination by offering a novel framework to connect the potential formation of data co-operatives with the necessary fertile sociopolitical ecosystem enabled through a certain degree of data sovereignty for citizens and communities [63].

At present, there are several data co-operative such as Salus, Driver's Seat, MyData, LBRY, dOrg.tech, and Polypoly, which are so far intensively implemented.

Salus Coop is a non-profit data co-operative for health research (referring to health data and lifestyle-related data more broadly, such as data that capture the number of steps a person takes in a day), founded in Barcelona in September 2017. Salus aims to create a citizen-driven collaborative governance model and management of health data. It legitimises citizens' rights to control their health records while facilitating data sharing to accelerate public research innovation in healthcare.

Driver's Seat is a data co-operative founded in 2019 in Milwaukee, Wisconsin. Driver's Seat is a driver-owned co-operative that empowers ride–hail drivers and on-demand delivery workers to use shared data ownership to make the gig economy work better for themselves and the communities they serve. Driver's Seat has developed an app to collect data from on-demand drivers to (i) return it to drivers in the form of actionable insights to optimise their earnings and (ii) sell the collected data to local and state government to use in planning and design, policy creation, and enforcement.

MyData is a health data co-operative started in 2015. MyData.coop enables citizens to securely store, manage, and control access to their personal data by helping them to establish and own national/regional non-for-profit MyData co-operatives. MyData co-operatives act as the fiduciaries for their members' data. MyData offers a platform on which user members can securely store copies of their medical records, genomes, and mHealth data. Members might decide to give their physicians access to all personal data through the platform. In contrast, a not-for-profit cancer research institute could be given access to only medical and dietary information. Members could deny access to a for-profit drug company. Members' revenues from the sale of data are donated to public research.

LBRY states 'we think users should own their content (and their privacy) instead of handing it over to a corporate giant and their advertising buddies. If you think we are paranoid, there are dozens of examples of companies abusing users and acting against their interests. It is not paranoia if they are actually out to get you'.

dOrg.tech currently transitioning to a data co-operative, is a full-stack development collective that works with industry-leading projects in Web3 by using a decentralised manner by builders worldwide through smart contracts, blockchain, and Ethereum.

Polypoly is a data co-operative that ensures that personal data no longer leave a device, whether mobile phone, computer, or web-enabled toaster. PolyPod, the member of the co-operative, has a private server that stores his/her data, and they are controlled by him/her.

Moreover, stemming from the author's previous empirical research on data co-operatives [17], and specifically as empirical evidence of this article, below in Table 1, is the full and updated list of 31 data co-operatives identified through the data set by the Platform Cooperativism Consortium [64].

Table 1. Data co-operatives: empirical evidence.

	Data Co-Operative	www *	Sector/Activity
		Intensively Implemented	
1.	Salus. Coop	www.saluscoop.org	Health
2.	Driver Seat	www.driversseat.co	Transport
3.	MyData	www.mydata.org	Data management
4.	LBRY	www.lbry.com	Blockchain-based file sharing and payment network
5.	dOrg.tech	www.dorg.tech	Full-stack development collective
6.	Polypoly	www.polypoly.org	Personal data storage
		Being Developed/Prototyped	
7.	Boniffi (former CULedger)	www.boniffi.com	P2P services network of verifiable exchange for financial cooperatives
8.	Cozy	www.cozy.io	Personal data storage
9.	Mydex	www.mydex.org	Personal data storage
10.	OpenAQ	www.openaq.org	Non-profit organisation empowering communities to clean their air by using open air quality data
11.	OpenHumans	www.openhumans.org	P2P knowledge production
12.	Decode	www.decodeproject.eu	Tools to keep personal data private
13.	Decidim	www.decidim.org	Free open-source participatory democracy for cities and organisations
14.	MetaDecidim	www.meta.decidim.org	Participatory process
15.	OpenDataManchester	www.opendatamanchester.org.uk	It is a not-for-profit formed a diverse group of open data advocates in 2010 that supports organisations to release data and helps people use it
16.	TheGoodData	www.thegooddata.org	This co-operative is now on hold
17.	Health Bank	www.healthbank.coop	App with personal health history
18.	Ubiquitous Commons	www.ubiquitouscommons.org	Commons-driven tools
19.	Data Commons Cooperative	www.datacommons.coop	Data co-operative running community-driven projects
20.	Waze	www.waze.com	Transport
21.	Bank of the Commons	www.bankofthecommons.coop	Cooperative banking service whose aim is to support alternative economy projects and social movements on both a global and a local level
22.	Market. Fair	www.market.fair.coop	FairCoop's online market.
23.	Find. Coop	www.find.coop	Directory of alternative economic projects in North America
24.	Gisc.coop	www.gisc.coop	Farmer owned national data cooperative headquartered in Lubbock, TX.
25.	Moedaseeds	www.moedaseeds.com	Blockchain-based digital banking, payments, and microcredit services
26.	OpenCreditNetwork	www.opencredit.network	Cooperative banking
27.	Patient Critical Co-op	www.patientcritical.com	Canada's only patient-owned and steered healthcare advocacy and education co-operative
28.	Privacy Co-op	www.privacyco-op.com	Data justice cooperative
29.	RChain	www.rchain.coop	Blockchain platform and key social coordination technologies
30.	RobinHoodCoop	www.robinhoodcoop.org	Generic coop
31.	SomConnexio	www.somconnexio.coop	Cooperative phone operator

* accessed on 1 September 2021.

Notably, the aim of this article is not to provide empirical data or any kind of experiment on this topic. Instead, this feature article aims to open up new research avenues by elucidating how data co-operatives (as a subcategory of platform co-operatives) [17] require a certain degree of data sovereignty as a technopolitical strategy to allow for being co-developed with local and regional communities. These communities show a long history and intrinsic co-operative traditions as a natural way to feed the new approach coined by UN-Habitat called 'People-Centred Smart Cities'.

3. Data Sovereignty: Sociopolitical Digital Right Claim for Communities and Citizens

According to Pentland and Hardjono, with 100 million members of credit unions, the opportunity for community organisations to leverage community-owned data is massive [52]. Nonetheless, data sovereignty has been used so far for advocacy, and it seems now more a claim than something that can be easily achieved in practice [65]. In fact, data flows are complicated and not easy to be tracked, as we are witnessing in the aftermath of COVID-19. Furthermore, the legal rights associated with data flows depict a complex set of boundaries when it comes to ownership of data. While there exists a remarkable degree of harmonisation and coherence around data protection's core principles in key international and regional agreements and guidelines, there are diverging implementation practices around data flows. In addition, Hardjono and Pentland advocate how financialising personal data, data co-operatives might emerge at the community level [53]. However, this is rather unlikely without any means of controlling data flows and ensuring data sovereignty for members of specific local communities [66].

Data sovereignty involves, or can be identified with, the control of data flows with national jurisdiction [67]. Nevertheless, as these studies themselves indicate, further systematic analyses are needed for questioning the generalisability of data sovereignty [68]. As such, data sovereignty presents a broad variety of themes, including the authority of national governments over data stored in domestic or foreign clouds, as well as indigenous-, community-, or nation-building groups, and patient data sovereignty over health data. The linkage between data co-operatives and data sovereignty lies in the fact that data co-operatives may rely considerably on the right and the degree of effectivity of this sovereignty in relation to their citizens' own data. Aside from this path dependency, the effectiveness of data sovereignty requires the willingness of co-operatives' members to donate their data altruistically. Consequently, this article acknowledges that the 'People-Centred Smart Cities' approach, led by UN-Habitat and inspired by principles of the foundational economy [31], may need to advocate for implementations of data ecosystems worldwide [20,69]—at the city–regional level through multi-level governance policy frameworks and data devolution schemes—to allow certain degrees of autonomy or data sovereignty in communities facilitating the creation of data co-operatives.

Hence, data co-operatives being a voluntary collaborative pooling by individuals of the personal data for the benefit of the membership of the group or community, present several shortcomings as well. Some advocates may see only the data pooling process as a purely technical process, whereas it is clearly a social–communitarian process based on trust and related to social capital. As Loukissas argued, all data ultimately are local; thus, the territorial and local dimensions of this discussion cannot be overlooked. It is key that the ability to balance the world's data economy inevitably depends on the fair interplay among stakeholders [70]. Consequently, it is clear that citizens and workers by themselves have no direct representation, yet consumers who were able to control their data would be a force to be acknowledged when their data would be localised/territorialised in certain data ecosystems [71].

Communities using their own data require decentralised and federated data ecosystems arranged by sectors (health-related data, environmental data, transport and mobility data, energy, consumption data, etc.) being clearly located in specific places, allowing to interoperation with each other, unless members of the community decide not to do so. This would mean owning data and being sovereign about their own data members produce.

This article suggests that data should be co-operativised among members (citizens or workers) of communities. For co-operativising data, this article considers that localising data require at the same time trans-local federated data ecosystems (via blockchain) to scale up the potential of the co-operative action and outreach [72]. Citizens in communities will thus be using their own data, gathered in local repositories owned by them while contributing to data sharing if they would allow. This notion has been defined in the literature as 'data devolution' [71].

Actually, this is the case of Eva.coop, a Montreal-based data co-operative [73,74]: They provide an infrastructure for groups but without accessing local data about passengers. Some data are shared, however. Eva.coop is built on the EOSIO blockchain protocol as a way to show how the co-operative model could mark a new blockchain-based iteration of the sharing economy driven by decentralised system that respects user privacy and fits into local needs [75]. Local data matters, and Eva might have shed light on the way to follow. Local communities have more input, drivers are treated more fairly, riding members maintain their privacy, and are comforted by a locally supported app. Could this third generation of blockchain be a protocol from which to scale up a federated co-operative commonwealth based on structured data ecosystems by economic sectors (transport, healthcare, education, etc.) [76]?

Obviously, there are also obstacles. Communities will have to be educated about co-operative principles. Beyond that, such local data co-operatives may not be easily replicated because they are rooted in their contextual and territorial critical factors. Over time, governance within such co-operatives may also become a challenge: they could erode or be destroyed as some may people join, and others may have to be asked to leave. Therefore, this article recognises that data co-operatives cannot be seen as a one-stop shop that will fix all the ills of platform capitalism. This article suggests data co-operatives as an approach that is part of a toolbox that also includes efforts such as Solid [77], but also unions, neighbourhood associations, regulatory intervention, public ownership, and hybrid among these forms.

This article acknowledges, therefore, the limits of the framing of data co-operatives through data sovereignty. What does data sovereignty or ownership of a digital platform as a data co-operative mean when most communities and groups have so far relied on commercial upstream services? What does it mean when data co-operatives are using proprietary software and the cloud services of large tech companies? An alliance of co-operative data services offered from the margins might gradually overcome commercial upstream services by decentralising data governance models at the local level. At the very least, smart cities, not only communities in the Global North but also in the Global South, should be at the table when discussing legal instruments of data co-operatives. Co-operative scholars, historians, and leaders of organisations, especially from LGBTQI communities, indigenous people, minority languages' activists, and defenders of the right to decide in stateless nations, should be part of the conversations about legal templates and technological infrastructure for these data institutions [78,79]. An alliance of data services offered from the margins might help to diversify the digital economy gradually [61]. Understanding the thrill of pioneering legal or technical models for novel data management is very much required to set up data co-operatives. Nonetheless, proposals for data co-operatives should be co-developed with co-operative practitioners and connected to the long history and analysis of the various forms of co-operatives. In summary, data co-operatives will need to be anchored in local communities shaped by their specific cultural traits and features as a way to resist data colonialism [80–82].

There are probably few policy aspects worth considering for scaling up data co-operatives [83,84]: First, there is a clear need to reactivate civil societies for experimentation, paying special attention to city–regional unique features as clear sources of community-driven sovereign data to foster the creation of locally based data co-operatives. Second, it is still likely necessary to provide enhanced training about the scope and functioning of co-operatives to enable fertilisation of data co-operatives. Third, procurement and public incentives are required to push ahead, enhance, and reinforce platform and data co-operatives beyond marginal experiments aligned with data donation and altruism.

Finally, initiatives around data co-operatives need to find their own strategic pathways amidst digital and social economy policy agendas in each regional context worldwide.

4. People-Centred Smart Cities: Transitional Framework to Subvert Surveillance Capitalism and Sensory Power

Against this backdrop, since 2018, UN-Habitat has been promoting the newly established smart city trend through its flagship programme entitled 'People-Centred Smart Cities' [13]. According to the UN-Habitat, 'digital technologies, depending on their use, can be a force that widens social gaps or reduces them'. Consequently, UN-Habitat aims to reduce digital inequality, building digital capacity, and ensuring that new technologies are a force for good. Insofar as UN-Habitat is supportive with the UN as the essential platform where all relevant actors, including governments, along with companies, technical experts, and civil society can come together to share policy expertise, and explore the possibility of a 'Global Commitment on Digital Trust and Security' (p. 1).

The 'People-Centred Smart Cities' programme flagged the necessity of bringing end users, citizens, and people back to the forefront of the analysis about smart cities. The recent awareness of the technopolitics of data in cities has led to a gradual, resilient, and joint urban reaction—pushed forward by the aftermath of the pandemic and exacerbated by the algorithmic crisis—which has put city governments at the forefront of safeguarding citizens' digital rights and communities' data sovereignty through the active procurement of data co-operatives, as was shown in the previous section. This awareness in cities has been supported by a policy reaction resulting in intensive discussions among cities and their urban stakeholders about ways to tackle the pandemic crisis by raising debates around the importance of data sovereignty. UN-Habitat is, therefore, currently amplifying an urban response that is gradually sparking an updated institutional, alternative, and experimental transitional version to the hegemonic smart city concept [16], as anticipated by the academic literature in the past [85,86]. UN-Habitat defines the 'People-Centred Smart Cities' approach as 'a way of re-thinking about the application of digital technologies by cities and communities that is grounded in human digital rights and principles of inclusion, hereby ensuring that no one and no place are left behind' [13] p. 1. According to this definition and further ongoing implementations on this reconceptualisation, this article elucidates that this new brand seems to foster an active role for end users, citizens, and people in communities as decision makers rather than mere data providers [26].

In a similar vein, the UN strategy on sustainable urban development highlights digital transformation and new technologies as one of four frontier issues that require a special, coordinated response. According to the New Urban Agenda, the adoption of a smart city approach should make use of opportunities from digitalisation, clean energy, and technologies. However, UN-Habitat acknowledges that in the absence of public oversight and accountability, data on citizens and communities are being extensively recorded, often by private companies, thereby raising concerns around privacy, surveillance, data sovereignty, and individual autonomy. In fact, the Office of the High Commissioner on Human Rights is working on understanding exactly how international human rights as digital rights can be applied in cyberspace and for smart cities.

In response to how digital literacy has been overlooked in many smart cities so far and closely following the contours of the 'People-Centred Smart City' debate, there has been a counter-reaction fuelled by the interplay of certain multi-stakeholders, highlighting the need for an ethically transparent data-driven society that reinforces the digital rights and data sovereignty of citizens through accountable data ethics [87,88]. This is the case of the Cities' Coalition for Digital Rights (CCDR), a city network established in 2018 by the local authorities of three main global smart cities: Barcelona, New York City, and Amsterdam [89]. Alongside this reaction, evidence-based decision making at local levels is needed to encourage the real and doable implementations of Sustainable Development Goals (SDGs) through local stakeholders.

In response to the research question of this article regarding how we can describe in parallel the potential emerging alternative around data co-operatives through data sovereignty, given that both technopolitical notions are intertwined and are explicitly presented as key principles of the new 'People-Centred Smart Cities' approach (coined by UN-Habitat to subvert the negative side effects on social exclusion, digital, and data divide stemming from the existing and highly hegemonic surveillance capitalism and sensory power), UN-Habitat acknowledges the following flaws on smart city implementations so far: (i) lack of awareness of longstanding smartness in cities; (ii) overreliance on the optimisation narrative; (iii) lack of evidence and key performance indicators (KPIs); (iv) failure to engage residents in a meaningful manner; (v) privatisation of public infrastructure and services; (v) lack of transparent and structured data governance [16,90–93].

Hence, the 'People-Centred Smart City' approach was coined to renew the main principles of the smart city. The aim is to empower local governments to take a multi-stakeholder approach to digital transformations that realise sustainability, inclusivity, prosperity, and human digital rights for the benefit of all [94]. There are three key features of this approach for smart city local governments that resonate with the notions presented previously on data co-operatives and data sovereignty. The first feature is that technology should be evaluated for its ability to address the needs determined by the people it serves, and, by extension, data are considered assets in the hands of citizens. The second feature refers to the fact that citizens should be empowered to intervene and shape interventions in collaboration with the government or establish their own initiatives by using shareable data. The third feature addresses digital rights as the core that should lead to digital inclusion at all levels in smart cities [95,96].

Stemming from the formulation of the 'People-Centred Smart City' approach, this new formulation elucidates the importance of autonomy and sovereignty about citizens' data and suggests p2p mechanisms to manage, store, and even own data; this in itself may be a direct invitation (i) to consider data co-operatives as a feasible, doable, and desirable organisational forms and (ii) to empower communities and citizens through their digital right to claim their own data sovereignty. Therefore, in building 'People-Centred Smart Cities', local governments are entitled to protect digital rights, as well as tackle data and digital divide in communities from exclusive private sector data ownership or, in its most extreme form, surveillance capitalism and data extractivism and colonialism [29,81]. Data sovereignty claims to (i) enable equitable access to information and communication technology (ICT), (ii) open channels to harness residents' capacity and knowledge regardless of demographic, and (iii) support residents' development of smart city solutions on their own terms.

In conclusion, taking a 'People-Centred Smart City' approach means redefining the classic 'smart city' approach along these parameters by including explicitly the notions of data co-operatives and data sovereignty—namely, (i) orienting data co-operatives towards reflecting and serving the interests of residents, rather than focusing primarily on efficiency, top-down control, and the narrow interests of the technology industry; (ii) building inclusive, meaningful, and deliberate citizen participation, including extensive consultation, collaboration, and co-production; (iv) creating a citizenship framework underpinned by civil, social, political, symbolic, and digital rights based on data sovereignty for citizens and communities [97]; (v) protecting and leveraging digital public assets, including data, for the common good; and ultimately, (vi) focusing on projects and programming that make equity, democracy, and social justice key aspects of smart city initiatives [98].

5. Conclusions

The main contribution of this article is that of opening new research avenues by suggesting an alternative pathway to subvert surveillance capitalism and sensory power in smart cities. In doing so, this article illustrates an open debate in data governance and the data justice field related to current trends and challenges in smart cities [99]. Although there is an extremely preliminary development of this new pathway, this article sheds light on two intertwined notions that are paving the way towards the new approach about smart cities—data co-operatives and data sovereignty—coined recently by UN-Habitat as 'People-Centred Smart Cities'.

The novelty of this article lies in the fact that, so far, smart city literature has seldomly addressed technopolitical aspects, including p2p data sharing and ownership organisational forms (e.g., data co-operatives) in relation to the current increased awareness of data sovereignty as possibly one of the most urgent challenges for post-COVID-19 smart cities. The research literature on co-operatives and sovereignty existed very much at the core of the debate about the technocratic mainstream and hegemonic approach of the smart city. 'People-Centred Smart Cities', as the main term popularised by UN-Habitat, may well provide a turning point in the understanding, meaning, and practices around the so-called smart city concept. Acknowledging the limitations related to the topics addressed, this article is, therefore, novel in terms of providing a sequence around previous research on data and platform co-operatives and technopolitical awareness of data in smart cities by advocating the need for serious consideration of data sovereignty, not only in its technopolitical dimension but also in its city–regional dimension.

Discussions on smart cities and recent literature on data governance and [100,101], more broadly, digital economy, society, and citizenship are already employing concepts, including data co-operatives [11,17,52,53,66,78,83,84], data sovereignty [12,18,19,46,49,50,65,68,78], data colonialism [21,80,82], and data devolution [14,20,22,69,71] (Figure 1). This article articulates this intertwined relationship by suggesting a more distinct interrelated conceptual angle that could be seen as an emerging trend in the field of smart cities [102].

In this vein, the new research line addressed in this article may evolve towards emerging horizons that stem from the current literature review and potential solutions that will probably lead to new research ideas around the unexplored city–regional and territorial dimensions so far. Despite the fact that data co-operatives are an emerging field of experimentation, there is still a necessary policy push worldwide to force them to leave the marginal or niche experiment zone. Data co-operatives are still not cemented in community-led structures and dynamics. Instead, data co-operatives may well exist because data altruism and donation are gradually taking over and opening up new possibilities for socially oriented data scientists and activists [103]. Regarding data sovereignty [104], it is equally true that data sovereignty—although interchangeably used sometimes as digital or technological sovereignty—is gaining momentum. Nonetheless, beyond the widespread assumption that these terms are broadly used, academic literature is scarce and inconclusive about the city–regional and territorial dimensions of sovereignty. As such, in several recent conferences such as 'Data Justice Lab 2021', data sovereignty seems to be reserved only for these 'global' issues by 'global' minorities; surprisingly assuming that linguistic minorities or stateless nations claims on their digital rights, particularly in Europe, are not 'global' enough as to be considered properly discussed in these academic discussions [61]. This article attempts to contribute to this necessary debate insofar as the European context is probably at stake at the moment without clear indications about how to federalise data through ecosystems, and, beyond the scope of this article, more importantly, how to federalise digitalisation through data ecosystems within and across nation-states [79,105]. This is the novelty to which this article contributes.

Thus, in the upcoming years, academic discussions and technopolitical implementations around data co-operatives and data sovereignty will evolve towards two main streams embedded in the city–regional (or territorial) dimension. Potentially, then, 'People-Centred Smart Cities' will inevitably need to consider and thus merge and gradually assemble both dimensions (Figure 1) [105], taking into account the following observations:

First, there is a need to establish data ecosystems at the city–regional level by ensuring a certain level of data devolution, which means bringing data back to citizens [14,71]. Consequently, data flows and sharing policy will be needed among different institutional layers through multi-level governance frameworks [20,69].

Second, in the post-COVID-19 era [10], data colonialism will disclose increasing differences among the Global South and the Global North [106,107]. Hence, the 'People Centred Smart Cities', as a newly branded concept coined by UN-Habitat, justifies this new approach for launching a new urban paradigm for both the Global North and the Global South, by which digitalisation and datafication require gradual decolonisation [108]. Indeed, it is noteworthy that as a result of the forthcoming new data regulation called Personal Information Protection Law (PIPL) in China, emulating the goals of the so-called GDPR and being effective from 1 November 2021, data sovereignty will conquer onwards an increasing amount of policy debates and discussions around the globe, sparking an insightful diversity of reactions [109].

This article has described in parallel the potential emerging alternative around data co-operatives through data sovereignty by presenting both. Consequently, the article offered a narrative to revisit and tackle the negative side effects on social exclusion, digital, and data divide characterised as clear consequences for communities and citizens of surveillance capitalism.

It goes without saying that the article attempted to address an ongoing debate on data and smart cities by providing existing practices and conceptualisations around data co-operatives, data sovereignty, and 'People-Centred Smart Cities'. As a way to open up the scope of the debate and enhance the plethora of options around it, it would be useful to clarify that this article offers an alternative view: It is far from the intention of this article to articulate the content as a dogmatic corpus. Instead, it offers ways to ensure inclusiveness by enriching the academic and policy discussions onwards.

Finally, it would be worthwhile if this article could be used as an inspiration for other conceptualisations and collection of cases worldwide regarding data co-operatives and data sovereignty by adding evidence to the prevailing nexus between smart cities and data.

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smart cities

Article

Optimal Planning of Electrical Appliance of Residential Units in a Smart Home Network Using Cloud Services

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Abstract: One of the important aspects of realizing smart cities is developing smart homes/buildings and, from the energy perspective, designing and implementing an efficient smart home area energy management system (HAEMS) is vital. To be effective, the HAEMS should include various electrical appliances as well as local distributed/renewable energy resources and energy storage systems, with the whole system as a microgrid. However, the collecting and processing of the data associated with these appliances/resources are challenging in terms of the required sensors/communication infrastructure and computational burden. Thanks to the internet-of-things and cloud computing technologies, the physical requirements for handling the data have been provided; however, they demand suitable optimization/management schemes. In this article, a HAEMS is developed using cloud services to increase the accuracy and speed of the data processing. A management protocol is proposed that provides an optimal schedule for a day-ahead operation of the electrical equipment of smart residential homes under welfare indicators. The proposed system comprises three layers: (1) sensors associated with the home appliances and generation/storage units, (2) local fog nodes, and (3) a cloud where the information is processed bilaterally with HAEMS and the hourly optimal operation of appliances/generation/storage units is planned. The neural network and genetic algorithm (GA) are used as part of the HAEMS program. The neural network is used to predict the amount of workload corresponding to users' requests. Improving the load factor and the economic efficiency are considered as the objective function that is optimized using GA. Numerical studies are performed in the MATLAB platform and the results are compared with a conventional method.

Keywords: energy storage; electrical appliance; home area energy management system (HAEMS); neural network; renewable energy resources; smart cities

1. Introduction

Electricity/energy management systems involve a series of related programs used by the operator of the electric grid and its customers to improve the efficiency and performance of the power/energy systems [1,2]. In this way, both the electricity supplier and the consumer will benefit more [3]. The energy management helps to obviate the requirement of constructing new/costly power stations on the production side, and reduces the energy price and related penalties for consumers on the consumption side.

A significant portion of the energy produced by distributed and renewable energy resources is consumed locally, which improves the efficiency of electric grids. However, the control/management of the local inverter-interfaced energy resources and consumers is a matter of concern that can be intelligently managed in the context of smart grids and micro-grids [4,5]. Current and future smart grids play important roles in delivering electricity from suppliers to industrial, commercial, and residential areas efficiently, reliably, and securely [6–8]. With the help of such smart grids on a micro/macro scale, the use of energy is reduced for families and business owners, and more renewable energy resources are integrated into grids.

Residential loads, as the major portion of electric power demand, have been considered in energy management programs [9,10]. Home energy consumption depends on the physical characteristics of the building, such as its geographical location, design, and construction [11]. Also, it is affected by the efficiency of the electrical appliance, the behavioral pattern, and the cultural background of its occupants [12]. About 10–30% in electricity consumption can be reduced just by changing the behavior pattern of residents [13].

The home area energy management system (HAEMS) is an emerging technology for the realization of future smart homes, benefiting from several areas of computation/communication, including amplitude measurement intelligence (AMI), internet domain, and home area networking (HAN) [14]. HAEMS receives network signals and sends control actions to smart devices. This system monitors/modifies the residents' consumption habits until control decisions become independent of HAEMS. It uses different solutions for different users, such as energy-saving and a comfortable lifestyle. HAEMS aims to produce an optimal solution for combining the weight of goals in a time horizon based on a series of user inputs and control actions [15].

