smart cities

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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.

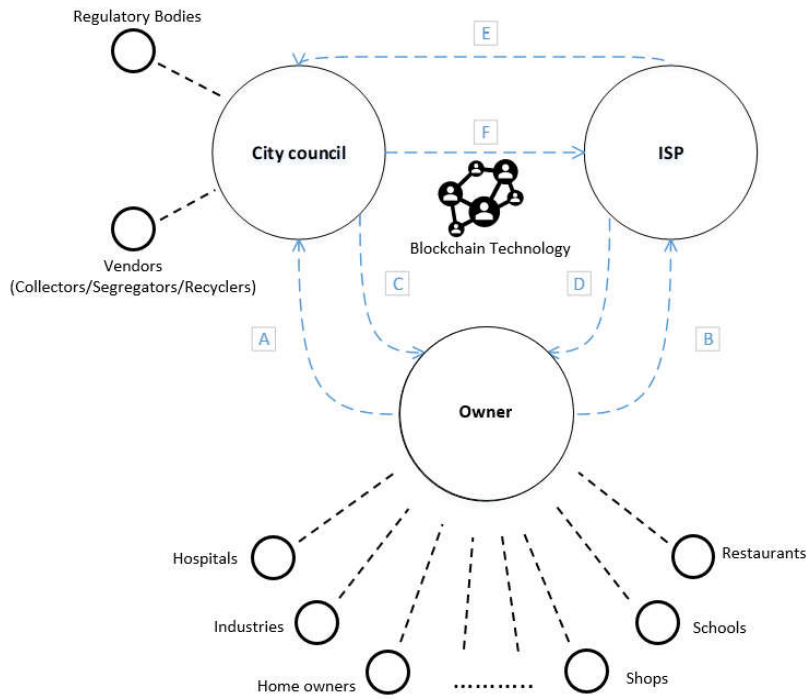

Figure 1. Relationship between entities in proposed business model.

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.