Digital two-way communication between power companies and conventional home appliances facilitates the joint operation of intelligent energy management systems. Advanced smart grid components enable users to improve their energy efficiency and to take part in different programs such as {time-of-day} pricing to reduce their energy costs [16,17]. Many electricity scheduling schemes have been proposed in both indoor and residential areas [18]. An optimization algorithm has been proposed to minimize the cost of users' electricity bills by considering their convenience level as problem constraints [19]. However, the authors have scaled the waiting time limits as per the user's convenience. Some methods are proposed based on game theory for optimal energy management in residential buildings and that justify their general suitability by giving several reasons [20]. Similarly, a home appliance sharing algorithm for home load scheduling is introduced in [21] to minimize power consumption costs. Several aspects of smart homes, including creating local access to energy and smartening the components of the house, improving the energy efficiency of the house, actively monitoring and strengthening the home environment, and the social welfare of the residents in the smart home have been considered [22]. According to studies, in recent decades, researchers have considered optimizing energy consumption in the presence of different loads and using different technologies to reduce common costs or to improve the quality of the delivered electric power/energy [23]. The methods used to design an intelligent energy management program can be divided into artificial intelligence and classical mathematical methods:

- Artificial intelligence and heuristic methods may reach a local sub-optimal point due to the local search for problem-solving or the use of expert experiences [24]. Fuzzy control methods, [25,26], genetic algorithm (GA) [27], and particle swarm optimization (PSO) [28,29] are examples of this category. The performance of these methods depends on the user experience and is weak against system changes and probability.
- Classical methods, on the other hand, are more complex but offer optimal and reliable solutions. For example, the linear integer linear programming method [30] has been used to optimize distributed generation sources' energy production and consumption to reduce common costs.

Further, smart apartments equipped with wind and solar-type generation units, storage batteries, and electric cars can be connected to the network; however, the important factor of common welfare and comfort has not been considered [31]. Also, a general model is used for building energy management that can optimize and compromise user convenience and the minimizing of energy costs. In this paper, the increasing use of grid-connected hybrid vehicles and their positive effects, such as not needing to consume fossil fuels and the use of energy stored in the vehicle to meet home consumption loads, have been considered. It is noteworthy that charging the battery of a significant number of vehicles is a big risk for the smart grid [32]. Simultaneous charging of batteries may cause a sudden overload of the distribution grid [32]. Especially if it coincides with the peak consumption time. This concurrence can cause congestion of the distribution grid. Thus, with proper planning, the destructive effects of electric vehicles can be reduced considerably [33]. In the optimal operation of home loads with electric vehicles and devices, energy storage has been done in response to the prices and the time of use. Energy storage and electric vehicles can interact and exchange energy between the smart home and the distribution network. However, the study was conducted without considering the sources of distributed production [34].

The primary purpose of this research is to provide an intelligent service for controlling the working schedule of home appliances in cloud computing to minimize the cost of electricity. Although this seems obvious and valuable even without using advanced technologies such as the cloud platform, the internet-of-things, and wireless sensor networks, implementing such a service would be efficient only with the provision of modern technologies. The main reason for this is that the timing of the activity of electrical devices will not be possible without the possibility of their automatic operation due to the urgent need for humans to control electrical devices. Today, however, due to introducing smart washing machines, smart dishwashers, and automatic vacuum cleaners, many tasks can be performed automatically with no human intervention. Second, with the internet-of-things, remote access to the home appliance is possible, and its control is also provided by central applications. Service in the cloud can implement this central control and management [35]. Monitoring the environment and specific tasks that will need to be more visible will require using environmental sensors as wireless sensor networks. Applications of wireless sensor networks in this regard, including technologies related to control and monitoring of children, sick people at home, aged care, and home temperature control, etc., require the use of networks of sensors. According to the source, the dynamic resource allocation mechanism in the supercomputer has been implemented [36].

In this work, an intelligent mechanism for dynamic allocation and management in the cloud is proposed to manage/allocate cloud services for the energy management system. The amount of daily demand for allocation of the virtual machines to each customer for the source's valid data is provided. Thus, implementation of the proposed service, given that it is implemented in a wireless manner using sensor networks and internet-of-things platforms as the essential technologies, depends on the specialized allocation of resources in the supercomputer and scheduling algorithms. Further, the following factors are considered in the program for optimal operation of the electrical equipment of smart residential homes under welfare indicators:

- Actual load profiles are used, whereas, in most articles, the average consumption of appliances has been used. Cloud service provides the computational/storage requirements to deal with large data;
- Local renewable energy resources, such as solar–wind hybrid systems, with their generation profiles, are considered in the management program as part of the smart home network;
- The battery energy storage systems are involved in the program and their optimal operation is determined including optimal charging and discharging at different tariffs;
- Economics and load factor improvement are considered as the objective functions of the problem.

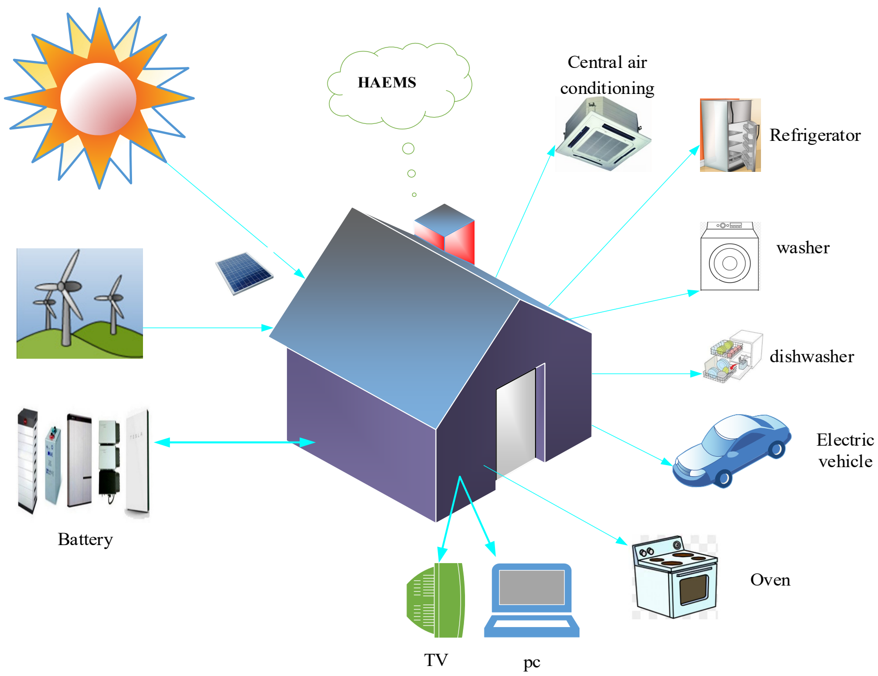
2. The System Description and Materials

The system under study, consisting of a smart home with electric appliances, is shown in Figure 1a. The proposed method, based on a three-layer HAEMS, as shown in Figure 1b, includes

(1) The access layer or the layer in which the sensors and actuators are located. The terminals are responsible for collecting data from the sensors of the intelligent building system and appliances. The collected data are sent to the next layer (fog layer) via Wi-Fi. Then, any equipment that is a part of the building can manage the smart terminal (socket) in the same part.

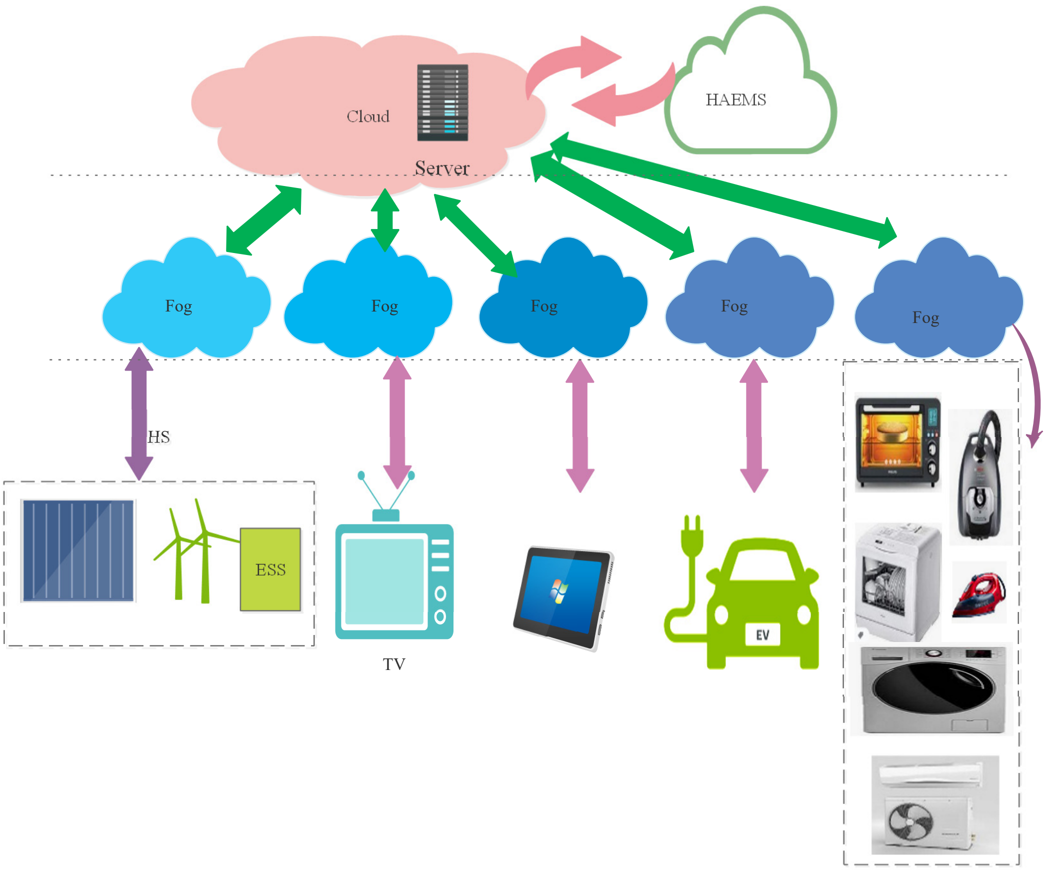
(2) The fog layer, in which all kinds of servers are located for computing and data storage; this sorter can easily manage the same batch layer of fog and avoid malfunctioning, and any input data can be stored in the data centre instantly. Then, using the received general data, a package of data is created to quickly issue the necessary decisions and commands based on the stored data to respond to the target equipment.

(3) The cloud layer of the data centres that are controlled and monitored by HAEMS. To achieve the goal of optimizing the HAEMS process of the building system, the data packet is sent from the top layer. Therefore, it provides more data for decision-making. In the third layer, the haze dots have an important feature of data processing capability compared to the second layer data, therefore it requires more data and connection to the cloud layer in our proposed model. Therefore, we can treat a point in the third layer as an independent unit from an intelligent building. The third layer is the cloud where the data received from fog layers are analyzed through the HAEMS and scheduled by GA and embedded neural networks. After planning, a smart insight into the first layer will emerge to optimize the status of the monitored points.



(a)

Figure 1. *Cont.*



(**b**)

Figure 1. The system under study: (**a**) smart home and appliances; (**b**) cloud computing architecture for HAEMS.

2.1. Mean Squared Normalized Error (MSNE)

The normalized value of the mean squared error is the normalized amount of squared error, which is usually used to evaluate the predicted continuous values. The squared value of the error makes it possible to consider a penalty for a more significant error so that the difference between the simulated value and the actual value, considering a power of two, reflects the magnitude of the error. Hence, the performance is evaluated accurately by considering the magnitude of the error and not its direction. Also, by normalizing the mean squares of the error, the evaluation is generalized, and the performance of the algorithm is generally evaluated based on the accuracy of the proposed method and not the data used. Calculating the normalized value of the mean squares of the error yields:

$$MSNE = \frac{\sum_{i=1}^{N} (Y_i - T_i)^2}{\sum_{i=1}^{N} (Y_i - Y)^2}. \quad (1)$$

where T_i is, the actual output value and Y_i is the simulated input value for the i member.

2.2. Linear Regression Matches the Predicted Value and the Actual Value of the Variable Value

The complementary measure for the accuracy or *MSNE* is a measure called the linear regression of the simulated value and the actual output value of the approximating algorithm. In fact, in addition to accuracy, another measure of reliability is needed to approximate a constant value. Reliability is calculated by a criterion called regression of correlation coefficients. The degree of reliability is numerical in the range (1 and −1). It is, in fact, an indicator for evaluating the degree of linear correlation between the actual value and the estimated value of a parameter. If R = 0, there is no linear relationship between the two values, but if R = 1 or R = −1, there is a stable positive or negative linear relationship. The optimum value for R is one, which indicates excellent reliability in the model. Calculating the reliability criterion through linear regression of correlation coefficients is:

$$R = \frac{\frac{1}{N}\sum_{i=1}^{N}(Y_i - T)(T_i - Y)}{\sqrt{\frac{1}{N}\sum_{I=1}^{N}(Y_i - T)^2} \times \sqrt{\frac{1}{N}\sum_{i=i}^{N}(T_i - T)^2}} \quad (2)$$

where R is a linear regression to measure the performance of the algorithm, T_i is the actual output value, and Y_i is the simulated input value for the ith member. Also, T is the actual output value and Y is the simulated input value of one step before step i. $MSNE$ and R regression accuracy criteria can jointly demonstrate the performance of supervisor learning algorithms, and each alone may be flawed. Hence, if each is used independently to describe the version of the machine learning tool (here is the predictive neural network), it is incomplete and not sufficient to ensure the proper implementation of the method. Thus, both criteria are used together and as a compliment, and the neural network performance indicator will predict the workload. According to the source [24], the performance of dynamic resource allocation can be examined in terms of the request rate rejection and the number of resources wasted.

2.3. The Cloud Rejection Rate

The number of rejected requests is the primary measure of the efficiency of the dynamic resource allocation mechanism in the cloud. Thus, the number of rejected requests relative to the total number of proposals submitted to the cloud calculates the amount of this performance criterion. The following equation calculates this:

$$Rj_t = \frac{R_t}{U_t} \quad (3)$$

where R_t represents the number of rejected requests and U_t represents all requests received at time t.

2.4. The Number of Wasted Resources in the Cloud

The number of resources wasted is the ratio of the remaining empty capacity in the servers to the total capacity of the cloud servers:

$$W_R = \frac{\sum_{i=1}^{N}(Cap_i - Ld_i)}{\sum_{i=1}^{N} Cap_i} \quad (4)$$

where N is the total number of servers, Ld_i is the current load on the physical server i, and Cap_i is the total capacity of the physical server i.

The neural network to predict workload needs to be trained first, and then its performance is measured by running on a test data set. However, the data set is based on the descriptions in the previous section of this paper; it has a percentage of noise to make the simulated data more realistic. It seems that averaging several times results in better neural network performance. The complete execution of the neural network on the Moore database should be evaluated so that the randomness of the noise can be more effective in accurately representing the overall performance neural network [33]. Thus, in this study, the neural network is run 20 times for different amounts of noise. Its efficiency is considered in terms of best performance and average efficiency shown in Table 1.

Table 1. CPU workload predictor neural network performance.

The Amount of Noise	Average Efficiency		Best Performance	
R	***R***	***MSNE***	***MSNE***	***R***
9879/0	9864/0	0077/0	0064/0	without noise
9801/0	9721/0	0083/0	0079/0	5%
9639/0	9513/0	0109/0	0094/0	10%
9398/0	9241/0	0174/0	0123/0	15%

3. Objective Function and Constrains

I: Objective function

All intelligent electrical appliances are controlled and programmed by the central control of the smart home network. The objective function is presented as:

$$\text{Objective Function Min} = \frac{SP}{LF} \tag{5}$$

where SP represents the cost of operating a smart home and LF represents the load factor. SP is defined as the difference between the cost of purchasing energy from the upstream grid C_{EP} with the profit from the sale of energy to the upstream grid C_{BS} and the profit from participation in the valley filling program C_{DM}.

$$SP = C_{EP} - C_{BS} - C_{DM} \tag{6}$$

$$LF = \frac{\text{average of load}}{\text{Peak of load}} \tag{7}$$

Increasing the load factor can reduce the peak consumption or increase the average consumption by filling the valleys of the total load profile.

Charging and Discharging the Battery

Charging and discharging is optimal when charging happens during off-peak hours and discharging at rather expensive/peak hours; for the battery from the time of charge or discharge and charge level is defined as:

$$Soc(h) = \begin{cases} \eta_{ch} \times P_{ch}(h) + Soc(h-1) & ; P_{ch}(h) \geq 0 \\ \frac{P_{ch}(h)}{\eta_{disch}} + Soc(h-1) & ; P_{ch}(h) < 0 \end{cases} \tag{8}$$

$Soc(h)$: Battery charge level per hour h. (KWH);
η_{ch}: Battery charge efficiency;
$P_{ch}(h)$: Battery charge or discharge rate per hour h. *(KWH);*
η_{disch}: Battery discharge efficiency:
where P_{ch} with positive (negative) sign indicates the charge (discharge) mode for the battery.

II: Problem constrain:

➢ Load clipping constrain: This upper and lower boundary limit in load clipping must be observed at any time. In the below equation, $\Delta P_{t,n}^{clip}$ is the amount of load from n that is curtailed at the moment t. U_n^{clip} is also a variable that determines whether or not the load participates in the load clipping strategy, which is one if it participates and zero otherwise. r_{up}^{clip} Is also the upper bound of the load clipping strategy specified by the user.

$$0 \leq \Delta P_{t,n}^{clip} \leq U_n^{clip} r_{up}^{clip} P_{t,n} \tag{9}$$

➢ Complete load transfer constraints: this means the complete transfer of load from one time to another in order to avoid the activity of electrical appliances in the peak load. In this strategy, it is assumed that the shape of the load does not change, it is only transferred from time to time. Load participation in the load transfer strategy is shown in Equations (10) and (11). In the equation below, the parameter $\Delta P_{t,n}^{trans}$ shows the difference between the load n, before and after the transfer at moment t. U_n^{trans} . also indicates the load participation in the transfer strategy, the value of which is zero or one. It can be one when the load can be turned off and transferred to another hour, and, vice versa, when the load is not transferable (for example for Central air conditioning), this index is zero. Also, in the following equations, the parameter $y_{n,\Delta t}$ indicates whether the load n has been transferred by Δt or not. The range of this index is zero or one.

$$\Delta P_{t,n}^{trans} = U_n^{trans}\left(P_{t,n} - \sum_{\Delta t} y_{n,\Delta t} P_{t+\Delta t}\right) \tag{10}$$

$$\sum_{\Delta t} y_{n,\Delta t} = u_n^{trans} \quad 1 \leq \Delta t \leq 23 \tag{11}$$

➢ Charging and discharging constrain: this constraint for the ESS system according to the minimum and maximum charge rate expresses a relationship as follows that, in the following relationships, $P_{ch,max}$ is the maximum battery charge rate in kW and $P_{disch,max}$ is the maximum battery discharge rate in kW. Also, EV_{BC} battery capacity in kW. Finally, the $EV_{SOC\ min}$ is the minimum amount allowed to charge the battery in kWh.

$$P_{disch,max} \leq P_{ch}(h) \leq P_{ch,max} \tag{12}$$

$$[Soc(h-1) - EV_{Soc\ min}] \times \eta_{disch} \leq P_{ch}(h) \leq \frac{EV_{BC} - Soc(H-1)}{\eta_{ch}} \tag{13}$$

4. Problem Solving Algorithm

In formulating the electrical task scheduling by the genetic algorithm, each sub-solution (the moment the electrical task starts) is defined as an individual within a set of sub-solutions called a chromosome. The main idea behind the genetic algorithm is that these chromosomes must include the subroutines that provide the most overall optimization during several stages of change. In fact, after a few steps of the algorithm, the algorithm's output should be the moments of performing electrical tasks so that the cost of power consumption is minimized. Each time the algorithm is implemented, each chromosome introduces a new generation of sub-solutions. In each generation, chromosomes are evaluated and allowed to survive and reproduce in proportion to their value. Generation is done in the discussion of the genetic algorithm with intersection three and mutation four operators. Top parents are selected based on a fitness function.

In the genetic algorithm, a group of points is randomly selected in the search space. A sequence of sub-solutions is assigned to each point in this process, to which genetic operators are applied. The resulting sequences are then decoded to find new issues in the search space. Finally, based on the objective function value in each, the probability of their participation in the next step is determined. Here, the objective function is the amount of empty capacity together relative to the total capacity.

The proposed protocol is implemented through the following steps (Figure 2):

1. The data of each device are collected based on their characteristics, i.e., the type of load and their basic operating hours;
2. All the types of equipment are classified and the values of the desired level of operation for each appliance are entered from the customer or residents' point of view;
3. All the 24-h data of the renewable hybrid system are called, and the amount of stored power is collected;
4. The amount of power requested from the network is determined;
5. In the next part of the formulation, the optimization problem is solved using the genetic algorithm, and optimal energy management and optimal timing for optimal operation of smart home equipment are achieved;

6. The HAEMS protocol is performed and, in the next step, according to the parameters trained in the artificial neural network, the values of MSNE, Rj_t, R, W_R are checked to be in the acceptable range. If the values are in the unauthorized range, the determined power of the main grid and the amount of power requested are increased by 5%, and this process continues until the evaluation parameters of the proposed protocol are converged and minimized;
7. The data of each device are layered by cloud computing taken bilaterally from the HAEMS protocol. The second is sent from the second layer to the first layer, and, in this part, which is the physical level of equipment in the smart home, they are controlled and operated optimally;
8. The 24-h time limit is checked, and the program is terminated.

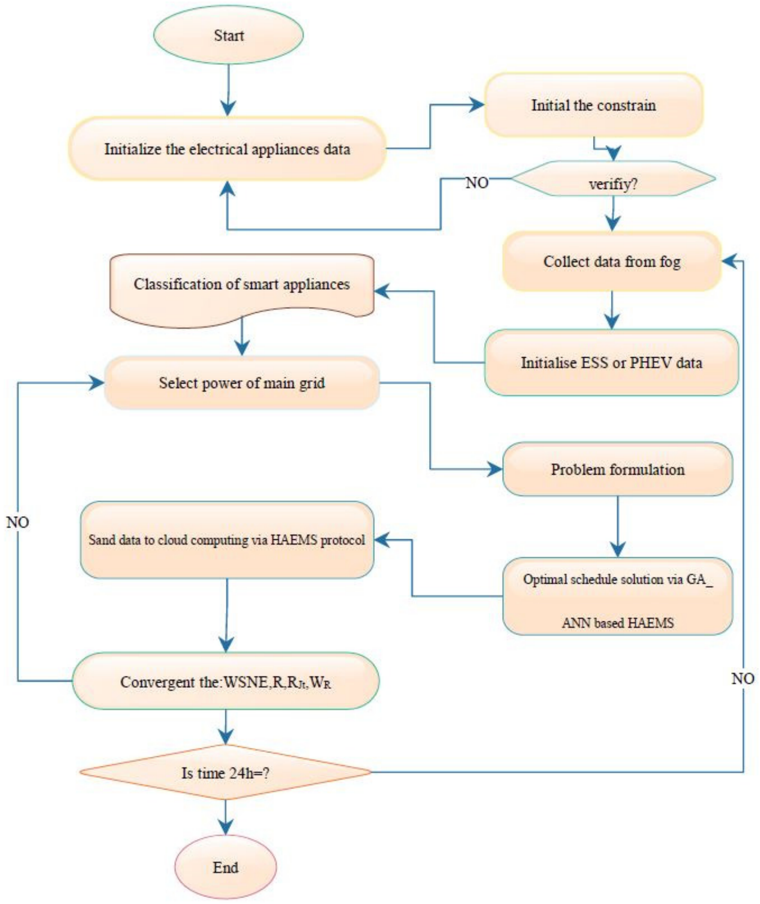


Figure 2. The Proposed protocol flowchart based on cloud computing.

5. Classification of Household Electrical Appliances

Household appliances are divided into responsive and non-responsive loads according to their capabilities in the load response program. Responsive loads such as washing machines and water heaters can transfer their consumption from time to time in response to the received tariff. Devices such as televisions and personal computers, which are usually used based on the customer's wishes and without considering tariffs, are called non-responsive devices. Although the time and amount of consumption of these devices cannot be controlled, several time intervals can be suggested as operating times to the owners of these devices. Here, it is assumed that the subscriber turns on his device at one of the recommended times. Responsive appliances are of two types: (1) appliances that only have their on/off status determined by the program provided, such as washing machines. These devices consume their energy consumption at each interval when they are on. The subscriber selects the allowable operating time for these devices. For some, the operating intervals of these devices should be consecutive and, for some, can be incoherent. For example, a washing machine must have a working clock to wash clothes properly. However, the clothes dryer can do its job at non-consecutive intervals. (2) Another category of responsive devices is devices whose consumption level in each allowable performance interval is determined by implementing the program. These devices have an acceptable range of energy consumption in each interval. The customer can also select the desired level of consumption of the device in each interval. To ensure the well-being of the joint, the total deviation from this desired joint amount can be limited to a certain amount. Among the devices in this category is the electric cooling/heating system.

6. Energy Storage Systems

It is expected that a modern family in an SMG is equipped with some storage/production devices; for example, energy storage systems such as batteries or plug-in hybrid electric vehicles (PHEVs). To keep returns high, battery, charge/discharge, and charge mode (SOC) should be limited to a specific range as follows:

$$P_{Batt,ch} \leq P_{ch,max}, \eta_{ch} u_{Batt}(h) \tag{14}$$

$$P_{Batt,dch}(h) \leq \left(\frac{P_{dch,max}}{\eta_{dch}}\right)(1 - u_{Batt}(h)) \tag{15}$$

$$Soc_{min} \leq Soc(h) \leq Soc_{max} \tag{16}$$

where P_{dch} and P_{dh} are the maximum charge and discharge power of the battery and Soc_{min} and Soc_{max} are the upper and lower limits of the battery SOC. Similarly, η_{ch} and η_{cdh} are battery charge and discharge efficiencies. u_{Batt} Is a binary variable that shows the battery status at h ("1" charge and "0" = discharge). Due to the above limitations, the SOC update function is equal to:

$$Soc(h+1) = Soc(h) + \frac{P_{Batt,ch}(h) - P_{Batt,ch}(h)\Delta h_{setp}}{E_{Batt}} \tag{17}$$

where, E_{Batt} is the battery capacity in kWh. Although a PHEV is essentially the same as the battery, a few additional limitations (such as a cut-off signal) indicate that the PHEV battery can only be charged/discharged when it is at home, and Soc_{min} hourly indicates the minimum PHEV battery power must also be satisfied.

F is scheduling tasks and residential load model.

Residential loads are generally divided into two categories:

(1) Schedulable loads (removable and interruptible tasks);

(2) Fixed loads.

While loads such as refrigerators and stoves are considered fixed loads, space heating and cooling, vacuum cleaners, washing machines, and clothes dryers are examples of timed tasks that provide the most electricity in a household. They consume and behave differently in response to changes in electricity prices over time [24].

7. Numerical and Simulation Results

7.1. Modeling the Production Capacity of the Wind-Solar Hybrid System

The power generation regime of the wind-solar hybrid system separately for each wind turbine and solar system is given in Figure 3, respectively. In this section, the first interval shows 00:00 to 00:15 in the morning.

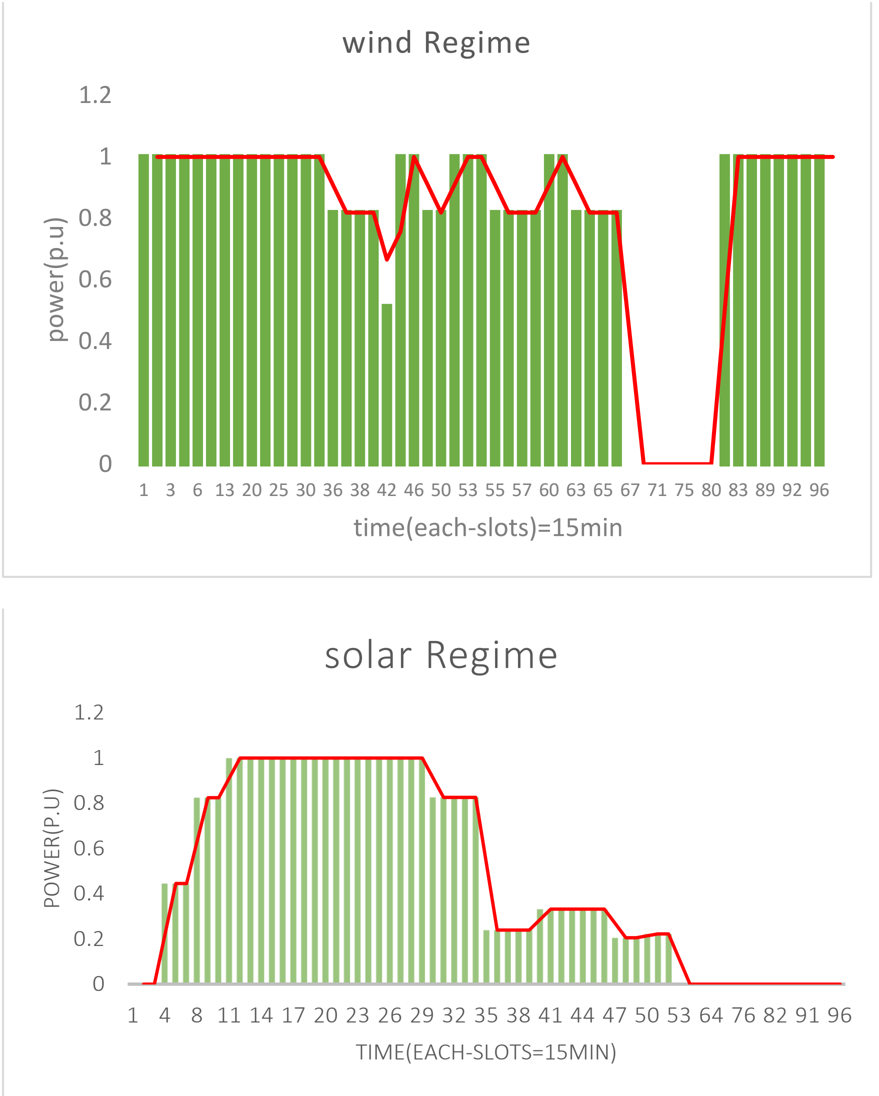


Figure 3. Solar power generation regime and wind turbine power generation regime.

7.2. Functional Range

One day will turn into 96 lot 15-min intervals. The interval starts at 6:00 a.m., and the last interval is at 5:00 a.m.

7.3. Bars and Their Profiles

Dishwasher: has three primary performance cycles. This time is considered a transferable load (Figure 4).

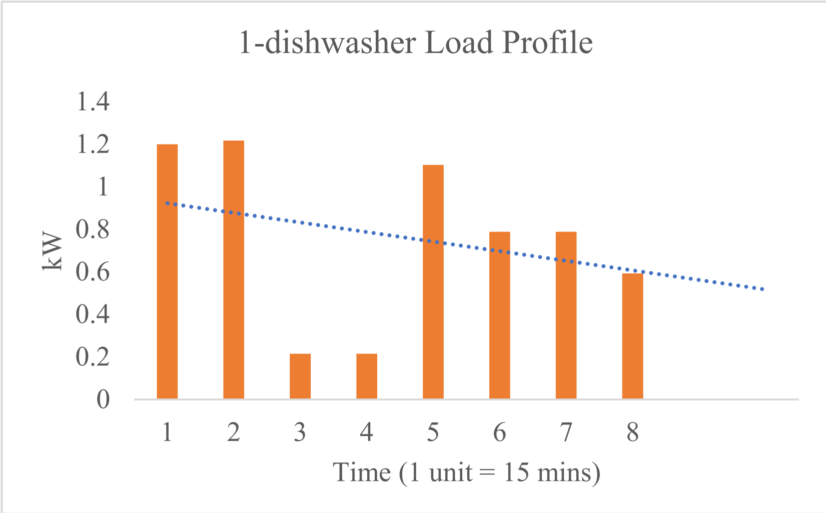


Figure 4. Dishwasher load profile.

Washing machine: which works for washing, rinsing, and then drying, this time is also portable (Figure 5).

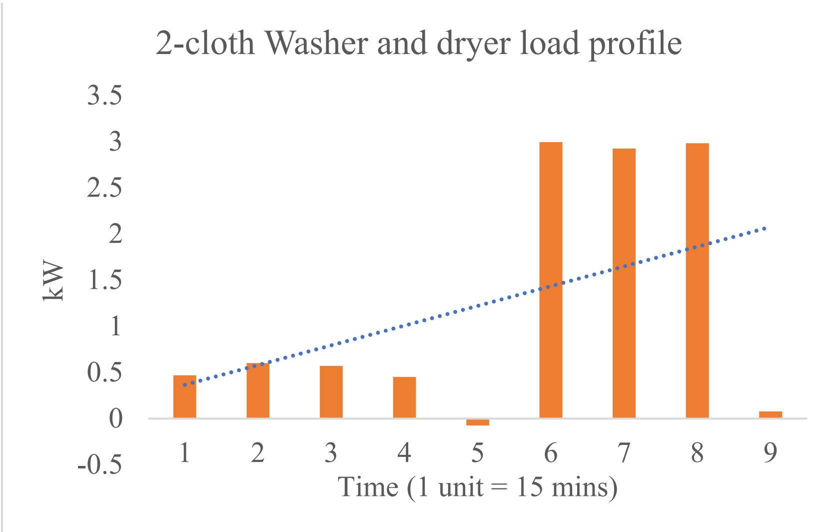


Figure 5. Washer and dryer load profile.

Refrigerator (cuft-6.15) with freezer: the refrigerator is a non-transferable and clipping appliance, and operates 24 h a day (Figure 6).

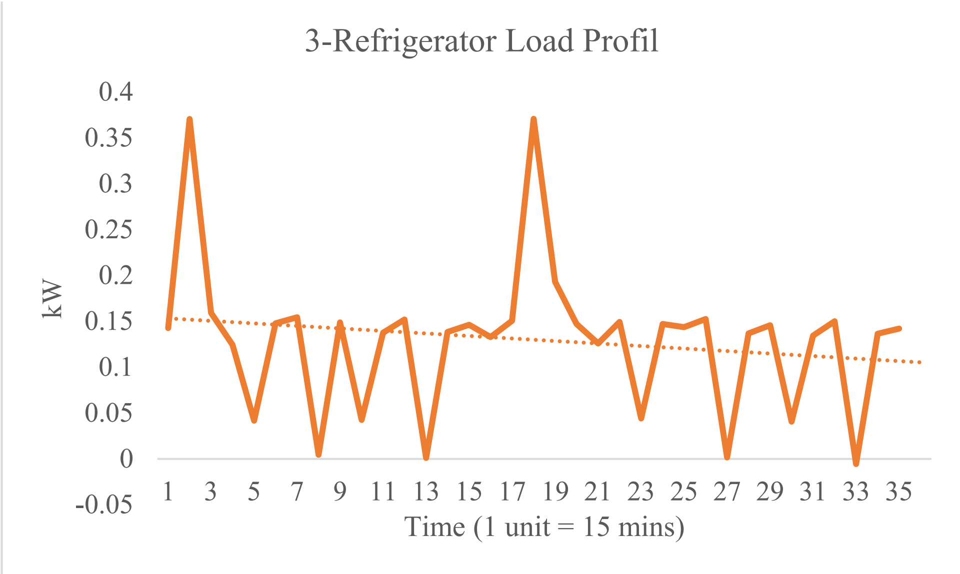


Figure 6. Load profile of refrigerator.

Central air conditioning: The use of this device depends on the weather and ambient temperature and is non-transferable (Figures 7 and 8).

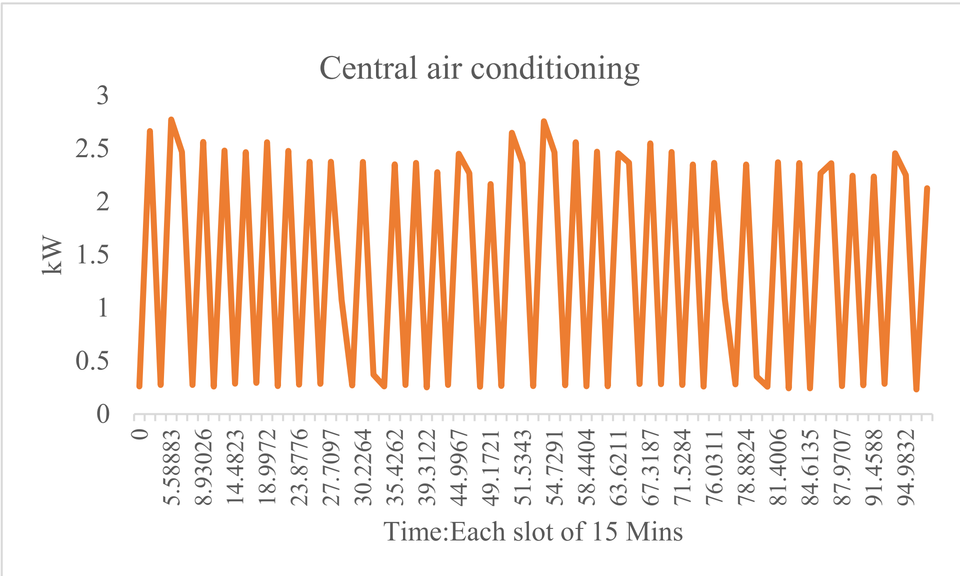


Figure 7. Central air conditioning.

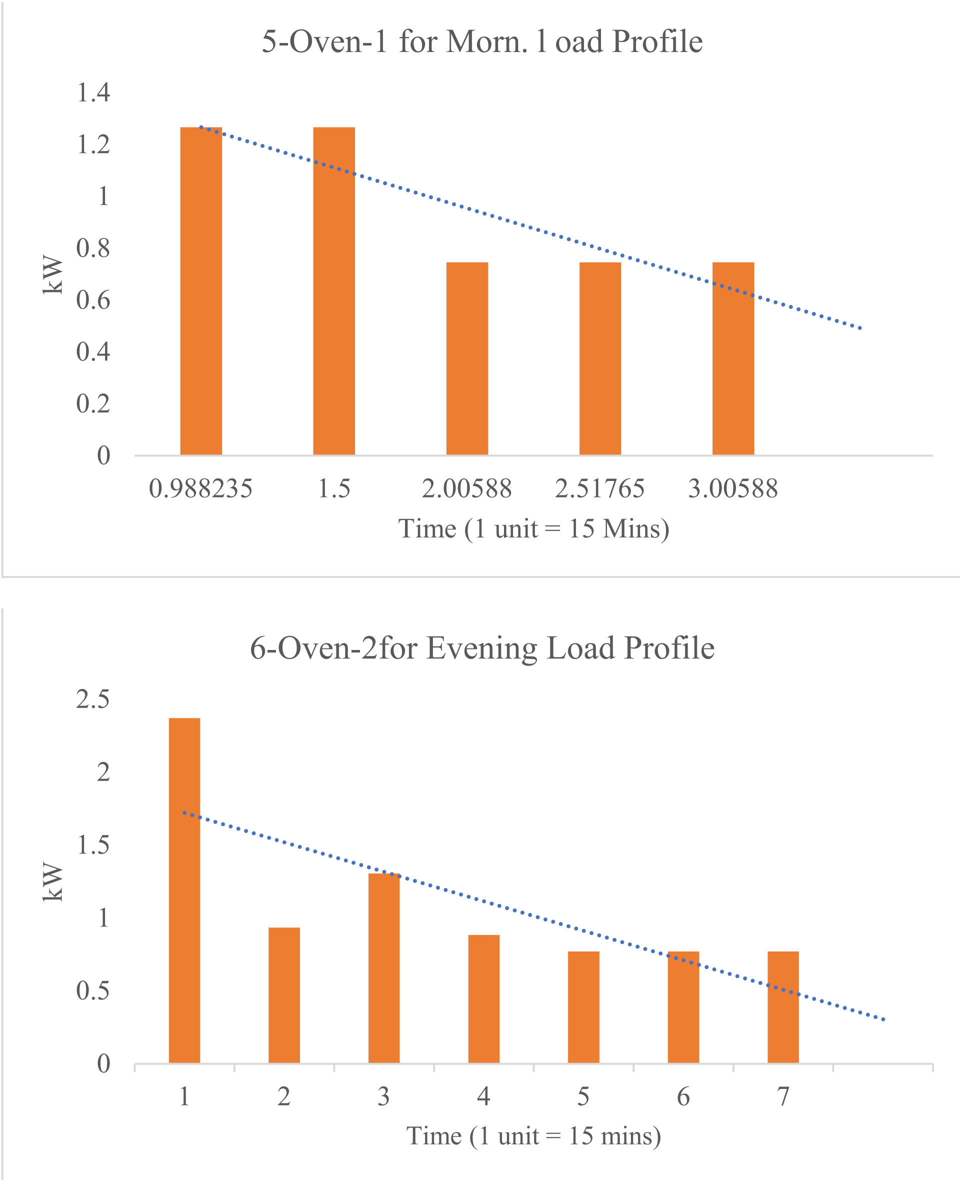


Figure 8. Load profile of oven for evening and morning.

7.4. Hybrid Micro-Grid

The proposed objective function, and the constraints considered for the HAEMS, including the wind/solar micro-grid, such as taking the energy storage by the genetic algorithm for the discussed input loads, have been solved. The price of electricity at different tariffs is shown in Figure 9.

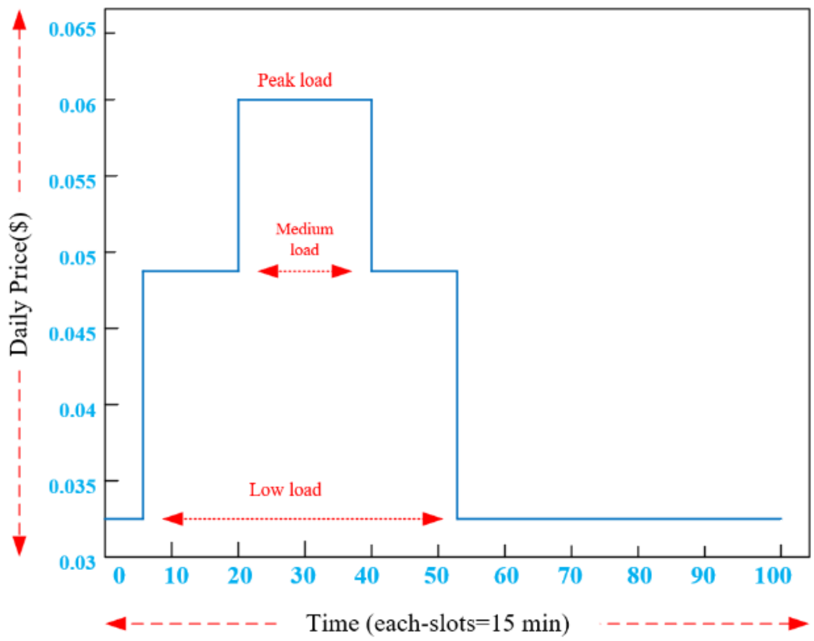


Figure 9. Different electricity tariffs.

The parameters and numerical values for solving the problem are shown in Table 2.

Table 2. The parameters and numerical values for solving the problem.

Wind turbine capacity installed	1 kW
The capacity of an installed photovoltaic system	1 kW
Minimum battery charge	0.2 kWh
Charging rate every 15 min	0.5 kW
Charging tool efficiency	0.9 Per Unit
Battery capacity	2 kWh
The cost of discharging or selling energy to the grid	1.03*daily-price
Profits from participation in consumption reduction	0.04*daily-price

All loads in the HAEMS and peak, medium, and low load times in the network base state and the initial assumption are shown in Figure 10.

Optimization, charging, and discharging of storage and load shift and load clipping operations on different loads according to the information given in the table below have been done.

According to Table 3, the central air conditioning is on at 96 time slots of 15 min, i.e., the whole day and night, and it is not possible to shift. Still, by adjusting the temperature, its consumption can be reduced, or its consumption can be increased by applying a lower temperature. Therefore, it is possible to reduce the load. The refrigerator is on all day, and it is not possible to shift or cut part of the load. The dishwasher can have both load shift and load clipping according to its settings. This equipment can shift and transfer loads from 67 to 96, and up to 2.0 saws for load reduction and clipping are considered. For washing machines and dryers from range 17 to 96, load transfer capacity and function are considered. It is assumed that the maximum load reduction is regarded as 30% according to the settings of this car. In the following, we will deal with the results obtained by applying the proposed simulation conditions, and the obtained results will be discussed:

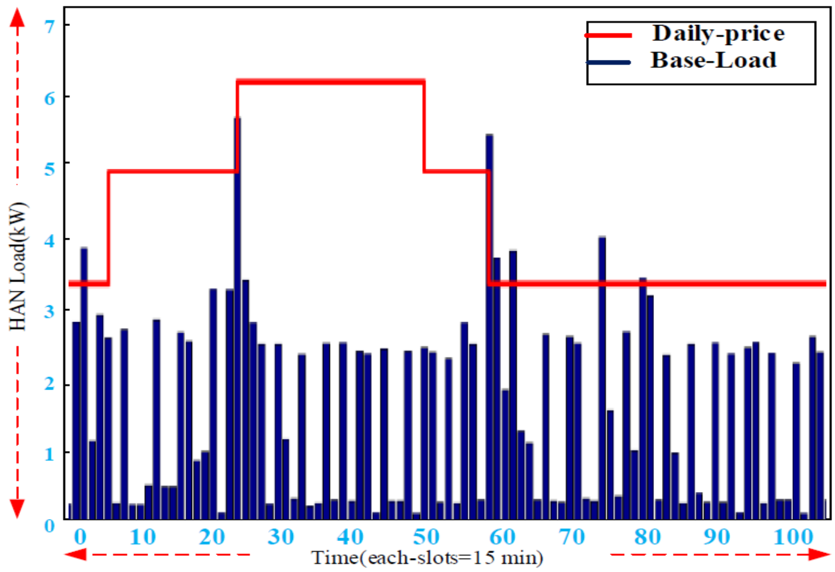


Figure 10. Total HAEMS load in the ground state.

Table 3. Starting and ending times for mixed time range schedule.

Main Profile	Max Shift	Max Reduction	Profile Length	Range
AC	0	0.3	96	[1 96]
Refrigerator	0	0	96	[1 96]
Dishwasher	29	0.2	7	[67 96]
Clothes washer	79	0.3	8	[17 96]
Oven Morning	0	0	2	[3 7]
Oven evening	3	0	6	[53 61]

7.5. Central Air Conditioning (AC)

After optimization, the AC power consumption profile was obtained as follows (Figure 11).

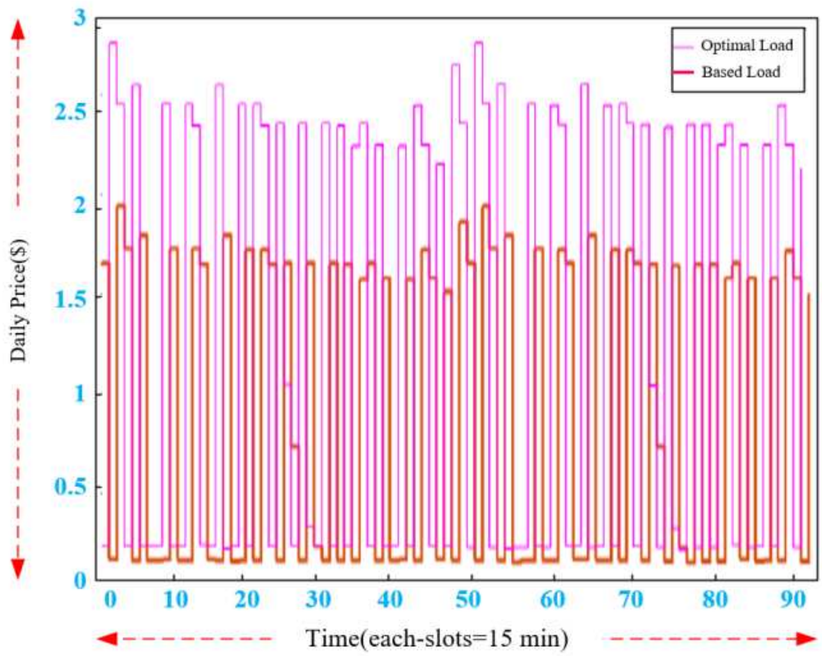


Figure 11. Comparison of AC consumption profile before and after application of the proposed method.

Dishwasher: The profiles before and after optimization are compared; the result is shown in Figure 12.

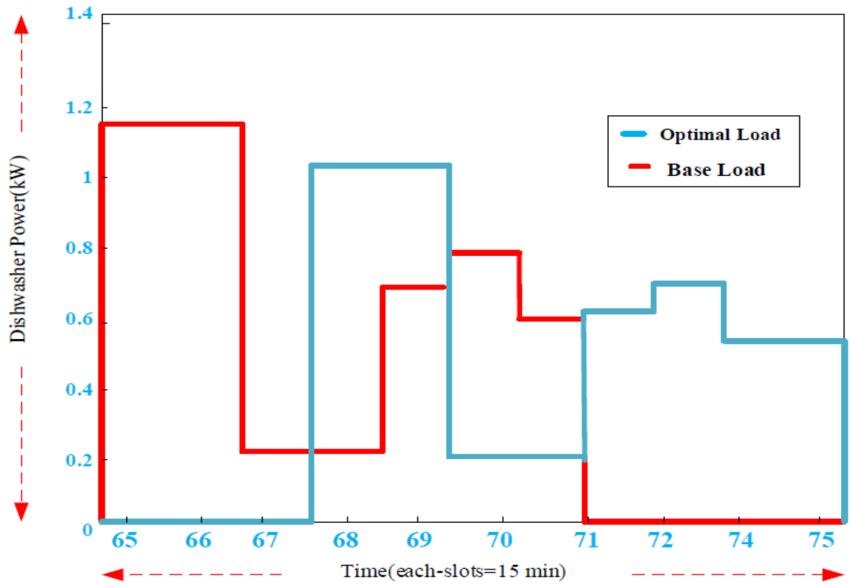


Figure 12. Comparison of dishwasher consumption profile before and after applying the proposed method.

Washing machine: the power consumption profile of the washing machine, and the dryer after and before the optimization is shown in Figure 13.

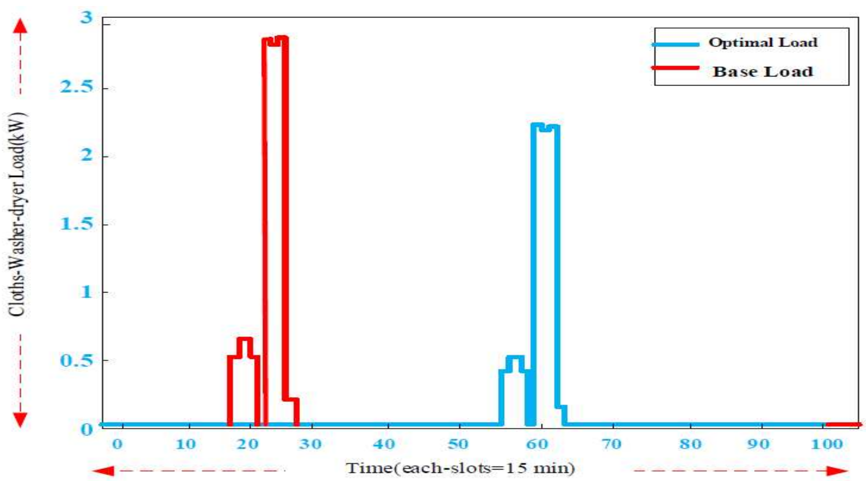


Figure 13. Comparison of consumption profile of washing machine and dryer before and after applying the proposed method.

7.6. Electric Oven

Total load, i.e., the sum of HAEMS loads is shown in Figures 14 and 15, and for comparison with profiles such as simulation and proof of the efficiency of the Figures 16 and 17 method, the load profile is more linear and the peak load is reduced.

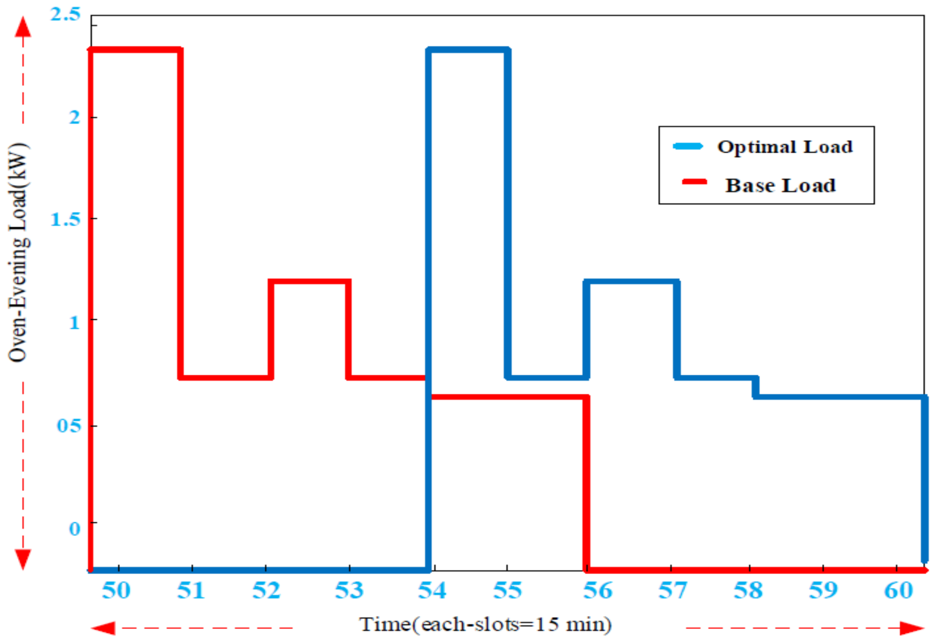


Figure 14. Oven consumption profile in the morning.

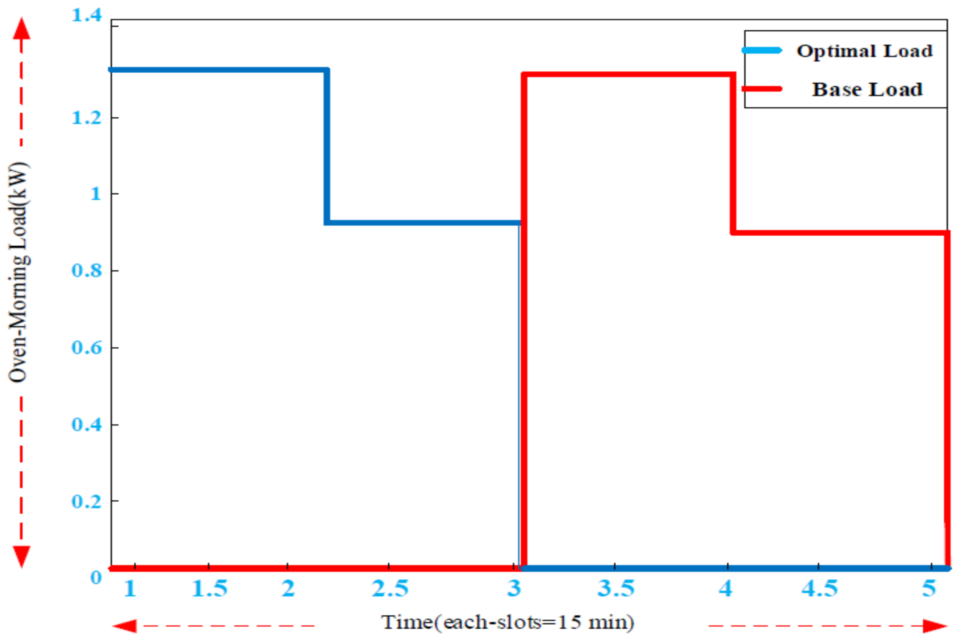


Figure 15. Oven consumption profile at night.

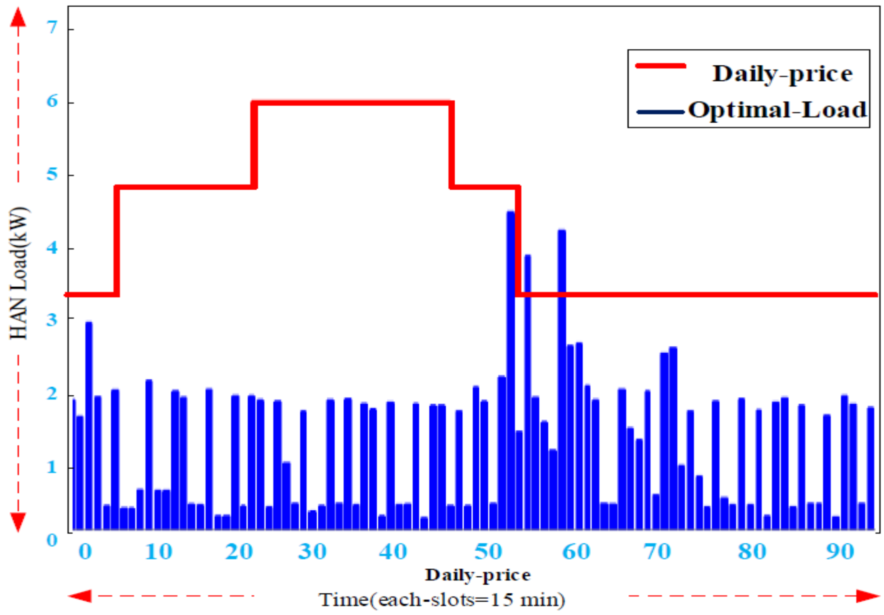


Figure 16. Total HAEMS load after optimization.

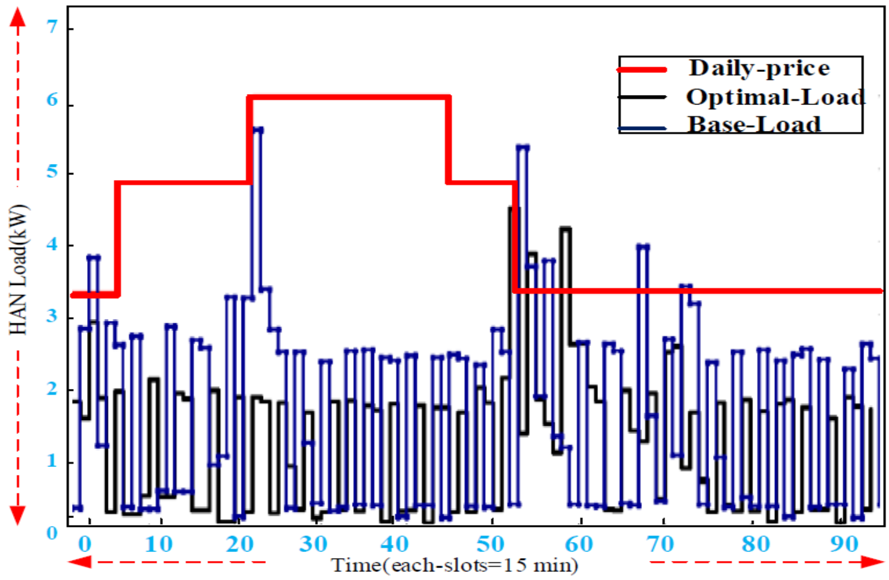


Figure 17. Total HAEMS load after and before optimization.

ESS is in charging mode during off-peak hours and is scheduled in discharge mode during peak hours. The maximum and minimum charge limits are 2 and 0.2 kW. Figure 18 clearly shows that, at the end of the day and low load rates, the charging mode strategy is planned by HAEMS.

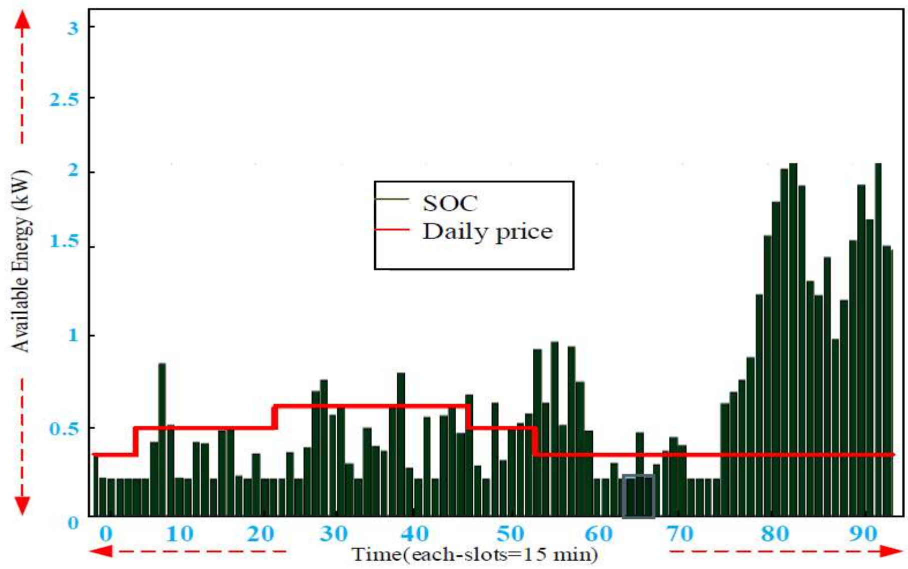


Figure 18. Storage charge level.

Power generation and consumption in the HAEMS smart home network are not the same. Figure 19 shows this difference.

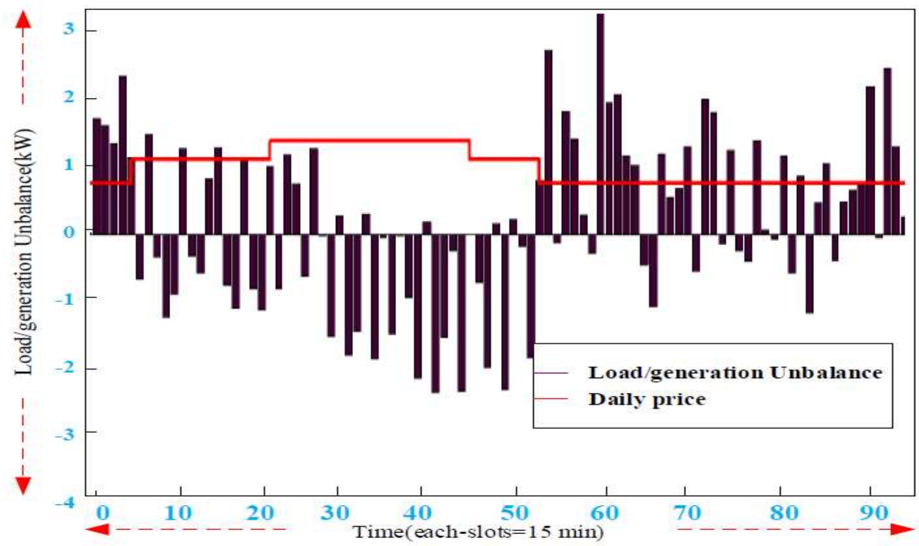


Figure 19. Difference between power generation and consumption in HAEMS in a 24 h day.

Figure 20 also shows the amount of power received from the main network to the smart home network. As has been made clear, the proposed method with optimal timing for the day ahead, in addition to high speed and accuracy, has been able to minimize the amount of power required from the main network. This has resulted in a 45% reduction in the purchasing power of the network from the main network. Figure 21 shows the total cost per day with and without considering the proposed HAEMS-based optimization method. As it turns out, this significantly reduced the cost of electricity. With this idea, customers save about $2 and 86 cents a day in payment.

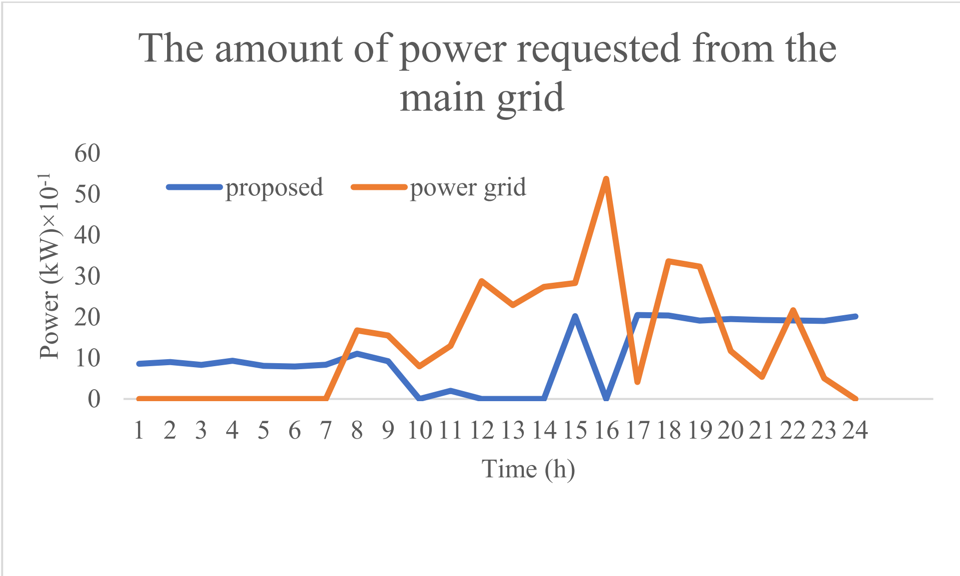


Figure 20. The amount of power requested from the main grid in 24 h a day.

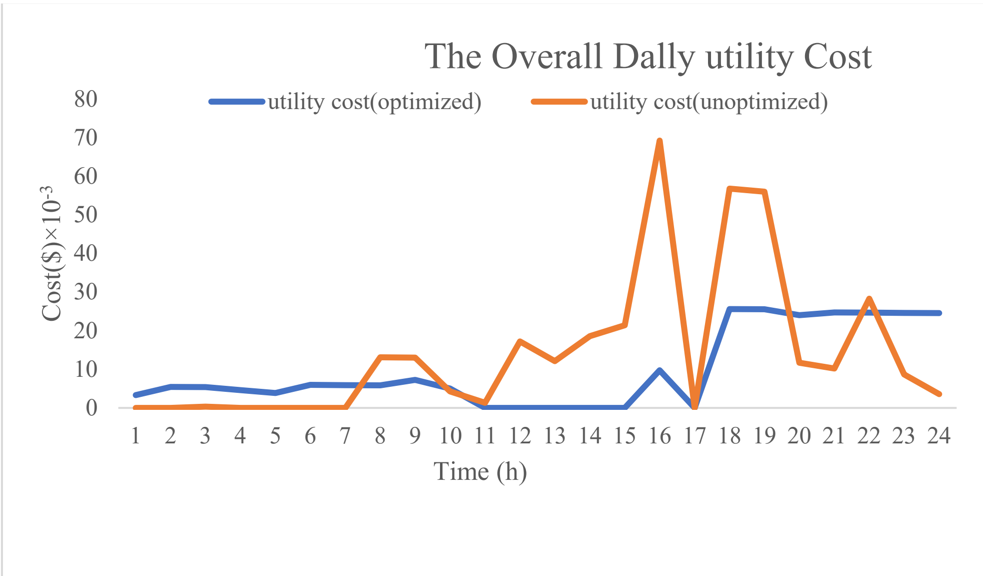


Figure 21. Total utility cost of the smart home after/before using the proposed HAEMS.

8. Conclusions

In this paper, the HAEMS protocol was presented using cloud computing. The data of home appliances were analyzed by using cloud computing, which was exchanged bilaterally from the HAEMS protocol. An optimal schedule was made for a day ahead for the optimal operation of the electrical equipment of smart residential houses under welfare indicators. The efficiency of the neural network was evaluated in the form of averaging, several times, the complete implementation of the neural network on the Moore dataset, and, finally, welfare indicators such as MSNE, Rj_t, R, and W_R were evaluated. In addition to welfare indicators, the proposed protocol with high accuracy, speed, and proper convergence at the level of welfare indicators was able to minimize the amount of power requested from the main network, which has resulted in a 45% reduction in the purchasing power from the grid. On the other hand, the total cost per day, regardless of the proposed HAEMS-based optimization method, has shown that the electricity costs were significantly reduced. With this method, customers save about $2 and 86 cents a day in payment. The proposed method was implemented by GA algorithm and artificial neural network in MATLAB software and the results proved the efficiency of the proposed method.

Author Contributions: Conceptualization, P.S. (Padmanaban Sanjeevikumar); methodology, M.Z. and M.A.N.; software, M.E.; validation, M.A.N. and M.Z.; formal analysis, P.S. (Pierluigi Siano); data duration, M.A.N. and M.E.; writing—original draft preparation, M.Z.; writing—review and editing, M.E., P.S. (Padmanaban Sanjeevikumar) and M.Z.; supervision, P.S. (Padmanaban Sanjeevikumar) and M.E.; project administration, M.A.N. and M.Z. All authors have read and agreed to the published version of the manuscript.

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smart cities

Review

Cloud-Based IoT Applications and Their Roles in Smart Cities

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Abstract: A smart city is an urbanization region that collects data using several digital and physical devices. The information collected from such devices is used efficiently to manage revenues, resources, and assets, etc., while the information obtained from such devices is utilized to boost performance throughout the city. Cloud-based Internet of Things (IoT) applications could help smart cities that contain information gathered from citizens, devices, homes, and other things. This information is processed and analyzed to monitor and manage transportation networks, electric utilities, resources management, water supply systems, waste management, crime detection, security mechanisms, proficiency, digital library, healthcare facilities, and other opportunities. A cloud service provider offers public cloud services that can update the IoT environment, enabling third-party activities to embed IoT data within electronic devices executing on the IoT. In this paper, the author explored cloud-based IoT applications and their roles in smart cities.

Keywords: smart cities; IoT; cloud computing; information processing; Cloud-based IoT applications

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1. Introduction

Cloud computing is the next phase in the advancement of internet-based computing, and it allows information technology capabilities to be used as a service. As smart devices move outside of the cloud infrastructure environment, the IoT can increase efficiency, performance, and throughput. Smart cities are residential regions that make systematic efforts to see for themselves the new location of records and communication technologies, achieve environmental sustainability, urban system authority, improved health, knowledge development, and network-driven advancement [1–3]. Cloud computing is the next phase in the growth of internet-based computing, allowing for the delivery of information and communication technology (ICT) resources through a network. In cloud infrastructure, the IoT can benefit from increased efficiency, performance, and payload. The presentation of cloud computing has supported the manner of development and dissemination, and industrial electronic business packaging. As a result, IoT and cloud are now very close to future internet technologies that are compatible with IoT systems.

The IoT is primarily concerned with challenges that arise in a dynamic and shared environment. IoT is a broad category that comprises of various adaptable and unusual devices with limited storage, power supplies, and performance capabilities. These constraints establish a barrier and impedance to the development of IoT systems, and include complex issues such as compatibility, efficiency, full functionality, and availability. One of the most promising methods that may be combined with IoT to overcome such limitations is cloud computing. The cloud provides shared resources (network, storage, computers, and software) distinguished by ubiquity, low cost, and aesthetic characteristics. This paper describes the existing communication, processing, and storage applications on a cloud-based IoT platform for smart cities. This platform may use cloud resources and services to gather, transfer, analyze, process, and store data. It may also use cloud resources and services to collect, transmit, search, analyze, and store data generated by complex scenarios. Figure 1 shows the cloud-based IoT platform to develop applications.

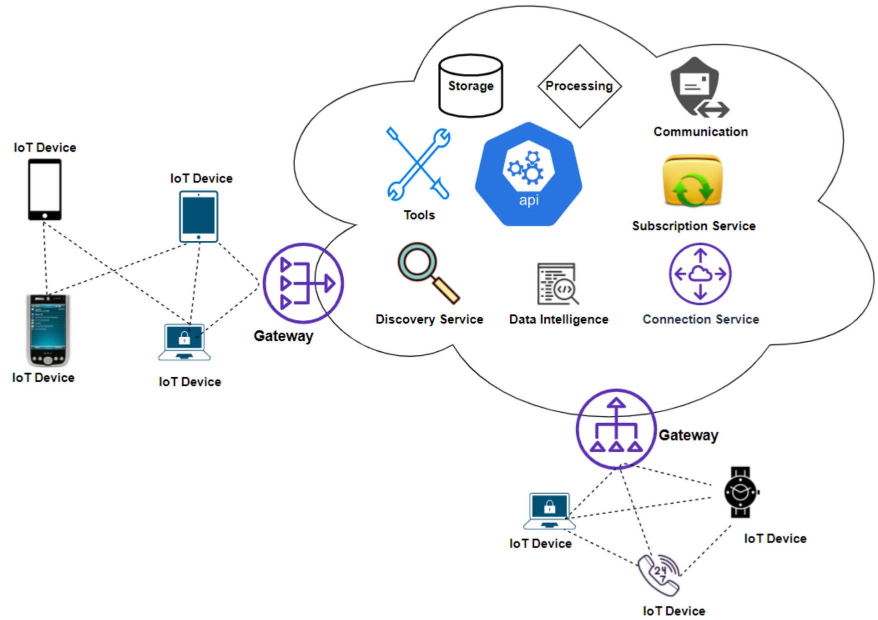

Figure 1. Cloud-based IoT System.

From industrial systems to emergency deliveries, public transportation, public safety, city lighting, and other metropolitan applications, the IoT has made its way into every commercial and public sector initiative. Cities are becoming connected as the IoT advances, allowing them to improve infrastructure installation efficiency and the reliability and responsiveness of emergency services. In the coming years, researchers are excited to explore new ideas for smart cities employing IoT solutions. Table 1 shows the related articles published between 2012–2021.

Table 1. Related articles.

Authors	Ref.	Year	Title
Khan et al.	[1]	2014	Towards cloud-based smart cities, data security, and privacy management
Khan et al.	[2]	2012	A cloud-based architecture for citizen services in smart cities
Suciu	[3]	2013	Smart cities built on resilient cloud computing and secure IoT
Roy and Sarddar	[4]	2016	The Role of Cloud of Things in Smart Cities
Silva et al.	[5]	2018	Towards sustainable smart cities: A review of trends, architectures, components, and open challenges in smart cities
Chai et al.	[6]	2021	Role of BIC (Big Data, IoT, and Cloud) for Smart Cities
Rubí et al.	[7]	2021	An IoT-based platform for environment data sharing in smart cities
Kaur et al.	[8]	2016	Building smart cities applications using IoT and cloud-based architectures
Saleem et al.	[9]	2020	Building smart cities applications based on IoT technologies: A review
Dlodlo et al.	[10]	2016	Internet of things technologies in smart cities
Hyman et al.	[11]	2019	Secure controls for smart cities; applications in intelligent transportation systems and smart buildings
Curry et al.	[12]	2016	Smart cities–enabling services and applications
González-Zamar et al.	[13]	2020	IoT technology applications-based smart cities: Research analysis
Saravanan et al.	[14]	2019	Smart cities & IoT: evolution of applications, architectures & technologies, present scenarios & future dream

Table 1. *Cont.*

Authors	Ref.	Year	Title
Shamsir et al.	[15]	2017	Applications of sensing technology for smart cities
Saha et al.	[16]	2017	IoT solutions for smart cities
Song et al.	[17]	2017	Smart cities: foundations, principles, and applications
Sookhak et al.	[18]	2018	Security and privacy of smart cities: a survey, research issues, and challenges
Park et al.	[19]	2018	The role of IoT in smart cities: Technology roadmap-oriented approaches
Mehmood et al.	[20]	2017	Internet-of-things-based smart cities: Recent advances and challenges
Visvizi et al.	[21]	2020	Sustainable smart cities and smart villages research: Rethinking security, safety, well-being, and happiness
Talari et al.	[22]	2017	A review of smart cities based on the IoT concept
Delsing et al.	[23]	2021	Smart City Solution Engineering
Lanza et al.	[24]	2016	Smart city services over a future Internet platform based on IoT and cloud: The smart parking case
Syed et al.	[25]	2021	IoT in Smart Cities: A Survey of Technologies, Practices, and Challenges
Almalki et al.	[26]	2021	Green IoT for Eco-Friendly and Sustainable Smart Cities: Future Directions and Opportunities

1.1. Cloud Is the Key for Internet-Based Computing

Cloud computing is the next phase in the growth of Internet-based computing, and it allows ICT services to be delivered as a carrier. Computer capabilities, infrastructure (e.g., servers and storage), systems, business processes, and other critical resources can all be connected via cloud computing [4]. The growth of cloud computing makes it easier to develop flexible business models, such as allowing organizations to use resources when their business grows. Unlike organizations that provide traditional web-based services (e.g., web hosting), cloud computing allows for immediate access to cloud delivery without a lengthy provisioning process. Each provisioning and withdrawal of resources in cloud computing can be repeated indefinitely. APIs (application programming interfaces) allow users to access cloud services and allow applications and resource records to communicate in the cloud. Invoicing and assessing providers are used in payment methods, providing the support required to use the rating assistance and to make payments in advance.

Monitoring and evaluating the performance: cloud computing infrastructure, in addition to the integrated system of physical computing and its methods, provides a carrier management environment to monitor and evaluate performance.

Security: cloud computing architecture offers secure operations that aim to protect sensitive information. The following are the two main business drivers behind the adoption of cloud computing and related services: (1) business enterprise. Cloud computing provides flexible, timely, and required access to computer resources as needed to fulfill business objectives; and (2) cost reduction. Cloud computing promises a cost reduction by converting capital expenditures (CapEx) into operating costs. This is because cloud computing allows for more flexible scheduling and resource allocation, and a preference for pre-existing management.

1.2. Six-Phases Startup Model for Building a Smart City

The following is a six-phase startup model for the formation of a smart city.

Phase 1: a fully smart city platform

The smart city implementation should start with a simple design. It will serve as the foundation for future development and allow you to add new services without losing overall performance [5]. The fundamental solution for smart cities consists of four requirements.

- A Network of Intelligent Objects

In smart city, IoT uses smart devices designed for sensors and actuators. The purpose of the sensory devices are to collect data and send it to a robust cloud control platform. Actuators allow devices to work, for example, by adjusting lights, reducing the flow of water in a pipe with leaks, and so on.

- Gateways for Secure Transmission

Every IoT device combines two elements: the hardware part of the IoT device and the applications part. Data cannot transmit from one object to another without applications. There should be gateways to control the data. These gates facilitate data collection and compression by filtering data before sending it to the cloud. The cloud gate ensures secure information transfer between local gates, and the cloud is part of the city's smart solution.

- Pool Facts

The main reason for the information pool is to keep records. Collections of data support evidence in smart cities. When data are requested, they are extracted from the pool and transferred to the destination.

- Large Record Warehouse

An extensive database is called a large records warehouse. Unlike statistical pools, it contains highly organized data. Once the actual data is determined, it is extracted, converted, and loaded into a large data warehouse.

Phase 2: data tracking and analytics

With data tracking and analytics, the process involves the collecting, recognizing, and classifying of data objects across the network system so that it may be used in data analysis. The technologies that corporations use to manage data, and the regulatory principles that they employ to safeguard consumer privacy and security, are all part of data tracking. For example, when reading data from soil moisture sensors planted in a park, cities can set digital valve rules to open or close at the identified humidity level. The information collected by the sensors can be seen in the dashboard of one platform, allowing customers to see all parts of the park.

Phase 3: analyze data

The amount of data produced by a community, transport networks, and digitization is incredible and continues to increase rapidly. With emerging IoT technologies, devices and cloud services significantly speed up the process of production. Analyzing, modelling, and extracting information from this data is a major contributor to the understanding of city contexts and can be used to improve the effectiveness of urban movement. Machine learning (ML) algorithms analyze ancient sensory data stored within an extensive database to determine progress and create predictable models. Models used by control packages send commands to IoT device actuators. Unlike the normal traffic modes designed to display a selected sign for a time period, smart visitors can adjust the entry times in traffic conditions. ML algorithms were developed on antiquated sensory systems to identify place visitor styles, control signal time, support average car speed acceleration, and avoid congestion.

Phase 4: smart control

Control systems ensure high automation of smart city devices by sending commands to their actuators. They "tell" the right employees what to do to solve a particular challenge. There are rule-based management systems mainly based on ML. Standards for deceptively based programs are explained manually, while ML-controlled applications use models created with ML algorithms. Those patterns are recognized based on statistical tests; and they are tested, approved, and updated often.

Phase 5: automatic traffic control

Next to the opportunity for automatic control, there should always be an option for customers to direct smart city programs (for example, in the case of an emergency). User programs perform this task. Citizens can make use of user programs to connect to the city management platform to detect and manage IoT devices, and receive warnings and notifications. A smart traffic control solution, for example, identifies a visitor jam using global positioning system (GPS) data from driver's smartphones. The response sends out an automatic message to local drivers, requesting that they seek alternate routes.

The smart city area uses a tourist control system to discover over-congestion in real-time and to use tourist guidelines to reduce site visitors within high-traffic areas. Moreover, the smart city ensures that site visitors do not harm the environment and combine a visitor management response with a smart air tracking solution. The staff of a visitor center, using a computer application, can receive a warning about crowded conditions. To relieve and reroute traffic congestion, a command is sent to the robot detectives to control the alerts.

Phase 6: integrating multiple solutions

The IoT-based multiple solutions should be integrated, which means increasing not only the various senses, but, more importantly, the number of features.

1.3. Functions of Cloud Computing in IoT

IoT and cloud computing are two platforms that have proved to be beneficial in many ways. The majority of people are aware of IoT policies related to smart cities, smart homes, etc. IoT is key to integrating smart city's responses into business tools and paving the way for high-quality feedback in healthcare, transportation, logistics, energy, and many other fields. The cloud is not far behind. The benefits of cloud computing in IoT are numerous. In other words, IoT and cloud computing are extremely compatible and both endeavors to increase the efficiency of daily activities. While IoT integrates with smart cities, it produces large quantities of data. Cloud computing, on the other hand, paves the way for more experiences. From service options to the access of remote data, IoT and cloud computing together enhance integration. They provide accessible and cost-effective storage, but there are many areas where we can analyze the gap between IoT and cloud computing [6–10].

1. Cloud computing has made a considerable difference in the solutions of business services and individual applications. In addition, the intensity and strength of cloud response statistics allow data to be made available remotely. As a result, it has proven to be a solution to transferring information through network channels and hyperlinks delivered directly based on business preferences;
2. The cloud is an excellent IoT helper that solves the challenges driven by commercial business data. The cloud, as a technology, provides an active platform for developing critical applications for the better use of online data;
3. Velocity and scale: the two main cloud computing methods are an unparalleled combination, and IoT provides communication and mobility. Therefore, the capabilities of IoT and cloud computing are enhanced through combination. Other features prove that the cloud is important for IoT access;
4. Depending on the building infrastructure, with the widespread use of IoT devices a significant amount of time is required to maintain a large number of devices and to control over-speed. In this context, the cloud brings the benefit of a good service environment;
5. The cloud improves the security and privacy of IoT data. IoT devices are portable and, with the involvement of the cloud, they can integrate significant security measures, renovations, and discoveries. With robust authentication and encryption agreements, the cloud empowers customers by providing full security features;
6. The connection and presentation of cloud services for IoT devices. With plug-and-play cloud hosting services, considerable infrastructure is often required, which is expensive for organizations or individuals. With the combined power of IoT and

cloud computing, this investment in infrastructure is not required and any access restrictions for IoT and cloud service providers are removed;
7. Advanced device connectivity: the cloud plays the role of a communication facilitator with its powerful IoT APIs. These APIs aid the pure connectivity of smart devices and also help in the conversation between intermediate tools;
8. Cloud technology prevents companies from the necessity of infrastructure development and, at the same time, provides adequate resources;
9. Cloud computing ensures business continuity, protecting against unexpected challenges that may arise throughout the process. Since the data is stored on separate servers, there is no risk of data loss, especially in particularly well-supported infrastructure;
10. Development within the IoT domain requires trouble-free secure responses. Therefore, cloud computing on IoT is the best solution. With cloud computing in place, IoT devices can use the power of remote statistical environments through applications. From a financial perspective, cloud computing on IoT is an excellent solution, as users successfully comply, and it saves considerably on future expenses. As a result, businesses may be able to utilize larger IoT systems. This reduces the access limit for high-level IoT-based organizations;
11. Cloud computing on IoT allows for seamless communication between IoT devices, enabling numerous strong API connections between connected devices and smart devices. In this way, cloud computing opens the way for the IoT explosion of connected technologies.

1.4. How Does the Cloud Allow IoT Applications?

Cloud-enabled IoT applications are growing and communicating across the network. The cloud enables service hosting, deployment, and the introduction of cloud-based IoT applications. Moreover, cloud computing is an appropriate Internet platform for storing and processing smart device data, such as connected cars, smart grids, smart cities, Wi-Fi, sensors, and actuator networks. The setup of network configurations can be conducted quickly and effectively. However, backend operations are performed using software, allowing rolling back, location monitoring, content labeling, and performance monitoring [11–15].

Additionally, cloud computing makes IoT systems robust. Using the integration of cloud and IoT, technologists can develop backups of devices and applications running in the cloud, increasing their tolerance to errors. In addition, they can be used to track data offline. Developers can also set up digital servers, run applications, and launch a database to help drive their IoT response.

1.5. What Are the Most Demanding Conditions Related to IoT and Cloud Computing?

Cloud computing accelerates the IoT explosion, and the integration of IoT and cloud computing can play a key role in the development of smart cities. However, IoT and cloud computing construction is complex, and the most demanding scenarios come from information generated at the network level [16–20]. The IoT cloud solution poses many challenges for users, including:

1. Dealing with many records

With several millions of devices in the network, the IoT produces a considerable amount of information. In contrast, there is no straightforward or proven cloud management system for the handling of big data. This can put the full functionality of applications at risk.

2. Communication processes

IoT and cloud computing includes device communication. This communication of devices to the machine occurs through a variety of processes.

3. Sensitive networks

Sensors are the primary source of IoT data. The sensory community enables users to comprehend and respond to critical directions from the environment. However, processing a large number of sensory records is a considerable undertaking. While the cloud helps compile the data, it likewise prevents privacy and security issues.

4. Cloud provider for IoT

Many businesses host their cloud platforms from secure locations for instant access to data. However, that may not be the most inexpensive solution. Therefore, a preferred cloud delivery service is a suitable response for organizations that share IoT responses. Currently, AWS and Microsoft Azure services are the leading cloud providers of IoT applications.

The rest of this paper is organized as follows: Section 2 presents the IoT and cloud convergence; Section 3 covers cloud-based IoT solutions; Section 4 presents cloud-based IoT applications for smart cities; Section 5 addresses the question of "why cloud-based IoT applications are essential for smart cities"; Section 6 discusses smart city applications; and Section 7 presents the conclusions.

2. IoT and Cloud Convergence

As IoT applications generate large quantities data and include multiple computational add-ons (e.g., real-time processing and analytics processes), integration with cloud computing infrastructure can be cost saving. Consider the following scenario as an excellent example. In a small to medium-sized enterprise, that manufactures a power control device used in smart homes and buildings, their ambitions for expansion may be unpleasantly and expensively achieved by spreading product details (e.g., sensors and WSN data) in the cloud. As small and medium-sized enterprises (SMEs) gain more extensive clientele and greater visibility for their product, they may collect and utilize an increasing amount of data. Furthermore, cloud integration enables SMEs to preserve and handle enormous data sets gathered from several sources [21–23].

A smart city can benefit from cloud-based building and system distribution. Intelligent power management applications, smart water controls, smart transportation controls, urban mobility, and other IoT packages are expected to be features of the smart city. Furthermore, they may provide higher volumes of data. The smart city can now handle these records and applications through estimating the cloud integration. Moreover, the cloud can assist in speeding up the expansion of the aforementioned packages and the deployment of recent ones, which have previously elicited substantial concerns over the provision of the necessary computer resources. A public cloud computing provider can expand the IoT ecosystem by granting third-party access to its infrastructure, allowing them to combine IoT data and computer resources operating on IoT devices. The company can provide IoT data for access and service. This shows the applicability and desire for IoT infrastructure and cloud computing modification. Integration has always been problematic, however, owing to the conflicting IoT and cloud architecture. IoT devices tend to be regionally constrained, with limited support, expensive estimating (depending on upgrade/shipping cost), and frequently unstable (according to resources and access). On the other hand, cloud computing resources are typically located in a reasonable and efficient place that provides rapidity and flexibility. Sensors and devices are established before integrating data and their offerings into the cloud, allowing them to distribute across any cloud resources and reducing inconsistencies.

Furthermore, service implementation and sensor acquisition are placed in the cloud so that services and sensors are available in real-time. IoT and cloud integration can transfer sensory and WSN information to cloud. This widespread infrastructure was one of the earliest innovations (widely used for radiation detection and radiation maps during earthquakes in Japan). There are, however, dozens of well-known clouds, including ThingsWorx, ThingSpeak, cloud-sensor, and real-time cloud services. Consumers that wish to save IoT packages in the cloud can pay as they go with these public cloud providers. Most of the providers include advanced developer tools that enhance cloud systems, making them akin to IoT services in the cloud. Additionally, cloud computing infrastructure, IoT/cloud infrastructure, and associated services might be designated as follows:

2.1. Infrastructure as a Service (IaaS)

IoT/clouds allow users to connect to sensors and actuators in the cloud. IaaS is a significant computation, which stores and communicates a solution upon request. It provides a cloud computing service. IaaS offers IoT management to manage objects as a prerequisite in the supply of appropriate services [24–27].

2.2. Platform-as-a-Service (PaaS)

The IoT/cloud public infrastructure described the high-performance PaaS model for IoT/cloud services. PaaS is a full cloud-based development and deployment architecture, including capabilities to provide services that range from the simplest cloud-based services to complex, cloud-capable businesses.

2.3. Software-as-a-Service (SaaS)

SaaS products are those that allow users to obtain complete software packages based specially on the cloud and IoT. The SaaS packages are similar to standard cloud-based packages using IoT sensors and devices.

The assertion is that SaaS IoT packages are typically developed on top of PaaS infrastructure and enable business models that are dependent on IoT software and services. It gives a broad understanding of IoT and cloud interactions and why they are so significant and advantageous. At present, a rising number of IoT devices are cloud-based, allowing users to benefit from their overall performance, business expertise, and the payment features they provide. The benefits of the IoT cloud, by assuring the interoperability of IoT data and contributions within the cloud, are optimized, which is why they enable high records for analytic purposes in regions involving smart energy, smart transportation, smart cities, and communications. Moreover, IoT components with IoT-based wearable computing can profit from IoT/cloud integration.

The IoT is a mechanism for connecting computer devices, machine tools, and virtual objects, animals, or people that were given indications and the power to modify records on a network without the need for human or computer contact. The IoT umbrella encompasses anything produced by humans or devices that can be specified by an I.P. address and possess the ability to send data over a network. With the advancement of information technology, the IoT has expanded. IoT devices enable communication between sensors, with billions of connected devices likely to become part of human lives in the future

Many businesses around the city, including the agricultural sector, health care, energy, transportation, and building management, were nearly completely taken over by IoT. Experts and active developers are attempting to determine other ways to connect to the IoT via cloud network. IoT applications are being developed, which are an extraordinary approach to aid future development. People no longer gain from the increased connectedness of devices, but the socially relevant devices they collect from IoT network. Machines can provide helpful information about performance and appearance in the field to the communication enabled by cloud solutions. Related devices are not limited to certifying businesses' devices, but they can also move away from personal devices for everyone via network cloud solutions. Through closed storage, processing power, energy, and other quick connections, the timing of things is controlled with the help of reality. Due to the wide variety of sensors, and the number of records they produce, the collection, storage, and efficiency of IoT remains challenging.

IoT also links devices and people while generating massive amounts of data. Due to sophisticated systems, typical connection agreements, and legacy application compliance, gaining access to information through enterprises can be a difficult task. IoT infrastructure (e.g., sensors, WSN, and RFID) is either unique or ubiquitous, and resources to build and convey access are restricted and often expensive. IoT devices are frequently afflicted by deficient processing and storage resources and a limited budget due to their productivity. Cloud computing provides limitless storage and is energy efficient. The cloud connects users to information and resources via an Internet-based link. Cloud infrastructure is a self-contained or ubiquitous region (resources that may be accessed from anywhere) that enables simple access to lower-cost resources. Virtualization in the cloud is the result of the resource base resources' autonomous effort. The IoT-cloud connection is a way to experience the resources and is constantly available during cloud computing. The demand for IoT systems for cloud compression, availability, and performance promotes the integration of IoT and cloud computing technology. This connection allows for the storing and processing of accumulated facts, identical data in different contributions, the integration of points from multiple devices and users, and user mobility. Several attempts were made to integrate IoT and cloud technology into the research network and the commercial community. The capacity to transfer data to the cloud because of this combination of power is extraordinary in terms of working, managing systems, monitoring, and controlling the distribution of data. For IoT packages, the cloud can make use of reliable restoration and processing equipment and retrieval packages. Large-scale IoT systems are inherently insecure. Large IoT systems contain a diverse set of diffuse sensors that create data and must be addressed. The cloud offers an oversized output service and can use IoT technologies to build a complicated system. Furthermore, many IoT services can benefit from a delivery system that focuses on establishing and delivering IoT systems and is primarily based on cloud infrastructure.

A platform for the IoT is primarily based in the cloud, with the capability to design, deploy, run, and manage networks of cloud-based IoT devices. This depicts the initial capabilities of the cloud-based IoT platform and architecture, in addition to their interactions with the three cloud computing fashions (i.e., Iaas, PaaS, and SaaS). All IoT devices will connect with a cloud-based ubiquitous resource pool. Devices can access without difficulty, accumulate, systematize, visualize, archive, proportion, and seek full-size volumes of sensor information from many programs using this platform.

The cloud's computational and storage resources may be used to produce, analyze, and save sensor information. Moreover, a cloud-based IoT platform permits customers and programs access to percentage sensor data underneath flexible usage situations, permitting sensor devices to meet specialized processing responsibilities. This platform is an extended-time period cloud computing solution for sensor control that includes sensor devices as a supply to the customers. It provides sensor monitoring and manipulates offerings to customers through a web browser. Furthermore, the cloud simplifies data throughout IoT information collecting and processing additives, considering simple setup and integration of latest issues, while retaining low deployment charges and complex data processing. Clients can execute any application on cloud hardware with the use of this platform's cloud infrastructure.

The platform streamlines application improvement, eliminates the need for infrastructure, makes problems less challenging to manipulate, and lowers refurbishment charges. It provides clients with unique tool control abilities, direct communication with devices, storage to accumulate data from issues, and event transition. The cloud's computing and service belongings may be used to save, process, and analyze a significant amount of sensor data. The developer suite is fixed on complex and rapid cloud carrier devices for developing IoT applications. This technology encompasses open service software programming interfaces, providing developers with high-degree improvement and deployment capabilities. Subscription management, network coordination, subjects' connection, matters discovery, statistics intelligence, and things composition are all part of the system, a package deal of cloud offerings that help with the deployment and specialization of processing services.

IoT devices are commonly grouped into IoT networks in cloud-based IoT structures, including a domestic community. Those networks are connected to the cloud through a dedicated gateway, generally a home router or a mobile phone. The committed gatemanner forwards the detected information from the networks to the cloud. The cloud continuously retains data and ensures it is on hand to contribution to applications. The provider can provide specific cloud services with permission to access and manage the information through cloud processing belongings. The cloud serves as an intermediary layer among issues and IoT applications, concealing all the implementation's complexities and functionalities. This platform can improve destiny software since data collection, and records transmission will offer a new solution. The design of the cloud-based, completely IoT platform aims to maximize the supply of data and services. Figure 2 depicts the cloud-based IoT platform connected through the cloud-based IoT applications. The cloud applications can be stored and visualized so that the customer may also access, monitor, and control from everywhere and at any time using a web browser or application.

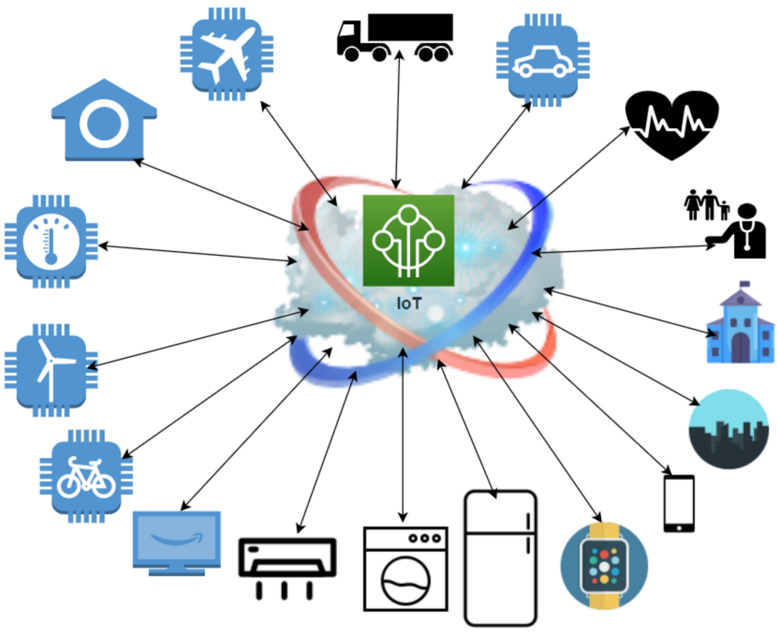

Figure 2. Cloud-IoT applications main areas.

3. Cloud-Based IoT Solutions

Many organizations recommend cloud-based systems for IoT devices. Provided below is a list of the companies and corporations that offer cloud-based IoT services. We can select one from the IoT system to obtain the required cloud platform for data collection and testing. With more than one IoT-based application, many statistics are created with the help of IoT devices.

3.1. Xively

A cloud-based solution that allows multiple teams to fix IoT-related problems without difficulties. The offer comes from the agency's trademark (linked product control), which assists in keeping records secure and interactive [27].

3.2. ThingSpeak

ThingSpeak is one of the most notable IoT-related names and was responsible for the conversion of many products within the IoT. It can expand the task in three easy steps: collection, analysis, and development. ThingSpeak features multiple offers, such as information recognition and analytics tools. With growing customer issues and building a reputation, ThingSpeak is a platform that holds valuable IoT data securely. Collected data can be stored on private or public cloud networks [28].

3.3. Plotly

Plotly is an open-source API, which is mainly used to transmit data from IoT devices, such as Raspberry Pi and Arduino. Services, such as formal or systematic cloud, can be used to streamline data. Plotly is more determined in terms of significant facts and its analytical strategies, making use of them to set displays and facts differently from your devices. It is one of the most popular data analysis and recognition tools among IoT professionals [29].

3.4. Exosite

Exosite is a prominent IoT framework for the building of linked things, solutions, and companies. It is fully-fledged organization, which offers cloud-based offerings to expand, launch, and incorporate the most advanced ideas into your applications. It provides a number of monitoring and analysis statistics, and is a significant business venture dedicated to development and innovation. It likewise includes the overall package from developing to enhancing existing sales skills. With automatic updates and installation services, this is an excellent platform for industrial applications. This platform is easy to use for builders of cloud-connected applications [30].

3.5. Grove Stream

One of the most widely used online systems, this platform is used to attach thousands of flows of large amounts of data via cloud computing. You can visualize, explore, store, and share data. It provides a sophisticated set of tools for users to investigate sensory information that help IoT applications. It also offers an extensive network of cloud statistics in addition to the data that drive the service and server [31].

3.6. Axeda

Axeda offers cloud-based contributions to build and strengthen IoT operations. This cloud platform is used for many tasks, such as building, converting data from sensors to information, and navigating IoT systems. In addition, it introduces awareness of the functions associated with IoT and M2M. The cloud device provides transforming strategies to manage advanced, technique-based cloud IoT applications [32].

3.7. ThingWorx

ThingWorx is a critical product within the IoT system. It provides an inexpensive and robust solution for cloud delivery to IoT. It has four crucial built-in functions for analyzing, constructing, managing, and gathering IoT data. With many plug-ins and extensions, this is considered one of the most widely used applications for connecting many devices to the cloud [33].

3.8. Yaler

Yaler is used to transmit large quantities of data among devices, an important feature that is used in the electronics industry and the Internet of devices. With the introduction of the new market, it has accelerated its use and operations into the IoT cloud. It offers cloud-based connectivity service as one of its top offerings [34].

4. Cloud-Based IoT Applications for Smart Cities

Table 2 shows the list of cloud-based IoT applications for smart cities.

Table 2. Cloud-based IoT applications and their roles in smart cities.

Applications	Ref.	IoT Based Application	Use Cloud Computing	Future Perspectives	Roles in Smart Cities
Bosch IoT Suite	[35]	√	√	√	1. Fast project success 2. Maximum security 3. Future-proof investment 4. End-to-end service solution 5. Flexible deployment
ABB Robotics	[36]	√	√	√	1. Robotics 2. Machine automation 3. Digital services 4. Providing innovative solutions for a diverse range of industries
Airbus	[37]	√	√	√	1. Design, manufacture, and deliver industry-leading commercial aircraft, helicopters, military transports, satellites, and launch vehicles 2. Providing data services, navigation, secure communications, and urban mobility.
Amazon Warehouse	[38]	√	√	√	1. E-commerce 2. Cloud computing 3. Digital streaming 4. Artificial intelligence
Boeing	[39]	√	√	√	1. Commercial and military aircraft 2. Satellites 3. Weapons 4. Electronic and defense systems 5. Launch systems 6. Advanced information and communication systems, and performance-based logistics and training
Caterpillar	[40]	√	√	√	1. Data-driven transformations 2. Intelligence platform 3. Shipboard sensors monitor everything from generators to engines, GPS, air conditioning systems, and fuel meters
Fanuc	[41]	√	√	√	1. Manufactures all products in highly automated factories 2. Factories are highly automated, with all devices being connected to a network 3. Each process is automated with robots and connected with an automatic transport system
Gehring	[42]	√	√	√	1. Honing technology 2. Supplying cutting-edge surface finish technology solutions for internal combustion engines, gears, and numerous other industrial applications
Hitachi	[43]	√	√	√	1. IoT-ready industrial controller 2. H.X. Series Hybrid Model 3. Executing control functions, such as sequence control and motion control 4. Execute information system communication

Table 2. *Cont.*

Applications	Ref.	IoT Based Application	Use Cloud Computing	Future Perspectives	Roles in Smart Cities
John Deere	[44]	√	√	√	1. Electrification 2. eAutoPowr transmission 3. Large spraying drone (VoloDrone) 4. Autonomy through automation 5. Artificial Intelligence
Kaeser kom-pressoren	[45]	√	√	√	1. Compressor system design to professional air service 2. Exceptional energy balance 3. Time-saving maintenance and operation 4. Exceptional material quality and durability
Komatsu	[46]	√	√	√	1. Construction 2. Demolition, waste, and recycling 3. Mining 4. Agriculture and livestock 5. Logistics 6. Industrial machinery
Kuka	[47]	√	√	√	1. Robot systems 2. Automated guided vehicle systems 3. Mobility 4. Process Technologies
Maersk	[48]	√	√	√	1. Global air freight transportation 2. Most time-efficient freight solution for many destinations around the world 3. Inventory costs reduction while improving flexibility 4. Highly reliable arrival and departure times
Magna Steyr	[49]	√	√	√	1. Ideal automotive contract manufacturer 2. Produce vehicles with conventional, hybrid, and electric powertrains
Bluescope	[50]	√	√	√	1. Provider of innovative steel materials, products, systems, and technologies
Real-time Innovation	[51]	√	√	√	1. Largest software framework provider for autonomous systems 2. Enabled comprehensive connectivity
Rio Tinto	[52]	√	√	√	1. Produce iron ore for steel, aluminum for cars and smartphones, copper for wind turbines, etc.
The Shell	[53]	√	√	√	1. Shell is a global group of energy and petrochemical companies that aims to meet the world's growing need for more and cleaner energy solutions in ways that are economically, environmentally, and socially responsible
Stanley Black & Decker	[54]	√	√	√	1. Outstanding performance and ceaseless innovation 2. Use industrial tools that build and rebuild infrastructure 3. Provide the security services and solutions

4.1. Bosch IoT Suite

In 2015, Bosch introduced the first toolbox in the cloud for IoT developers. This was an important invention, and supported future-oriented products and the design of emerging revolutionary commercial strategies. IoT is the essential technique for improving practices, performance improvement, and continuous improvement. IoT allows businesses to learn consumer demands, enhance flying operations, and instantaneously introduce unique characteristics [35].

4.2. ABB Robotics

The IIoT is one of the most visible to undertake the idea of protection and the usage of connected sensors for robots. ABB Robotics is a global leader in robotics, industrial automation, and cloud solutions, offering cutting-edge products to a wide range of sectors, including manufacturing, telecommunications, and transportation. ABB Robotics engages over 11,000 professionals in 53 nations and has sold over 500,000 robotic systems, making it one of the world's most extensive robotics and industrial intelligence companies [36].

4.3. Airbus

Airbus is a company that provides IoT solutions all over the globe. Regarding worldwide connection, Airbus uses Astrocast nanosatellites to deploy its IoT technologies and connectivity network. Inside a centralized design, the IoT application has a communication link. It relies on a dependable infrastructure that can accommodate thousands of users utilizing sensors and functioning on the same radio signals [37].

4.4. Amazon Warehouse

The supermarket that sells online is not generally known as an IIoT enterprise, but the organization is the inventor of things approximately inventory and inventory planning. Amazon looks at the limits of automation and human interaction, and the enterprise's coverage of the use of delivery drones has obtained considerable attention [38].

4.5. Boeing: The Usage of IoT to Force Manufacturing Performance

Aviation pioneer William Boeing stated that it "behooves no one to dismiss any novel idea with the statement, it can't be done". The worldwide airline founded on Boeing is manifestly in agreement with that ethos. The enterprise has made splendid strides in reusing its commercial enterprise. Boeing and its solutions have aggressively used IoT time to force operations among factories and convoy chains. Smart technologies that enable travelers to engage with the aircraft as never before, such as devices that speak to smart toilets or smart lighting handled by the networks, might be introduced into the commercial flight cabin environment [39].

4.6. Caterpillar: IIoT Pioneer

Caterpillar is using the Internet of Things to boost production. Heavy equipment has long been a pioneer of IoT initiatives. Throughout aggregate, 560,000 Caterpillar trucks are networked across the globe. Furthermore, the firm has developed a collection of software and analytics tools and APIs to assist it and its clients in processing, analyzing, and storing information. Whereas the firm has an in-house analytics department, it has also developed a community of partnerships to give customers various alternatives for these objectives. Notably, the firm has formed a new collaboration with Zuora to provide customers with cloud-based solutions for managing and analyzing subscription facilities [40].

4.7. Fanuc: Supports Decreasing the Downtime in Factories

This maker of robots is determined to reduce the downtime in industrial facilities. Through the usage of sensors in its robots, alongside cloud-primarily based analytics, the organization can determine when the failure of a robotic device or system is imminent. Fanuc strives to reduce downtime in all of its factories across the globe. It offers continuous servicing to its products for as long as they are utilized by consumers, with more than 260 service centers in 108 nations, showing an adherence to the philosophy of "Service First." [41].

4.8. Gehring: Pioneer in the Production

Gehring generation, a 91-year-old manufacturer of metallic sprucing machines, started early to adopt IIoT manufacturing. At present, the organization empowers its customers to obtain details of the way Gehring machines paint prior to receiving an order. It does so via virtual technology, illuminating real-time realities from modern machines to ensure it meets customer needs. Gehring makes use of real-time cloud-based monitoring to lessen downtime and improve its productiveness through its related production centers, visualizing and controlling data from devices within the cloud [42].

4.9. Hitachi: Established IIoT Manner

Hitachi is a Japanese company that adheres to diverse change institutions to integrate its software and operations. The H.X. Family Combo Models is a revolutionary IoT-ready industrial controller from Hitachi. This controller could perform computer network communications and software platforms tailored to data processing and functionalities, suchas sequence control and motion control, without impacting control functions [43].

4.10. John Deere: Future of Farming

Changing climate conditions is only one of the numerous problems that farming faces. John Deere is devoting a significant amount of effort towards addressing these issues. Electrification, automation to autonomy, and artificial intelligence are three key innovations that will shape the future. Due to Washington's position in 2015, Google no longer leads the revolution in self-driving automobiles and, instead, John Deere does. The business is smartly designed to pioneer using GPS [44].

4.11. Kaeser Kompressoren

In 1919, the German producer of air pumps, air dryers, and filters has integrated digital communications into its merchandise. Kaeser Kompressoren is a leading provider of air compressor solutions across the globe, with around 7000 people working for the firm [45].

4.12. Komatsu

The Japanese heavy machine producer has plenty of the latest IIoT substances. In 2011, it spent the period linked to its Japanese manufacturing facilities. Komatsu has related all its robots to its key production centers and network, allowing managers to keep an eye on global operations in real-time. The organization is a mining revolution. Its big pickup vehicles will be visible at the future Rio Tinto mine in Australia [46].

4.13. Kuka: Robots

German robotics professional, Kuka, has an IoT system that reaches many enterprises. Kuka makes robotic systems and factory industrial Internet of Things. The Kuka consultation method is built on a flexible training philosophy that constantly focuses on providing value addition [47].

4.14. Maersk: Global Air Freight Transportation

Maersk is well-known for its industrialized cargo shipping services, but the firm is expanding beyond that. Maersk is becoming an end-to-end supply chain logistics company by integrating solutions. The firm utilizes Microsoft Azure IoT technology to detect and control 380,000 refrigerated containers as they travel across the globe. Customers will always know wherever their goods are, and environmental factors may be changed to ensure that the food and medication from one side of the global reach the other in pristine condition. It is confident in Azure's IoT capabilities because of the platform's development and adaptability [48].

4.15. Magna Steyr: Smart Automotive Production

Austrian car producer Magna Steyr is a pioneer within the field of smart industry. It has 161,000 employees, working on automobile parts and automotive components, automatically ordering cashback although emerging technologies. Magna is also experimenting with using "smart packaging" and improving it through IoT [49].

4.16. BlueScope

As per Andrew Spence, BlueScope Constructing Products' regional director of operations and production, smart, connected devices enable the firm to improve current systems and develop entirely new alternatives. Process parameters are pressure, temp, flows, ongoing, tier, mobilization, and acid content. For example, according to Spence, improvements to the production process and producing information that could be used in designs to assist more advanced and accurate control strategies can now be easily evaluated through the Internet of Things. The Internet of Things is also helping to improve the safety and health of workers [50].

4.17. Real-Time Innovation (RTI): The Largest Software Framework Provider for Autonomous Systems

The leading software framework firm for autonomous systems is Real-Time Innovations (RTI). It is the most widely used paradigm for creating smart decentralized systems around the world. Its context is unique in that it immediately distributes information, linking A.I. techniques to real networking of devices to develop autonomous systems. It offers an established product portfolio that allows hundreds of applications to securely share data in real-time and function as one integrated solution in the race to serve clients who are changing the world into a better place [51].

4.18. Rio Tinto

Rio Tinto generates elements that are necessary for human growth. The British/ Australian mining conglomerate has unveiled a new computerized program in Pilbara, western Australia. Non-motorized trucks and trains pull steel far away from mining sites simultaneously as a faraway operator controls drills from an available console. Non-pilot vessels may be appropriately terminated. The organization has a Perth-based facility that connects to its mines, similarly to rail and port operations, wherein engineers, analysts, planners, and experts remotely direct mining operations [52].

4.19. The Shell

Shell was named the most significant oil and gasoline exchange employer in a Rigzone in 2016. Shell's senior chairman for technology officer, Yuri Sebregts, stated, "The new possibilities in dealing with data over the last several years have unlocked great potential in all parts of what we do in the firm", and "Right now, this will assist us in scaling ideas we've been going to develop". Shell is also working with Microsoft experts to enhance horizontal drilling using A.I. and machine intelligence. By switching from traditional drilling wells to lengthy, horizontal drilling, the oil and gas sector has realized considerable cost savings, decreased its footprint, and discovered new oil and gas resources onshore [53].

4.20. Stanley Black & Decker

Stanley Black & Decker delivers the equipment and creative solutions for the constructors and adventurers, creators and explorers, and those influencing and remaking the world through hard work and imagination. It bands together and brings the best in the world to build realistic, relevant goods and solutions that make lives more accessible, while also enabling individuals to have smarter, healthier, and more rewarding jobs. This achievement was fueled by quality and creativity, and through the understanding that there is more that they can do for the world. by providing value to customers, coworkers, and societies [54].

5. Why Cloud-Based IoT Applications Are Essential for Smart Cities

Cities have transitioned to IoT technologies and communication technologies for a variety of reasons.

- The IoT systems enable sensors to detect data to manage appliance consumption, potentially resulting in significant cost savings;
- Since installing and maintaining IoT applications is more accessible, the cost is a significant consideration when determining whether to go physically or online. Furthermore, the prices are decreasing, and communications' durability and power output allow for new circumstances that were previously not possible;
- Efficiency is one of the most significant considerations [55]. Service providers must physically go to the web page to examine and execute communications infrastructure for the most stressful solutions;
- Wireless communication provides monitoring and control of IoT transmission through various analyses. This allows administrators to upgrade firmware and apply security solutions to all completed plans and get automatic alerts in the event of an issue;
- Reduced assistance is frequently the cause, as it should be, especially in operating situations and when smart road lighting and tracking equipment are repaired.

Table 3 represents the previous studies on smart city solutions.

Table 3. Smart Cities Solution (previous studies).

Lea et al.	[55]	2014	City hub: A cloud-based IoT platform for smart cities
Sikder et al.	[56]	2018	IoT-enabled smart lighting systems for smart cities
Ding et al.	[57]	2018	Intelligent data transportation in smart cities: A spectrum-aware approach
Ramos et al.	[58]	2020	Smart water management towards future water sustainable networks
Chung et al.	[59]	2021	Smart Tourism Cities' Competitiveness Index: A Conceptual Model
Biyik et al.	[60]	2021	Smart Parking Systems: Reviewing the Literature, Architecture and Ways Forward
Miyasawa et al.	[61]	2021	Spatial demand forecasting based on smart meter data for improving local energy self-sufficiency in smart cities
Khalifeh et al.	[62]	2021	Wireless Sensor Networks for Smart Cities: Network Design, Implementation and Performance Evaluation
McCurdy et al.	[63]	2021	Waste Management in Smart Cities: A Survey on Public Perception and the Implications for Service Level Agreements
Chatterjee et al.	[64]	2021	Smart Cities and Their Quality of Life: An Interdisciplinary Perspective
Múnera et al.	[65]	2021	IoT-based air quality monitoring systems for smart cities: A systematic mapping study
P Kasznar et al.	[66]	2021	Multiple Dimensions of Smart Cities' Infrastructure: A Review

6. Smart City Applications

"Smart cities" are a collection of enterprises that include city lighting, traffic, wastewater management, emergency services, tourism management, and so forth. Inventive new city occupations are likely to become more widely adopted and technology focused based on the needs of specific use cases. Figure 3 shows the smart cities applications.

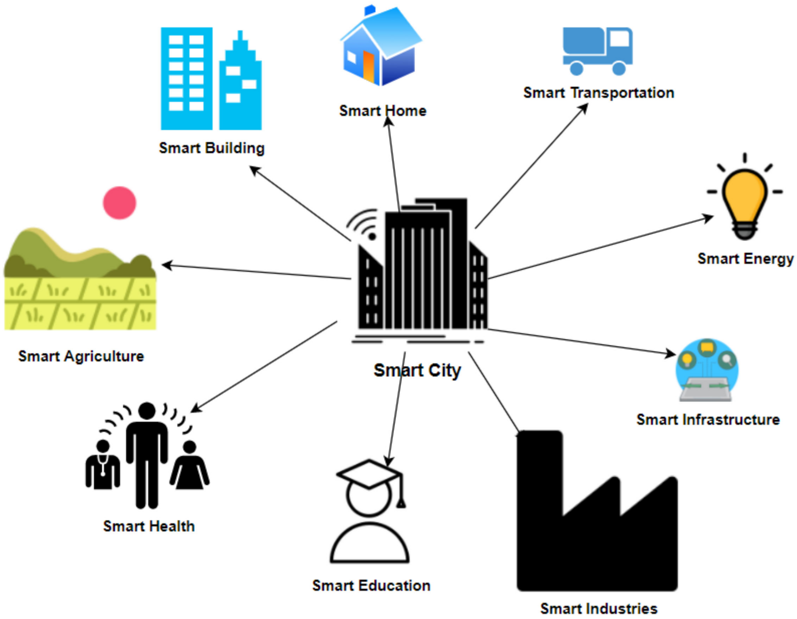

Figure 3. Smart cities applications.

6.1. Lighting Systems in Smart Cities

Light sources are one of the most ubiquitous IoT applications for smart cities, with several governments currently relying on IoT to save money and energy. The system includes a ruggedized Digi wr44r router class, which provides connectivity and authentication for transferring numerous device nodes to a smart pole. The smart lighting may be used for a range of tasks, as follows:

1. Controls for lighting;
2. Cameras for surveillance;
3. Natural perceptions;
4. Electronic billboards;
5. Electric vehicle charging stations;
6. Access to wireless technology.

The use of IoT in smart houses makes street light maintenance and management practical and cost-effective. The lighting can be synchronized by equipping streetlights with sensors and linking them to a cloud management service [56]. Smart lighting systems monitor light, people, and vehicle movement, then integrate it with old and contextual data (e.g., unique functions, public delivery system, time and year, etc.) and analyze it to enhance the lighting schedule. When pedestrians cross a road, the lights around the crossing could be turned on, when a bus is about to arrive at the bus stop, the streetlights could be brightened, and so on.

6.2. Transportation

Transportation infrastructure is another rapidly expanding component of smart city applications. Transportation businesses and smart cities stand to gain considerably in cost savings, security, route management, and advanced passenger experience. While many communities have seen a reduction in shipping in recent years with the advent of buses and trains and wireless passenger links, many are now experiencing additional improvements. They help the smart, urban transit organization for fast-moving authorities, as they operate over 330 biodiesel buses and power buses in all of Michigan's Macomb, Oakland, and Wayne cities. The smart transportation system's IoT response contains several functions, all of which are powered by the Digi wr44 r router:

1. The vehicle circuit system and a wireless connection are between the motors and the smarts dispatch center. This increases concerns regarding the transition from the existing analog network to IP-based voice-to-voice communication;
2. Collection of comfortable fares and mobile ticketing are via wr44 r state wall firewall, IPsec VPN, social isolation, and verification;
3. Intermediate communication and passenger controlled;
4. With online service, we can track and maintain our groups and devices, including crowd updates and vehicle monitoring—these enhancements aid transportation employees, couriers, and passengers in feeling safer in their communication and development [57].

Furthermore, as the number of green automobiles increases, smart cities will experience a fresher atmosphere. In addition to the modernization of vehicles and suburban residents who travel by car, the goal is to reduce traffic congestion and air pollution.

6.3. Water Management

Water management software in smart cities is used for various purposes, including wastewater solutions, water tracking, and environmental restoration projects [58]. IoT packages are becoming more common in locations such as state-owned companies and nearby municipalities. It improves access to aging infrastructure, increases efficiency, improves visibility of remote tanks and water management plans, and lowers the cost of tracking and assisting their facilities. The gateway connects to a network of services that can help with various issues, such as tank pressure and water levels. Digi far-flung is a remote-control solution for testing the components of an IoT distribution tool, which can also integrate IoT devices and systems into modules and sensors. U.S. Water, which delivers water treatment services to commercial customers across the United States and Canada, evolved out of a response from Digi to establish a regional, remote tracking and management solution with their cutting-edge technology.

6.4. Smart Tourism

Finding ways to boost site traffic is one of the most challenging difficulties that big cities face. For example, Los Angeles is one of the world's busiest cities, and it has devised a smart shipping strategy to manage tourists. Sensors embedded in the pavement feed real-time traffic crash updates to a critical traffic control platform, analyzing the data and adjusting the site visitor lights to traffic. Simultaneously, past data is used to predict where traffic will travel, with none of these tactics requiring human intervention. Smart cities ensure that their citizens move as accurately and efficiently as possible from one place to another. Municipalities imposed IoT development and compelled visitor reactions to the smart site to achieve this goal. In addition to collecting GPS data on smartphones, smart traffic solutions use sensors to help drivers determine cars' range, location, and speed [59]. Simultaneously, intelligent visitor lights connected to a cloud control platform allow for the measurement of time and management of the lights, based on the present status of the visitors, to avoid traffic congestion. Furthermore, by analyzing past data, intelligent traffic management responses can predict where people will cross and take precautions to prevent power outages.

For example, being one of the world's most popular tourist locations, they employed tourist responses to help regulate traffic flow. On a robust guest management platform, street-surface sensors and closed-circuit cameras provide real-time information virtually to traffic flow. The platform analyzes data and sends alerts to the customers about traffic congestion and misuse of road signs through applications.

6.5. Smart Parking

Cities also employ smart parking solutions that detect when a vehicle has departed from a parking space. Sensors embedded in the ground notify the driver of available parking spaces via a smartphone application. Smart parking is an authenticity, requiring no specialized infrastructure or significant expenditure. Smart parking responses check if parking spaces are available and construct a real-time parking map using GPS data from drivers' smartphones (or road level sensors embedded in the ground in parking lots) [60]. Drivers are told when the nearest parking space opened and, instead of relying on memory, they can make use of a map on their phone to find a parking space. IoT sensors can be utilized to send messages to the connected devices. Public transportation operators can use this information to improve visiting data, resulting in increased safety and punctuality.

Many train companies in London are waiting for passenger cars to be loaded for journeys inside and outside. The data are gathered from ticket sales, motion sensors, and CCTV cameras located near the platform. Train operators expect each car to load with people and urge customers to disperse from the area when a train arrives at a station to enhance loading. Train operators prevent train delays by boosting energy usage. Citizens in smart communities can save money by allowing them to handle extra resources at home.

6.6. Smart Meters

Cities can give citizens the most crucial linkages to service delivery structures through the smart meter community. Smartly connected meters can now transfer data to general applications over the network in real-time, giving it accurate meter readings [61]. With the cooperation of the entire group, the smart meter allows service organizations to charge the quantity of water energy, and fuel used more accurately.

Service organizations can be more visible and observe how their clients use power and water through the smart meter service. Resource organizations can use a smart meter service to show real-time calls and redirect resources as needed or encourage consumers to use less energy or water during shortages.

6.7. Smart Remote

Smart city solutions based on the IoT can also give inhabitants application management services. These contributions enable citizens to utilize their smart remote on, for example, their television and air conditioning to take advantage of their remote capabilities [62]. For example, a homeowner may switch off heating in his home using a mobile phone. Additionally, in an emergency (e.g., water leaks), utility companies can notify homeowners and send experts to remedy these issues.

6.8. Waste Management

Waste management solutions help to increase the efficiency of the waste chain and reduce operating costs, while, at the same time, dealing with any environmental concerns associated with an inefficient waste chain. In these responses, the waste container receives a stage sensor; while reaching the boundary, the truck driver's management platform gets a notification by their phone. The message helps them to avoid empty drains by performing the related task. Many open garbage collection operators can follow these procedures. IoT-powered city-based responses help increase waste collection schedules with the help of waste tracing and the introduction of methodology and performance analysis [63].

Each waste field receives a sensor that collects records about the level of waste in the area. The waste management solution detects sensor data, evaluates it, and sends a notification to the truck's mobile application. Similarly, the truck driver pours out the entire container to empty it. IoT smart city solutions in the surrounding region allow tracking of the crucial factors required for a healthy environment. A major city, for example, may incorporate a sensory community across the water grid and bring them together on a cloud management platform to reveal the most significant waste.

6.9. Social Security

IoT-based smart city technology provides real-time tracking, analytics, and alternatives for increasing social security. Public security systems can predict the power of crime by combining statistics from sensors and CCTV cameras provided to the city with data from social media feeds and readings. The police would be able to dissuade or punish criminals as a result of these social security applications. The solution is to use networked devices in the smart city. For example, in the case of a crime, the device information is sent to a cloud platform, the data is analyzed, and the criminal is identified. The platform calculates the time and the distance between the gun and the mobile phone that reported a gunshot. The cloud software can then alert police with a mobile application [64].

6.10. Air Control Platform

Smart cities are also valuable tools for detecting and forecasting pollution in real-time. Cities can get to the source of their emissions problems and consider strategic approaches to reduce air pollution. Monitoring the amount of greenhouse gases in the air is essential; regulatory systems follow the rules and can be used to, for example, take control of tourists' local flights. Before that, there may be a need to ensure that visitor changes do not cause accidents in other areas. This is possible because of the combination of the way visitors control the air quality control system [65].

6.11. Smart Infrastructure

Building infrastructure must be planned carefully and effectively. Virtual technology is becoming increasingly important for cities to maintain growth conditions [66]. Cities should invest in electric motors and self-propelled vehicles [67] to cut carbon dioxide emissions. Smart technology is being leveraged to create energy-efficient and environmentally friendly infrastructure. For example, smart lighting provides light while someone passes through a smart lighting area, reducing energy expenditure [68,69]. Artificial intelligence could perform a key role in enabling wireless connectivity to the IoT infrastructure [70]. Smart cities will improve individuals' lives and can lead to a new age of efficient and data-driven decision-making, ranging from enhancing transport flows and allowing interconnected and affordable services, to wireless connections, mobile edge computing, and the IoT [71,72]. A tracking system for people, for example, designed to track children or the elderly in crowded environments using mobile applications for smart cities is discussed in [73]. The data processing in smart cities using blockchain-based big data integrity service is discussed in [74].

7. Conclusions

Accurate information could be accessed, analyzed, and controlled by cloud-based enabling technologies to assist experts, businesses, and people in making smarter policies to enhance the standard of peoples' life. People interact in smart city environments using their mobile devices through linked vehicles and smart homes. When devices and information are connected to a city's physical systems and facilities, expenses may be reduced and efficiency improved. Through the assistance of the Internet of Things, cities could enhance resource transmission, expedite garbage collection, reduce accidents, and remove pollutants. The author explored and discussed the cloud-based IoT applications and their roles in smart cities in this paper. The author also covered IoT and cloud convergence, cloud-based IoT solutions, and cloud-based IoT applications for smart cities. More applications can be discovered, and their importance in smart cities discussed, in future research.

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Abbreviations

The following abbreviations are used in this paper:

IoT	Internet of Things
IIoT	Industrial Internet of Things
ICT	Information and Communication Technology
API	Application programming interface
CapEx	Capital expenditures
IaaS	Infrastructure as a service
PaaS	Platform-as-a-Service
SaaS	Software-as-a-Service
WSN	Wireless Sensor Networks
RFID	Radio Frequency Identification
ML	Machine learning
GPS	Global Positioning System
SMEs	Small and medium-sized enterprises
AI	Artificial Intelligence

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smart cities

Article

Application of Deep Learning on UAV-Based Aerial Images for Flood Detection

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Abstract: Floods are one of the most fatal and devastating disasters, instigating an immense loss of human lives and damage to property, infrastructure, and agricultural lands. To cater to this, there is a need to develop and implement real-time flood management systems that could instantly detect flooded regions to initiate relief activities as early as possible. Current imaging systems, relying on satellites, have demonstrated low accuracy and delayed response, making them unreliable and impractical to be used in emergency responses to natural disasters such as flooding. This research employs Unmanned Aerial Vehicles (UAVs) to develop an automated imaging system that can identify inundated areas from aerial images. The Haar cascade classifier was explored in the case study to detect landmarks such as roads and buildings from the aerial images captured by UAVs and identify flooded areas. The extracted landmarks are added to the training dataset that is used to train a deep learning algorithm. Experimental results show that buildings and roads can be detected from the images with 91% and 94% accuracy, respectively. The overall accuracy of 91% is recorded in classifying flooded and non-flooded regions from the input case study images. The system has shown promising results on test images belonging to both pre- and post-flood classes. The flood relief and rescue workers can quickly locate flooded regions and rescue stranded people using this system. Such real-time flood inundation systems will help transform the disaster management systems in line with modern smart cities initiatives.

Keywords: flood detection; deep learning; landmarks detection; UAV dataset; disaster management

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1. Introduction and Background

On average, 60,000 lives are lost to natural disasters every year, accounting for 0.1% of the global deaths [1]. These natural disasters include floods, earthquakes, hurricanes, landslides, and others. Floods are the most frequently occurring natural disasters globally, representing 40% of global natural disasters [2]. Climate change, hurricanes, heavy precipitation, glacier melting, and winter storms are the underlying factors to be blamed for the dramatic rise in flood risks [3,4].

Floods have induced damages amounting to hundreds of millions of dollars on average, along with the loss of thousands of human lives [5–8]. Apart from the loss of lives, floods cause great damage to the infrastructure and property, agricultural lands, crops, and livestock, resulting in huge economic losses, which must be minimized in the era of focus on sustainability and smart cities [9–11]. Extreme rainfall events occurring in the first decade of the new millennium have caused a substantial increase in flood events, raising the flood-related losses from USD 6 billion to USD 10 billion. Accordingly, billions of dollars have been invested in implementing effective flood control measures [2,12]. The associated rescue missions, rehabilitation, and relief services also place an additional economic burden on the economic development of the affected country. According to an estimate of flood-related economic loss in 2012, the world lost USD 19 billion to floods in various global regions. Due to untimely detection of floods and lack of accurate and fast technologies that could automatically detect the occurrence of flooding in an area, lives are lost as aids and recovery services cannot be provided on time. This signifies the need to use advanced digital technologies to detect flood-affected areas quickly and accurately so that rescue activities can be initiated as soon as possible [2,12–18]. Such timely flood detection is crucial to efficiently plan relief missions and rescue the stranded people, thus minimizing its economic impacts and casualties [19–21].

Geographic Information System (GIS) is an important component that provides essential disaster management decision support and analytical capabilities [21,22]. It enables the authorities to acquire, save, manage, and analyze spatial or geographic data to provide appropriate disaster response [23,24]. GIS can automatically determine the flood-affected regions and integrate the results with the available geographic data, thus assisting in the better detection of floods [21]. It has been used to determine rescue routes and the available transport facilities in flood-affected areas [25,26]. However, this technology relies heavily on the availability of information about the disaster. Such information is only available after a couple of days, if not weeks, resulting in a slow response in an emergency case such as a flood. Global Positioning System (GPS) is a global navigation satellite system (GNSS) that provides geolocation and time information to a GPS receiver anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites [23]. This technology has been frequently used in post-flood disaster management and relief activities. An example is that of the GPS sensor nodes installed on the rooftop of a building, providing relative position information from both pre- and post-flood disaster periods.

The changes in geolocation points between different building components before and after the flood are calculated and used to estimate damage, building movement scale, and factors such as stress and strain for a precise assessment of the damage. Similarly, the images captured by GPS-enabled devices can be further analyzed using image processing techniques to detect a flood event. However, GPS-based estimations have a certain degree of ambiguity, as the exact location of the flooded area cannot be mapped. This is because there is roughly an error of 15 m for every 3 km in the GPS results [27]. Moreover, another limitation of the GPS is that it relies on internet services. In times of emergency, network services such as the internet and Wi-Fi are mostly unavailable. Hence, technologies such as GIS and GPS become inaccessible. This leads to a lack of precise data about the location of flooded areas and the affected people requiring aid. Accordingly, the rescue services may be delayed or interrupted.

Satellite imaging has been used to capture high-quality images of the target area. These images are analyzed using image processing methods such as edge detection, segmentation, and pixel-based analysis [28,29]. However, the quality of these satellite images is greatly affected by noise, illumination conditions, weather, and other barriers between the earth and the satellite, such as clouds [30]. Furthermore, due to the large number of high-resolution images stored in the satellite databases, the speed of image processing is affected, resulting in a slower response. To address the speed concerns, remote sensing techniques are used to collect data of large areas quickly. Moreover, these techniques also allow the generation of detailed descriptions of the objects without having any direct connection. The working mechanism involves using optical and radar imagery to measure water levels to define the scope of a flooded area [31].

Similarly, object detection has been utilized with aerial images to extract features that can be analyzed to make flood-related response decisions. Target recognition of landmarks such as roads and buildings from aerial images has been done using Hough transform and isotropic surround suppression to find rescue routes [32,33]. Furthermore, edge detection methods can be used to identify and extract objects from images, such as detecting a horizontal water line representing the surface level of water on roads and streets or the height of a dam [28]. Bridge detection has been performed using aerial images to aid disaster relief missions by mining and analyzing multispectral aerial image patterns [32,33]. Synthetic Aperture Radar (SAR) has been used to capture remote images, define a pixel-based threshold and classify flooded or non-flooded regions [34]. Mason et al. [35] used image segmentation and classification techniques on SAR images for real-time flood detection. However, the quality of images and availability of internet or satellite connectivity may affect disaster response planning. Therefore, alternate methods need to be explored and utilized for disaster response planning in flooded regions [36].

Accordingly, Unmanned Aerial Vehicles (UAVs) can be used as efficient tools that can capture high-resolution spatial images from the target sites [22]. These UAVs are widely used these days instead of the traditional imaging tools such as satellite imaging and GPS-based monitoring as smart technologies in the industry 4.0 era [37–41]. UAVs can quickly collect precise image data and transmit it to their respective off-site servers for sharper, smarter, and more informed responses [41]. Similarly, Artificial Neural Network (ANN) models are increasingly used for flood prediction and detection [42,43]. Chang et al. [44] proposed a hybrid ANN-based model using a self-organizing map (SOM) and the recurrent nonlinear autoregressive network with exogenous inputs (RNARX) to generate regional flood inundation maps during storms events. The authors stated that the 4×4 SOM network could cluster inundation depths of the target area, while the RNARX network can forecast the inundation depths.

Similarly, Chang et al. [45] developed an early flood warning system by integrating a hydrodynamic model, k-means clustering algorithm, and support vector machines (SVM) to detect typhoon flood events and accurately predict both the inundation depth and extent [46]. Fuzzy-logic-based systems are also quite popular and have been used to forecast river water levels and raise an early alarm in case of floods [47]. Harmonic analysis and change detection have been used on multi-temporal data for flood detection, with an accuracy of 80% [48]. Likewise, a new method for change detection and thresholding (CDAT) was used with SAR images to delineate the extent of flooding for the Chobe floodplain in the Caprivi region of Namibia [49]. A Bayesian network has also been proposed to integrate remotely sensed data, such as multi-temporal SAR intensity images and interferometric-SAR coherence data, with geomorphic and other ground information such as roads and buildings [50].

Furthermore, a back-propagation-based ANN method called Multilayer Perceptron (MLP) has been used to predict floods using rainfall time series data and water levels in a weir that can spread into the cities [51]. Similarly, a Wavelength Neural Network (WNN) has been used for flood modeling [52]. Thus the pertinent literature shows that image processing and machine learning techniques have been widely used for flood detection, but deep learning is rare and not well experimented with or documented for such purposes [46]. This presents a gap targeted on the current study.

Accordingly, a set of key landmarks comprising roads and buildings is detected and extracted in this study. These landmarks are added to the original dataset used to train a deep learning model to help the disaster management team plan an effective response. The study demonstrates the results using original and altered datasets and compares them with previous flood detection methodologies to highlight their significance. A case study approach is adopted where the flood-prone area of northern Pakistan, known as Swat, is investigated, and the technique is applied to extract landmark objects in the flooded region.

The motivation for using UAVs for capturing aerial images of the disaster-hit region is due to its potential to capture high-resolution images in a short period without requiring human assistance. This makes UAVs safe to investigate high-risk areas that are unreachable by humans during disaster events. Thus, UAVs are ideal for acquiring image data in disasters. The idea of integrating machine learning and image processing for flood detection and damage assessment facilitates generating results in the least amount of time, which are accurate and precise without relying on human intervention. The problem addressed in this paper is the "detection of floods". For this purpose, UAVs are used that are complemented through the implementation of deep learning models on aerial images acquired by them. The detection and monitoring of flooded areas in rural zones are essential to assess the damages to critical infrastructure, find and locate the population, and find an evacuation route for the disaster victims. The proposed system ensures the extraction of key landmarks such as roads, buildings, and bridges that are georeferenced with the stored maps to make appropriate post-disaster decisions.

Pakistan is a developing country with a growing economy that is faced with several challenges. These challenges range from cost and time overruns in projects to brain drain, lack of competitiveness of local industries, corruption, political instability, lack of legal frameworks and insurances, and frequent natural disasters such as floods and earthquakes [21,24,53–58]. The regularly occurring devastating floods severely dent the local economy. In Pakistan, flood events in 2010, 2011, and 2013 caused immense destruction and fatalities [21]. Pakistan has faced a loss of approximately USD 38 billion owing to floods in the past 70 years [59,60]. In 2010, massive floods caused by the monsoon rains caused 2000 casualties, affected 20 million people, caused food shortage for 7.8 million people, and resulted in damages worth USD 16 billion [21]. The healthcare facilities of the country also suffered as 436 settings providing health-related facilities were lost in the disaster [61]. The underlying cause of floods in Pakistan is heavy rainfall every year during the monsoon season (July–August). Last year alone, more than 230 lives were lost to the floods generated by monsoon rains in Pakistan [62–64]. Therefore, there is a dire need to propose effective flood mapping techniques in Pakistan.

For pertinent flood detection in this study, Convolution Neural Network (CNN) is used. It is a multilayer neural network, and one of the most classical and common deep learning frameworks [65]. Previously, this classification model has demonstrated excellent performance for image classification, segmentation, and extraction [65,66]. One advantage is its self-learning ability, as it can automatically learn features from large datasets by organizing multiple layers of neurons. Traditional machine learning models such as SVM have been used for flood detection that has shown good results, but the complexity of this model grows significantly as the training dataset increases. Apart from that, SVMs need to be tuned to find the optimal kernel function for training. The parameter optimization related to the kernel function is the key factor affecting the classification effect [66]. Therefore, to handle datasets such as the one in the current study, researchers are moving towards deep learning and utilizing deep learning models such as RNN and CNN for image classification and segmentation problems. Previously, CNN has been applied for the classification of data captured through remote sensing [67]. However, the application of CNN for flood mapping is rare and has not been thoroughly investigated. Therefore, the current study utilizes CNN to detect floods from aerial images captured through UAVs in Pakistan.

In the current study, a detailed literature review of the recently used flood detection technologies was performed to obtain insights into the existing methods used for flood detection. This information was subsequently used to select the most appropriate methodologies/parameters well suited to our data set. Moreover, by reviewing the existing work, current gaps in the research were identified, and proper strategies to overcome these gaps were devised and implemented. For this purpose, several search queries were formulated and used in literature search engines (i.e., Scopus and Web of Science) to extract the most recent studies using literature retrieval methods [2,9–12,17,18,68,69]. The search process was restricted to the last decade (2010–20) so that the most recent articles were retrieved. The review process was conducted in two phases: article retrieval and screening, as shown in Figure 1. The literature review was performed by removing duplicates articles, and screening research articles, book chapters, and conference papers published in the English language only.

After the screening process, a total of 98 articles were shortlisted. Among these, 34% of articles proposed image-processing-based techniques for flood mapping, 26% used machine learning, 21% were based on deep learning, and 19% of articles used methods belonging to other domains, as shown in Figure 1.

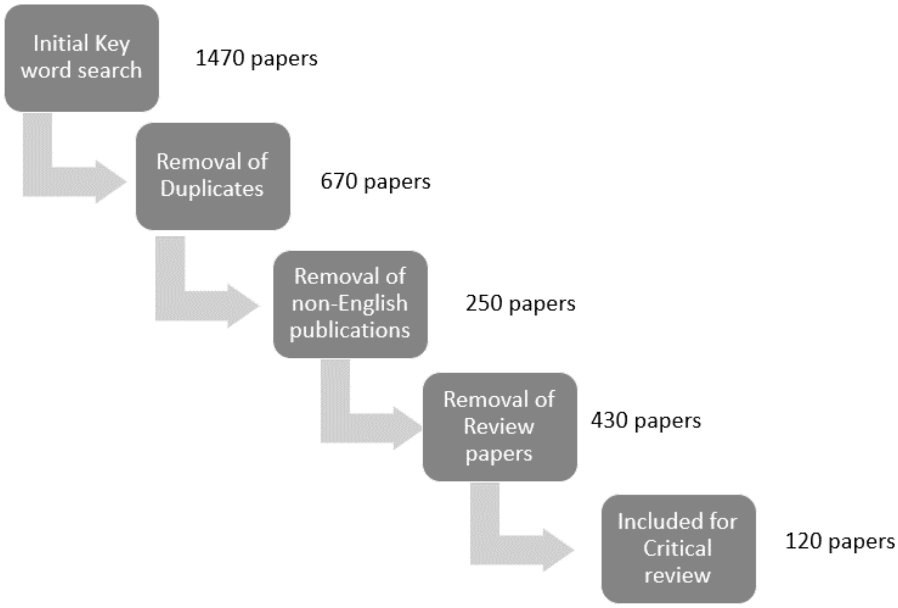


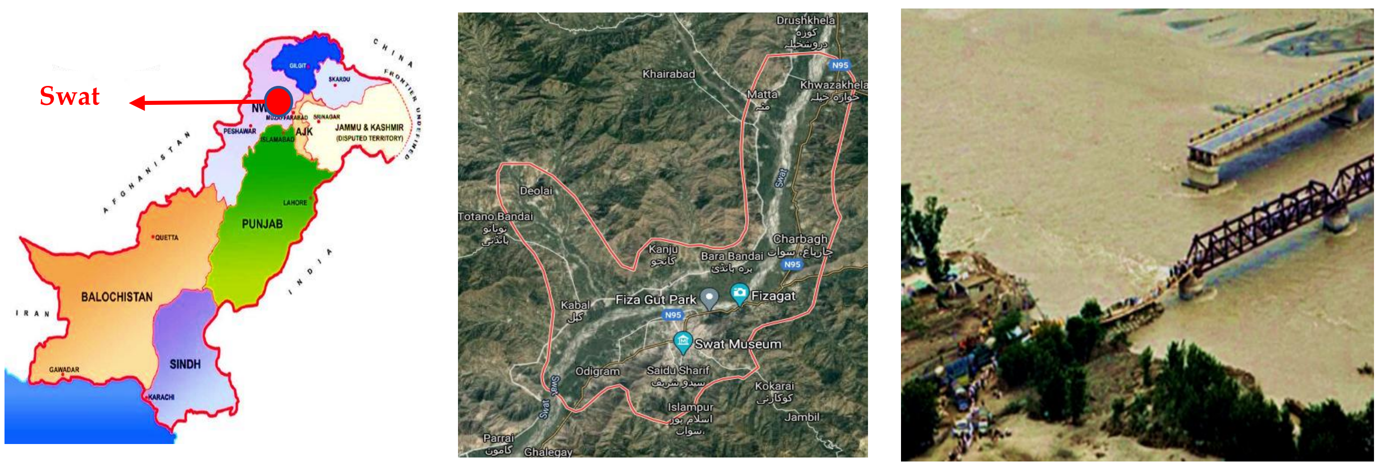
Figure 1. Detailed process of screening for the most relevant papers related to our research questions.

The paper is organized as follows. The Section 2 explains the research methodology adopted in this study. One of the most flood-prone areas in the country, i.e., Swat, is discussed as a case study, and the process of acquiring images for the dataset from this area is also elaborated. The Section 3 presents an overview of the evaluation process, experimental results, and comparison with existing techniques. Finally, the overall achievements and limitations of the proposed study are presented, and the study is concluded.

2. Research Methodology

2.1. Case Study Area

The case study for the current study is the Swat valley, a district of Khyber Pakhtunkhwa, situated in northern Pakistan, as shown in Figure 2a,b. Located at the convergence of two rivers, called "Daral" and "Swat", this region is constantly at high risk of floods and was severely affected by floods in 2010. Last year alone, 30 lives were lost, and 38 others were injured in this region during the recent flash flood event. In addition, more than 130 houses, 1 bridge, and a worship place have been damaged or destroyed in these flash floods. Furthermore, several roads have been blocked or damaged by flash floods, isolating many communities [64].



(**a**) (**b**) (**c**)

Figure 2. (**a**) Swat District on a map of Pakistan; (**b**) Swat area; (**c**) aerial image of a flood-hit area in Swat.

Swat is enlisted under the high-risk areas for floods by Pakistan Disaster Management Authority (PDMA). According to PDMA, this area can become completely inaccessible if hit by a massive flood again. The recent flash flooding tested this statement and proved rightful as there occurred a significant delay in rescue services due to the inaccessibility of the land and damage of connecting bridges leading to more fatalities. Owing to this significance, this area is selected as a case study for the current research.

To address the flood risks in this region, multispectral aerial images from this area were captured for developing a comprehensive dataset. A Red-Green-Blue (RGB) image captured by UAV from this region is shown in Figure 2c that covers a residential area of Swat. The spatial resolution of the image is 0.23 m, allowing precise detection of inundated areas. The image has a size of 19,956 × 12,444 and covers an overall area of approximately 11 km^2. In total, 300 images were captured by the UAV, whereas the remaining dataset was constructed using the pre- and post-flood images collected from the local databases maintained by PDMA.

2.2. Proposed System Workflow

An abstract-level flowchart of the proposed methodology is shown in Figure 3 that has six major steps:

1. Image acquisition and data collection using UAV;
2. Preprocessing of the images;
3. Selection of landmarks features for detection;
4. Training the model on the dataset;
5. Flood detection using image classification;
6. Performance evaluation of the proposed system.

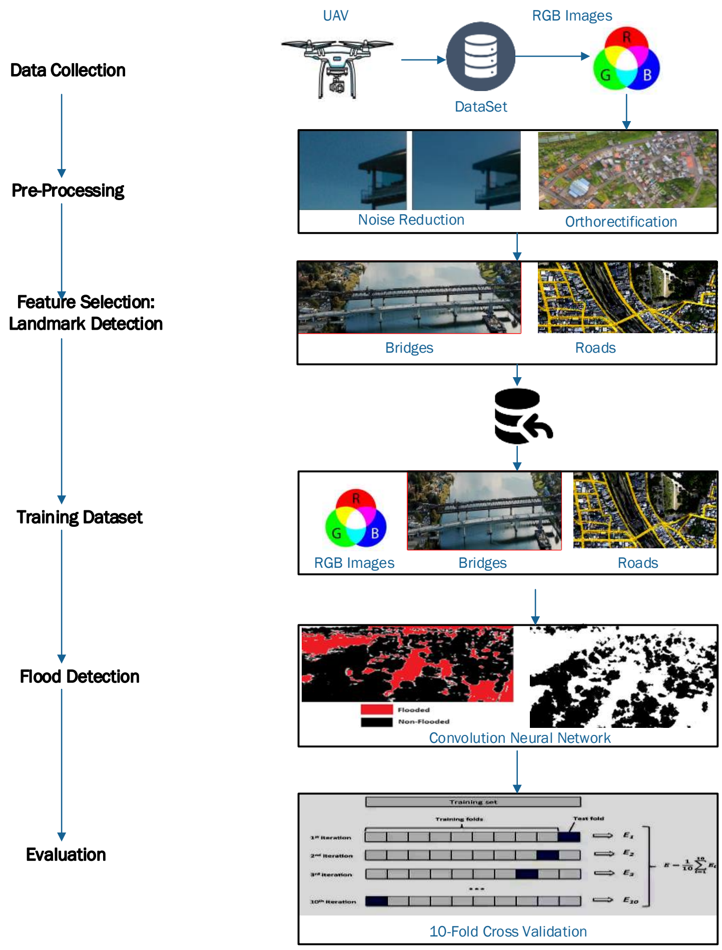


Figure 3. Proposed methodology.

2.2.1. Image Acquisition

For surveillance of the flooded areas and their inundation detection, a small-sized UAV called River-map was selected. Go-Pro® digital camera was onboard for capturing high-resolution RGB aerial images of the case study area. Using this set up, real-time surveillance of the case study area was performed on 2 September 2020, as shown in Figure 4a,b, highlighting the destruction caused by the flood in this area. The images show that most roads are sunk into the water, and buildings are collapsed due to the high intensity of floodwater, making the process of relief work more difficult and time-consuming, if not impossible.

(**a**) (**b**)

Figure 4. Flooded regions of Swat Valley. (**a**) A village (**b**) A damaged bridge.

The data acquired by the UAV was in the form of RGB images with some level of distortion. Such distortion is an inherent characteristic of the images captured through satellite imagery or an aerial imaging system. Furthermore, the surface of the earth has some topographical differences, and due to an inclined angle of satellite, the UAV, or the aerial camera, the distance between the displayed features may not be 100% accurate or a true representative of the ground realities. The distortion in images increases with an increase in the topographical variance of the landscape. This distortion must be eliminated to infer meaningful insights from the captured images. For this purpose, the image processing technique of "orthorectification" was applied. The orthorectification process removes the effects of tilts and terrain from the images to create a planimetrically correct image. The resultant orthorectified image had a more constant scale showing captured features in their 'true' positions.

Furthermore, the captured images may have some noise due to environmental factors such as air pollution, dust, smoke, and fog. Therefore, a median filter with good de-noising power and mathematical accuracy is applied to the captured images to reduce this noise. The median filter is one of the popular order-statistic filters that is effectively used in digital image processing. It is a nonlinear filter used to remove "salt and pepper" noise from images while maintaining the edges of features. This filter was applied to the captured images in the current study so that the feature extraction in the next steps would not be affected, and high-quality images can be utilized for inferring meaningful results. A fixed filtering window size is used in a median filter, and the pixel value (target pixel) is replaced by the median value of the intensity levels of its neighboring pixels. Herein, the filter sorts all pixels in a window according to their numerical value and replaces the value of the target pixel with the median of the values of pixels in that window as shown in Figure 5. The working of the median filter is described using Equation (1) and Figure 5, respectively:

$$I'(u,v) \leftarrow Median\{I(u+i,\ v+j)|(i,j)\,\varepsilon\, R\} \tag{1}$$

Here, R is defined as the moving region for all values in the median filter, $I'(u, v)$ represents the current location, and $I(u + i, v + j)$ denotes the corresponding image element.

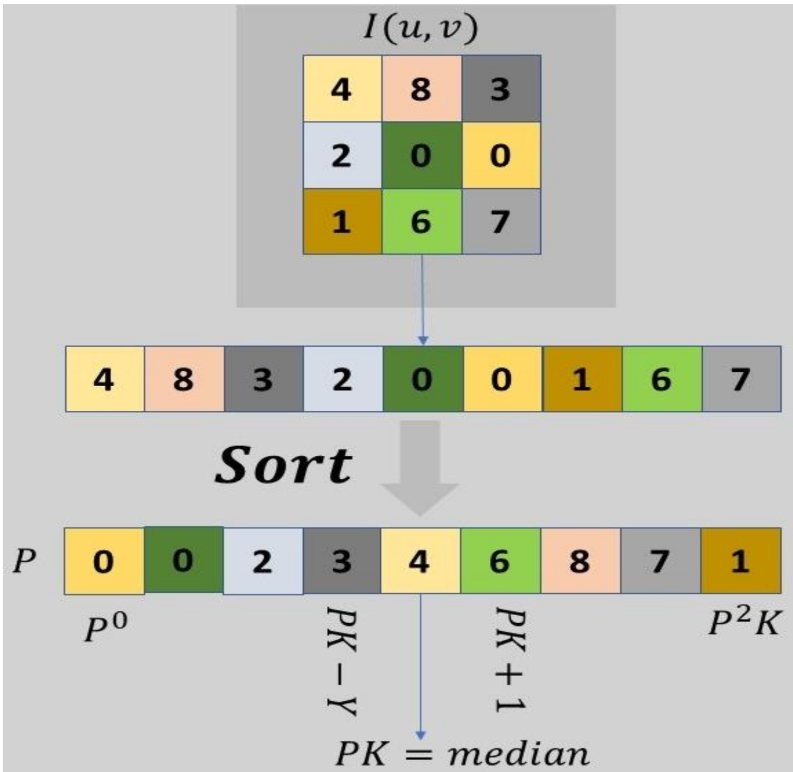


Figure 5. The working of the median filter for noise removal.

2.2.2. Preprocessing

Image preprocessing is a prerequisite step to enhance the quality of the input images and prepare them for further processing in the subsequent steps. It involves downloading the raw images from the UAV's digital camera, storing them in a database, removing noise, and applying orthorectification. Data preprocessing is performed to take into account different variations (i.e., size, shape, and brightness) in images. Therefore, after data collection, preprocessing was performed in the current study to remove unwanted objects and noise from the captured images. Additionally, the brightness and sizes of the collected images were also adjusted, followed by the removal of unwanted background regions/surfaces using image cropping. For the proposed CNNs, data augmentation was performed based on random image cropping and patching that was further used for label generation and flood detection in the entire training procedure [70]. Furthermore, the feature selection was conducted by extracting landmark features from the preprocessed images using a supervised learning approach.

In the current study, landmark objects are restricted to bridges, buildings, and roads. The extracted landmarks are then combined with the raw Red-Green-Blue (RGB) images to build the feature space for training a CNN classifier. Furthermore, the classifier is evaluated to test its flood detection capability on new test images. Finally, the performance is assessed using the confusion matrix derived from the validation process.

2.2.3. Selection of Landmarks Features for Detection

In the context of image classification, feature selection plays a vital role in achieving high accuracy. Good features can enhance the inter-class separation and decrease the in-class variance [71]. Thus, it is imperative to capture and select high-quality images with more pronounced attributes for getting accurate results. The images captured by the UAV in the current study had three color bands: red, green, and blue, which are not sufficient to achieve high classification performance since many other objects on the ground may have the same color leading to false detections by the classifier. Thus, it is necessary to extract relevant features from the input images, increase the inter-class separability, and remove irrelevant and redundant parts of the images. By analyzing the aerial images, it was noticed that most of the key landmarks were roads, buildings, and bridges that were subsequently chosen as target landmarks to be extracted using an automated tool. From the literature review, common image processing techniques used for road detection from images are edge detection and line-based extraction used in this study.

Supervised learning was utilized in this study to detect the objects of interest using the Haar cascade classifier. This classifier uses Haar-like features to identify objects from images. The main advantage is its high computational speed, making it suitable for real-time landmark detection when planning emergency responses. Thus, this method is adopted to detect roads, bridges, and buildings such as houses from the input images in the current study. Instead of looking at the pixels in an image, a Haar-like feature detector analyzes rectangular blocks and computes the total pixel intensity in the region. It then determines the differences between the calculated sums of each region.

For example, consider the shaded area shown in Figure 6. If 'I' denotes the integral image and '*P*', '*Q*', '*R*', and '*S*' are points of a rectangular area in this image. The points *P*, *Q*, *R*, and *S* represent the four reference points used for the computation of images values on the black region. These points are described as $P(x_0, y_0)$, $Q(x_1, y_0)$, $R(x_0, y_1)$, and $S(x_1, y_1)$, respectively, as shown in Figure 6. The sum of the shaded region/area with points *P*, *Q*, *R*, and *S* is calculated using the *sum*(*PQRS*), as described in Equation (2). Thus, the *sum*(*PQRS*) can be computed in a constant time using only four references, i.e., $I(P(x_0, y_0))$, $I(Q(x_1, y_0))$, $I(R(x_0, y_1))$ and $I(S(x_1, y_1))$ to the integral image (Equation (2) [72–74], as follows:

$$sum(PQRS) = I(S) + I(P) - I(Q) - I(R) \tag{2}$$

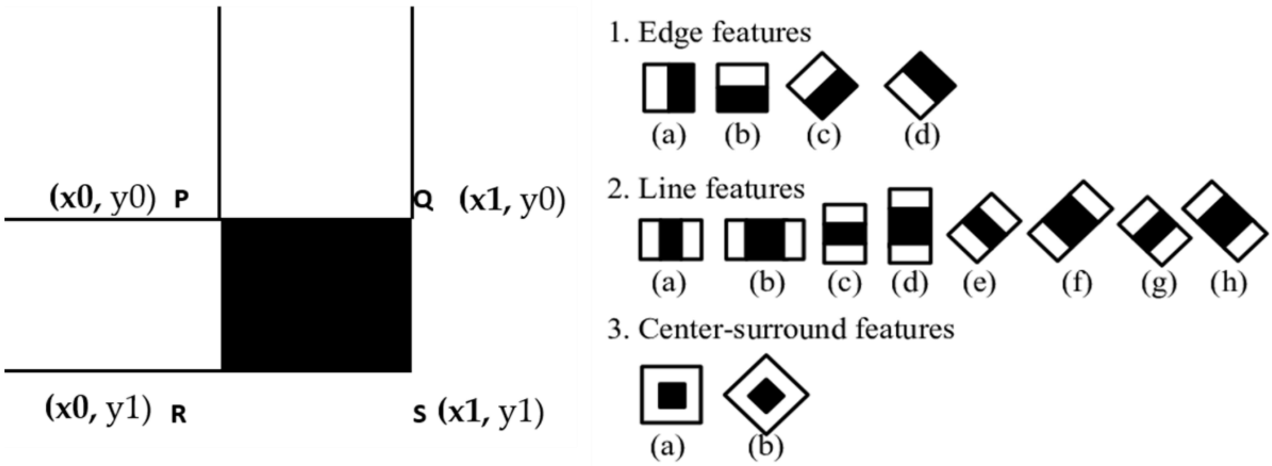


Figure 6. Integral image and Haar-like features.

This use of integral images helps in achieving computational efficiency, which is lacking in traditional methods. Haar-like features consist of predefined edge, line, and center-surround features, as shown in Figure 6. A strong classifier such as the Haar classifier can detect a feature under varying illumination, scale, and color. This makes the Haar classifier an ideal method for landmarks detection in aerial images, as these images can have varying lighting conditions and color properties during day and night or under different climatic conditions. Accordingly, it has been used in the current study.

2.2.4. Training Datasets

The RGB format is one of the most prominent encoding formats used for the representation of most natural images. As discussed earlier, for training the CNN, we used the original images in the RGB format that were used to extract landmark features from the preprocessed images using a supervised learning approach. The collected dataset contained both original RGB images and the landmarks extracted from these images in the feature selection stage. Generally, during the training procedure, the high performance CNNs are likely to display chances of over-fitting, which might be due to the memorization of the non-generalized image features by the CNNs that are present in the training set. Therefore, using a sufficient set of training samples is extremely important to avoid the over-fitting of the model [75]. Collecting a sufficient set of training samples is costly; therefore, data augmentation methods such as flipping, resizing, and random cropping are used to cater to it [76,77]. Applying the aforementioned augmentation techniques is essential to increase the level of variations in the collected images to prevent model over-fitting [76,77]. Accordingly, these have been used in the current study.

Additionally, for the current study, both training and test sets were visually interpreted. The visual interpretation of both sets highlighted that the test set images contain five pixel classes (i.e., buildings, bridges, roads, soil, vegetation, and water). However, all the classes were not present in all training images, thus leading to an imbalance problem. This imbalance problem was resolved using a balancing function based on median frequency in which a weight is assigned to each of the five-pixel classes that are absent in an image using the following Equation (3):

$$w = \frac{Median(cf)}{class\ frequency} \tag{3}$$

where '*cf*' represents the class frequencies calculated over the whole dataset that are calculated using Equation (4):

$$class\ frequency = \frac{Number\ of\ pixels\ in\ each\ class}{Total\ pixels\ in\ the\ image} \tag{4}$$

The frequency of each of the classes in the training dataset of the current study is shown in Table 1.

Table 1. Frequency of each class in the dataset.

Class	Frequency (%)
Buildings	30.1
Roads	42.8
Soil	11.9
Grass	10
Water	5.2
Bridges	1.1

By analyzing the map of Swat, training samples containing the images of river "Swat" and river "Daral" were eliminated to avoid the ambiguity arising from their classification under the flooded category. Overall, the training dataset contained 3000 images that were utilized for the current study. These images are used to extract the landmark features and subsequently aid in rescue operations.

To train the classifier, a set of labeled positive sample images containing the object to be detected and a set of labeled negative samples that do not contain the object are needed [78]. These datasets were constructed from scratch for the case study area as there is no previous research that used supervised learning for object detection in aerial images in the case study area. Images were gathered from available online databases of Microsoft Bing Maps, Google Maps, and Google Earth. Furthermore, images were extracted at varying altitudes, brightness, and scales to form a dataset containing diverse images. A total of 3000 aerial images of buildings (1000), bridges (1000), and images of roads (1000) were extracted for the case study area.

Figure 7 shows part of the road and building images datasets used for training the classifier. The next step was to label objects in each of the downloaded images. This involves highlighting, cropping, and naming the target object in each image. Furthermore, a negative training set was developed by cropping the regions not containing the target object from the images. In total, 1000 negative samples were collected for buildings, bridges, and road datasets, respectively. Finally, the OpenCV computer vision library, which provides the utility to train a Haar cascade classifier, was used for training. This involves creating a feature vector of the training dataset and providing it as an input to the classifier. The detected images of buildings and roads were cropped and added to the original dataset containing the RGB images, as shown in Figure 7.

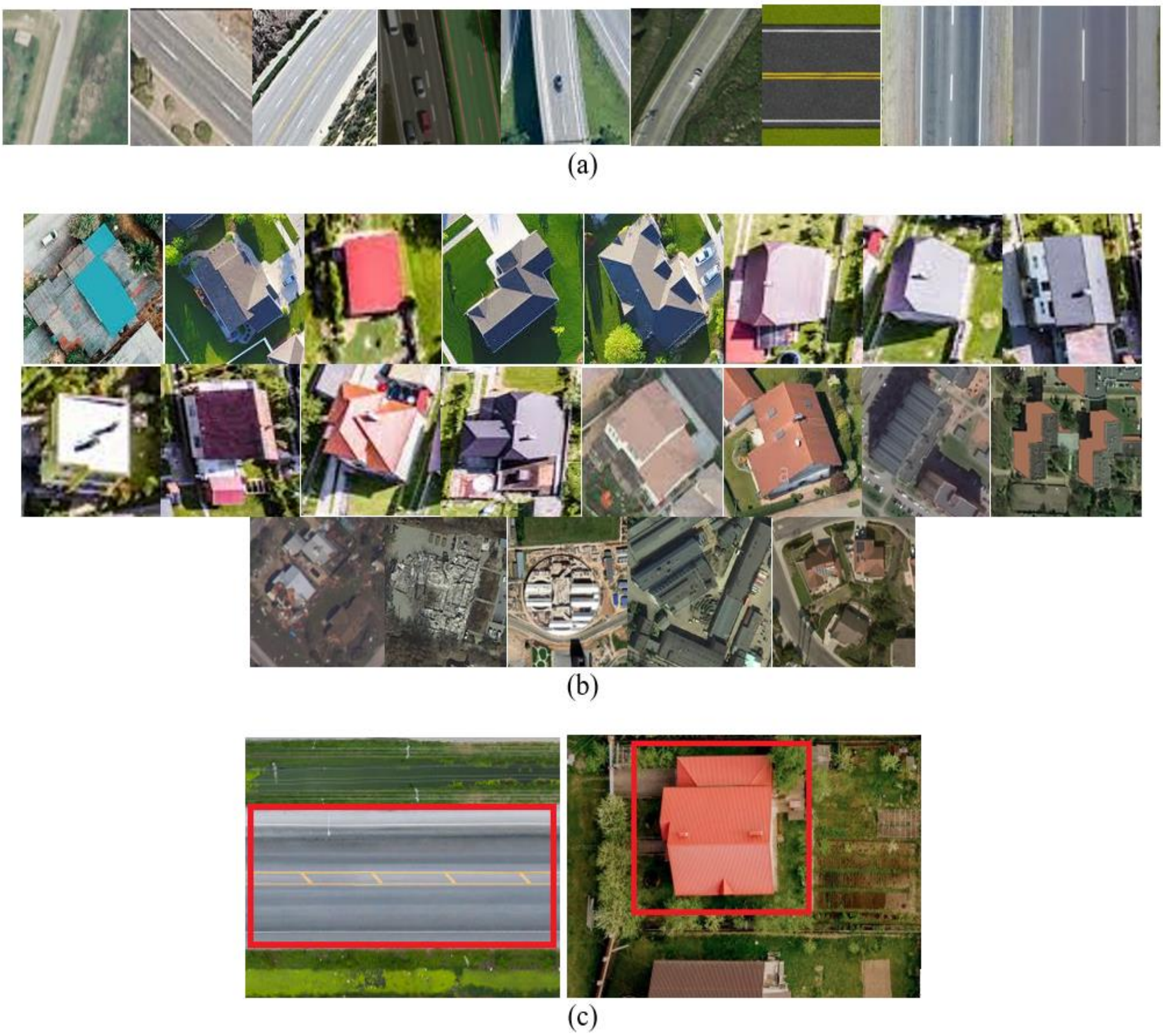


Figure 7. (**a**) Subset of aerial road images used for training (**b**) Subset of aerial building images used for training (**c**) Haar Cascade Classifier Results.

2.2.5. Flood Detection Using Image Classification

CNN has been used in this study for detecting floods. The architecture for CNN is shown in Figure 8, in which three layers are used: convolution, pooling, and fully connected layers.

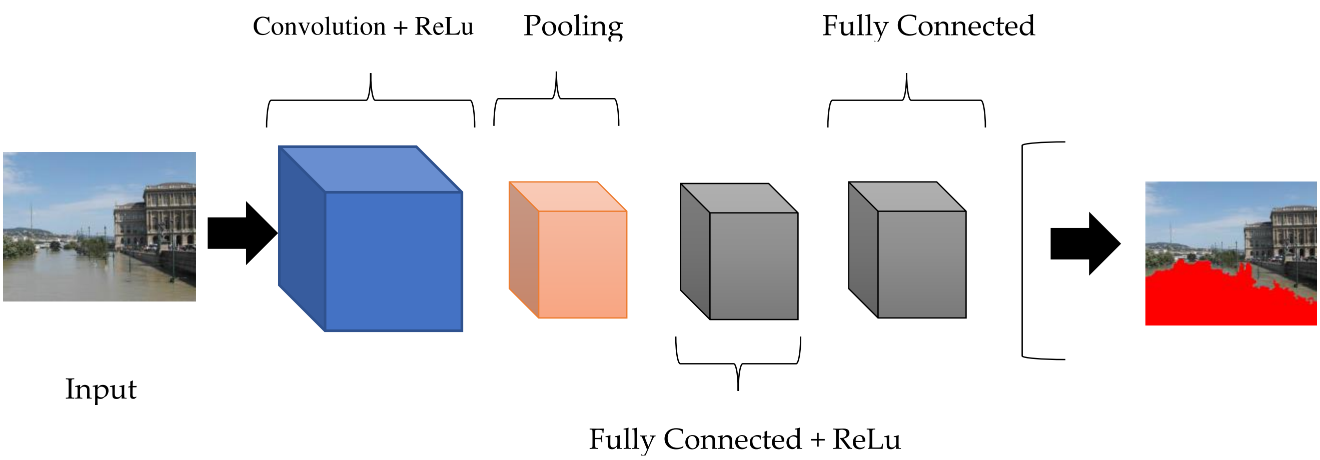


Figure 8. Proposed architecture diagram of CNN.

Convolution is a common analytical operation that is applied to signal and image processing problems. Different features from an image, such as texture and edges, can be obtained using a convolution function. The overlapping area of two functions, '*x*' and '*y*', can be computed using the convolution operator. If '*x*' is the original function and '*y*' represents its flipped form, Equation (5) can determine the third function 'c' [43,52] as follows:

$$c(t) = x(t) * y(t) = \int_{-\infty}^{+\infty} x(\tau)y(t-\tau)d\tau \tag{5}$$

Furthermore, a digital image is viewed as a two-dimensional function such as '$x(a, b)$' in image processing. Therefore, using a two-dimensional convolution function, '$y(a, b)$', the output image '$c(a, b)$' can be determined through Equation (6) as follows:

$$c(a,b) = x(a,b) * y(a,b) \tag{6}$$

Similarly, in the case of a colored image that contains three channels, red, green, and blue, the input image of width '*w*' and length '*l*' is an array of size '*S*', which is calculated using Equation (7) as follows:

$$S = 3 \times w \times l \tag{7}$$

A feature map is obtained as an output of the convolutional layer. This is obtained by taking a sum of the inputs (y_j) of all neurons multiplied by their weights (w_{jk}), plus a bias value (v_k) and an activation function as shown in Equation (8):

$$O = \sum_{j=1}^{n} w_{jk} \times y_j + v_k \tag{8}$$

The Rectified Linear Unit (ReLU) is a standard activation function for neural networks. It makes the model easier to train and brings better performance outcomes. This function activates a node by outputting the input directly if it is positive and otherwise returning zero. This has been applied in the current study.

A pooling layer is added immediately after the convolutional layer and applied to decrease the width and height of the test image in the current study. This simplifies the computation as the number of parameters is reduced by decreasing the spatial size. This also tackles the over-fitting problem. Max pooling is the most widely used pooling technique in which a filter of size "$s \times s$" is selected, and a maximum operation is applied over the "$s \times s$"-sized subset of the image. After the pooling layer is added, a fully connected layer is introduced in which each neuron receives input from every neuron present in the previous layer. Computation, based on the multiplication of matrices and a bias offset, is used to determine the output. The aim is to compute class scores to classify the image in the current study.

2.2.6. Results Extraction and Performance Evaluation of the Proposed System

Images captured by the UAV in the current study contained rich spatial information and hence consumed more memory space. Due to limited memory capacity, these images were divided into smaller patches of 525 $\times$ 525 in size. To test the model, an evaluation method based on 10-fold cross-validation was applied, in which the dataset was divided into 10 equal parts or folds. This method was used to overcome the problem of overfitting of data and enhance the generalization performance of the classifier. One fold was used as the test set in each iteration, and the remaining parts were combined and used for training the system. This step was repeated 10 times, taking a new set for testing in each iteration, thus using unique testing set in each step. The classification accuracy and error were calculated using accuracy and error percentages from all 10 folds.

To train the CNN, images from both flooded and non-flooded categories were fed to the first convolutional layer, followed by two convolutional layers, a pooling layer, and finally, two fully connected layers. Initially, data is collected when the concept of CNNs is introduced, and models are trained using machine learning. Accordingly, in this study, data collection was performed using images from the flooded and non-flooded categories. This was followed by data preprocessing and labeling. For data labeling, different techniques, including bonding box and semantic segmentation, can be used. Accordingly, in this study, we have used semantic segmentation, which is a pixel-by-pixel labeling method where the water pixels, and the background pixels were extracted separately. Thus, an improved version of CNN was used in this study. Herein, the final fully connected layers produce only two outputs that classify the image into either a flooded or non-flooded category.

During the learning process, weights of the input variables were tuned in the convolutional layer in this study by taking random values for the parameters and updating them using back-propagation. The learning rate was 0.0001, and the maximum epoch value was set as 5 for all classes. A total of 167,400 iterations were conducted in the training process of the 10-fold validation. As a result of the training, the model learned to link images with class labels and make predictions about test images. It took a 24-hour period for cross-validation using an Intel Quad Core i7-8550U Processor at 1.8 GHz to extract the results. For assessing the performance of the system, a confusion matrix was used to assess and highlight the accuracy of the classification method. It provided a complete measure of the performance of a classifier by separating correct predictions from the incorrect ones for each class in the dataset. The confusion matrix was divided into four cells representing true positives (T.P.), true negatives (T.N.), false positives (F.P.), and false negatives (F.N.), as shown in Table 2.

Table 2. The confusion matrix.

Predicted Values	**Actual Values**	
	Positive	**Negative**
Positive	TP	FP
Negative	FN	TN

Other measures such as precision, recall, and F-score were taken along with accuracy for performance evaluation of the classifier, as the accuracy alone does not give sufficient information about the class-wise results. For example, consider a dataset having 100 images, of which 95 belong to the non-flooded class and 5 belong to the flooded class. If all the images are classified as non-flooded, the accuracy will still be 95%, even though the flood was not successfully detected in any of the images. Hence, relying only upon accuracy may not be the right approach, and other measures are needed need to be put in place. Accordingly, in this study, other measures such as recall, precision, and others calculate the

TP. The formula for these performance measures, including the accuracy, recall, precision, f-score, true positive rate, and false-positive rate, are given in Equations (9)–(14):

$$Accuracy = \frac{TP + TN}{TP + FN + TN + FP} \times 100\% \tag{9}$$

$$Recall = \frac{TP}{TP + FN} \tag{10}$$

$$Precision = \frac{TP}{TP + FP} \tag{11}$$

$$F - Score = 2 \times \frac{Precision \times Recall}{Precision + Recall} \tag{12}$$

$$True\ Positive\ Rate = TPR = \frac{TP}{TP + FN} \tag{13}$$

$$False\ Positive\ Rate\ (Specificity) = FPR = \frac{FP}{TN + FP} \tag{14}$$

Overall, in terms of the time taken to conduct the study, it took almost nine hours to preprocess the input raw images. This included noise removal and orthorectification operations. Landmarks extraction by training a Haar cascade classifier and cropping the landmarks took 5 h. Finally, training the CNN-based deep neural network using the updated dataset took 24 h. Using the trained model to extract flooded regions took almost eight hours. This is a reasonable time to preprocess, analyze, extract features, and train a flood detection model from scratch, beginning with remotely sensed raw data to instigate an immediate response plan. Compared to other techniques that take weeks or sometimes months to plan a proper response, the current method is speedy and accurate. Upon completing the training process, testing was carried out using 300 aerial images of buildings and roads that included images captured at varying altitudes, scales, and illumination conditions. The classifier correctly identified roads and buildings from the dataset with 91% and 94% accuracy, respectively.

3. Results and Discussions

As explained in the method section, the model was first trained using the original dataset and the generated test results. Table 3 shows the confusion matrix generated by applying a dataset of test images to the trained model. The test dataset consists of 400 flooded and 400 non-flooded images. The results show that out of a total of 800 images, 675 were correctly classified, showing an 84.4% accuracy.

Table 3. Confusion matrix generated for a model trained using an original dataset.

		Predicted Class		
		Flooded	**Non-Flooded**	**Total**
Actual Class	Flooded	352	48	400
	Non-Flooded	77	323	400

Table 4 shows the confusion matrix generated after applying the test images dataset to a model trained using the altered (improved) dataset. This resulted in 728 out of 800 images being correctly classified, making the trained model 91% accurate.

By applying Equations (9)–(12) to determine accuracy, recall, precision, and f-Score, respectively, we get the values as reported in Table 5. The results with and without landmarks addition have been compared in Table 5. The overall accuracy of 91% has been recorded after adding landmarks to the dataset, with a 6% improvement in the accuracy achieved using the original dataset. Furthermore, as shown in Table 5, the precision, recall, and f-scores of the model have been improved by 8%, 5%, and 6%, respectively, when the altered dataset is used to train the CNN model.

Table 4. Confusion matrix generated for a model trained using an altered dataset.

		Predicted Class		
		Flooded	**Non-Flooded**	**Total**
Actual Class	Flooded	371	19	400
	Non-Flooded	33	357	400

Table 5. Experimental results.

No.	Metrics	Altered Dataset (Landmarks + Original Images)	Original Dataset (Without Landmarks)
1	Accuracy	91%	84.4%
2	Precision	0.92	0.84
3	Recall	0.95	0.90
4	F-Score	0.93	0.87

Compared to other studies, Fuentes et al. [64] used semantic metadata and visual cues to train a CNN model for flood detection and achieved an average accuracy of 83.96%. Feng et al. [71] obtained an accuracy of 87.5% using texture features and random forests along with RGB images for flood mapping. Elkhrachy [79] obtained an accuracy of 84.4% using an Analytical Hierarchical Process (AHP) to determine the relative impact weight of flood causative factors. Tehrany et al. [80] used different kernel types with an SVM classifier to develop a flood susceptibility mapping system integrated with GIS and achieved an accuracy of 84.97%. Thus, the current study system shows superior results compared to similar studies.

Table 6 compares the performance of the proposed system with recent methodologies for flood detection. These results show that the proposed flood-mapping model outperforms the recently proposed techniques for flood detection. The only method that shows results superior to the current CNN method is the deep learning neural network. However, the difference is minor (1%); hence the two methods can yield nearly similar results. Hence based on its high performance, the proposed model is very promising for real-time flood mapping.

Table 6. Comparison of flood mapping results of the current study with previous research.

No.	Method	Accuracy Result	Images in Dataset	Location
1	Deep Learning Neural Network [81]	92%	1464	Lao Cai, Vietnam
2	Semantic metadata and visual data with Convolutional Neural Network [82]	83.96%	6600	Misc (Flickr images)
3	Random Forest Classifier [71]	87.5%	5000	Yuyao, China
4	Analytical Hierarchical Process [79]	84.4%	519	Najran City, Kingdom of Saudi Arabia
5	Support Vector Machines (SVM) [80]	84.97%	1000	Terengganu, Malaysia
6	Proposed Model (CNN with landmarks extraction)	91%	3000	Swat, Pakistan

Figure 9 depicts the dependence of the classification accuracy on the number of images in the training set used in the current study. The x-axis and y-axis represent the number of training samples in the dataset and the corresponding classification accuracies, respectively. This graph indicates that the accuracy increases considerably with an increase in the number of input samples in the training set. Hence, expanding the size of the training dataset is one way to improve the performance of this model. If more training data, say a million or even billions of samples, are used, a better performance will be achieved as predicted by the graph. Adding the key distinguishing features to the training set helps the network learn more about classifying the images. The idea is to increase the size of the dataset by applying processes that imitate real-world variations. In this research, the background or irrelevant features present in the images were cropped.

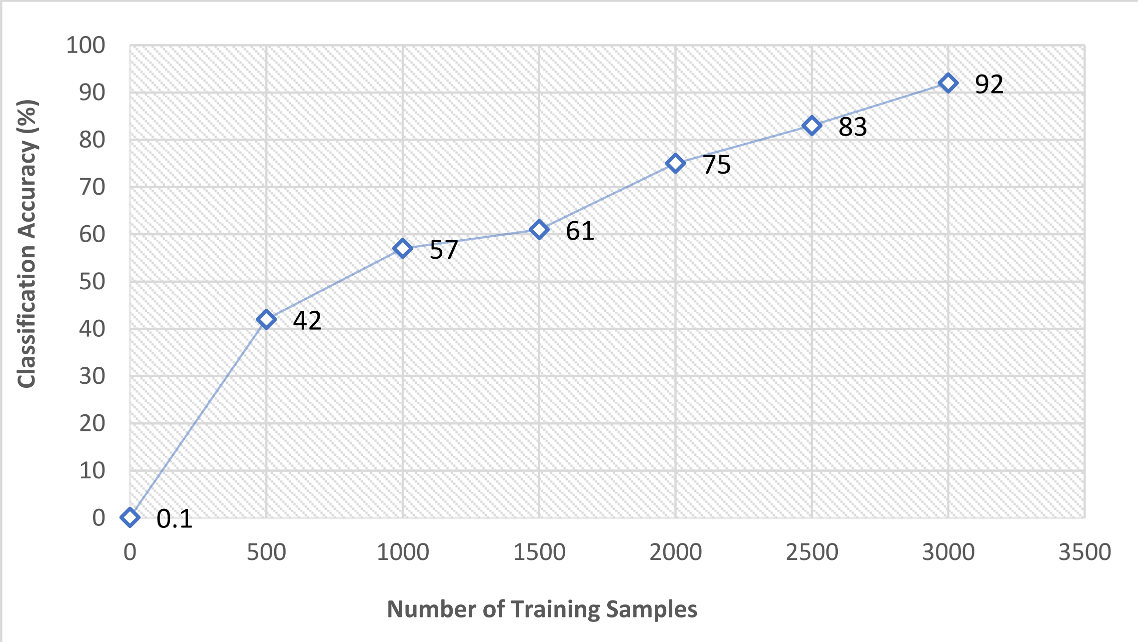


Figure 9. Graph showing classification performance with the number of samples in the training dataset.

Furthermore, the classification model was trained on a set of key features to be analyzed while distinguishing the classes. This is synonymous with the tactics used by a human while differentiating between a set of images manually. The performance of a learning model depends deeply on the training dataset, so expanding the dataset in a meaningful way is one way to yield a high classification accuracy. However, this approach can be expensive and slows down the training, so the tradeoff should be carefully analyzed.

Figure 10 illustrates a Receiver Operator Characteristic (ROC) curve plotted using true positive rate (TPR) (y-axis) against False Positive Rate (FPR) (x-axis) with a cut-point of 0.5 probability. The area under the curve (AUC) represents one value that summarizes the result of the ROC curve. A value of AUC close to one represents its good classification performance, while AUC = 0.5 represents a bogus or no-skill model. For the CNN-based model in the current study, the values of AUC, TPR, and FPR are 95.7, 88.0, and 86.7%, respectively. Accuracy is the most simple and intuitive measure for highlighting classification performance. However, there are certain conditions where accuracy may not be a satisfactory measure. For example, if only one of a thousand test images belongs to the flooded class, the accuracy of a model predicting each image as "negative or non-flooded" will still be 99.99%. Unlike accuracy, ROC curves are not sensitive to the imbalance of classes in the dataset. They depict the ability of a model to distinguish between classes. The classification model in the example provided will have an ROC curve of 0.5, representing a "no skill" prediction model.

The output of the flood detection model is tested with 50 new test images captured from the case study area using the UAVs. Figure 11 shows sample test images used with the current model. Firstly, orthorectification and noise filtering were applied to the input image. The image at this stage was smoother, with certain noise arising from the shadows, reflections, or other factors completely removed or reduced to some extent. The color attributes of the image were preserved as the prediction model was trained for classifying multispectral images. This image was then fed to the trained CNN model for predicting its class. The classifier presented its output as shown in Figure 11, where the red highlighted regions show flooding. Accordingly, the image was classified as "flooded", and hence responses can be instigated. The results clearly demonstrate the efficiency of the model for detecting and mapping flooded regions. All major areas in the image showing floodwater were identified. Some little patches of flooded regions may have been misclassified due to shadows or reflections in the image. However, the image will still be classified as flooded, which is the main objective of the CNN model in the current study. Furthermore, it must be noted that whenever we utilize real time imagery for capturing the shore or collateral regions, there are chances of achieving true negatives. Therefore, the edges of water were not classified in Figure 11. Overall, all the significant flood-affected areas were detected by the model.

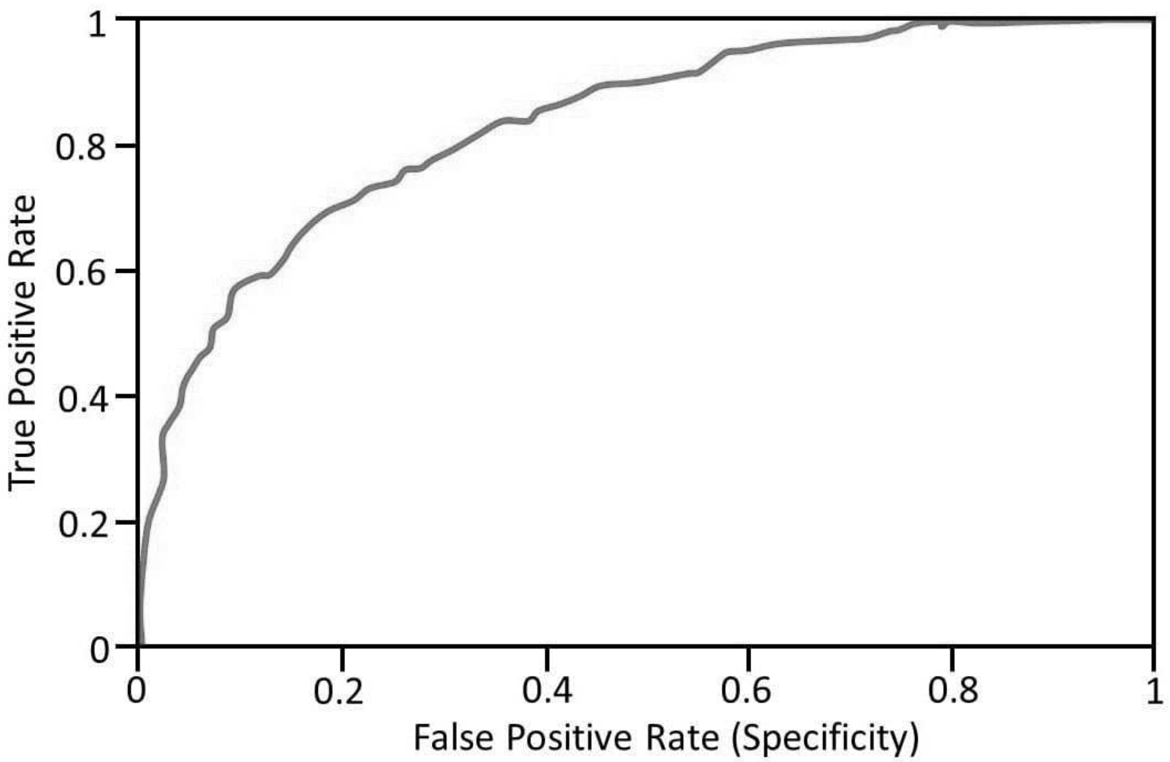


Figure 10. ROC Curve.

In summary, UAV-based image acquisition is a promising method to capture high-resolution spatial images of the disaster site during emergencies such as floods. Such images containing rich information about the ground objects boost the performance of machine learning models. The associated image processing techniques result in increased precision and accuracy of the landmark identification and helps instigate a proper emergency response. UAVs are not restricted by their takeoff and landing conditions, making them more flexible and safer to be used than man-driven aerial vehicles. They also fly at a low altitude, enabling them to overcome the limitation of satellite imaging, such as blocking target view due to cloud cover or other barriers and accessing otherwise inaccessible locations. Thus, such imagery has the edge over GIS-based satellite imagery.

Furthermore, the type of sensor used with the UAV determines the effectiveness of the real-time data. By using a digital camera such as the Go-Pro® used in the current study, high-quality images can be captured and quickly sent to the server based on the ground station. These images can be seen on screen in real-time, allowing for relief workers to make quick decisions in an emergency. This addresses the limitations of commercial cameras where RGB images will only be accessible after the landing of the UAV and cannot be viewed or analyzed in real-time hence delaying the response and hindering the rescue operation. Thus, to provide the feature of real-time surveillance, a versatile camera such as a Go-Pro ® should be used with the UAV.

Figure 11. Flood mapping results on input test images.

A deep learning approach based on CNN was used in the current study to classify the images that showed highly promising results. By including landmark features with the original dataset, a 5% improvement in overall accuracy was recorded. This is because expanding the dataset results in more data to the model, leading to increased learning and forming a better and improved prediction model. However, the results are highly dependent on the content of images and features for training. Key landmarks must be extracted and added to the training dataset to provide the model with the most relevant features. A comparison with recent flood mapping techniques that used SVM, random forests, deep learning, and AHP shows that the CNN model of the current study had superior performance. Furthermore, it had comparable results to deep learning neural-network-based image processing. Hence, deep learning approaches are highly recommended for flood detection in aerial images captured through UAVs. This will help pave the way for smart disaster management in the Industry 4.0 era and move towards the goals of smart cities and regions.

The current study does not detect or assess the population to provide aid and potential calculating damages to the population. Furthermore, it is limited to a maximum coverage area through a limited number of UAVs. Due to limited battery timings of UAVs, i.e., 30–45 min, the regions should be prioritized for capturing images and detecting floods. To deal with this, swarm intelligence should be considered where UAVs can be made smart/intelligent by a heuristic-based approach.

4. Conclusions

This study presented a hybrid model for landmarks-based feature selection and CNN-based flood detection. The key landmarks (i.e., roads, bridges, and buildings) were detected using supervised learning and added to the training dataset through swift response instigation, which was further used for training the CNN model. The inclusion of landmark features with the original RGB images significantly improved the model's performance. Moreover, using the CNN model on a large dataset based on aerial images has shown superior results, which surpassed traditional machine learning classifiers. Thus, successful implementation of UAV-based imaging for flood inundation mapping has been demonstrated in the study, proving that UAVs are ideal for the facilitation of real-time surveillance of inundated regions. Additionally, an accuracy of 92% was observed for extraction of the inundated areas from images. An overall 5% improvement in accuracy was observable when landmark features were included in the dataset. Overall, our model demonstrated an improvement over previous techniques that used classifiers such as SVM and random forests.

The outcomes of this research are directly aligned with the United Nations International Strategy for Disaster Reduction and Sendai Framework for Disaster Risk Reduction 2015–2030 that is aimed at providing practical solutions to rescue people in flood-affected areas. Our study can help the disaster management authorities (i.e., PDMA) in Pakistan to carry out post-disaster rescue services efficiently and quickly. This will help them to supply aid and relief to the stranded people, thus saving lives and reducing the impacts of disasters such as floods. This will pave the way for the adoption of smart technologies in the Industry 4.0 era.

A limitation of the proposed model is that it highlights the flood-affected and submerged areas using the two-dimensional images captured by UAV and cannot specify the depth of floodwater in the region, which may be needed to analyze the extent of flood intensity in a region. This issue can be overcome using technologies such as Digital Elevation Model (DEM) and Light Detection and Ranging Equipment (LiDAR). In the future, the accuracy of the system can be enhanced by expanding the dataset through the addition of more landmarks and features. Additionally, the feature selection based on rivers, people, and vehicles can also improve the quality of the dataset. Furthermore, other deep learning approaches, including RNN and LSTM, can be explored to perform flood inundation mapping in addition to its detection. Similarly, the study can be merged with vehicle routing techniques to plan rescue and emergency first aid responses in disaster-struck areas. This will help the flood management, fire, and search and rescue authorities in any country. Accordingly, the goals of modern smart cities and smart regions could be achieved.

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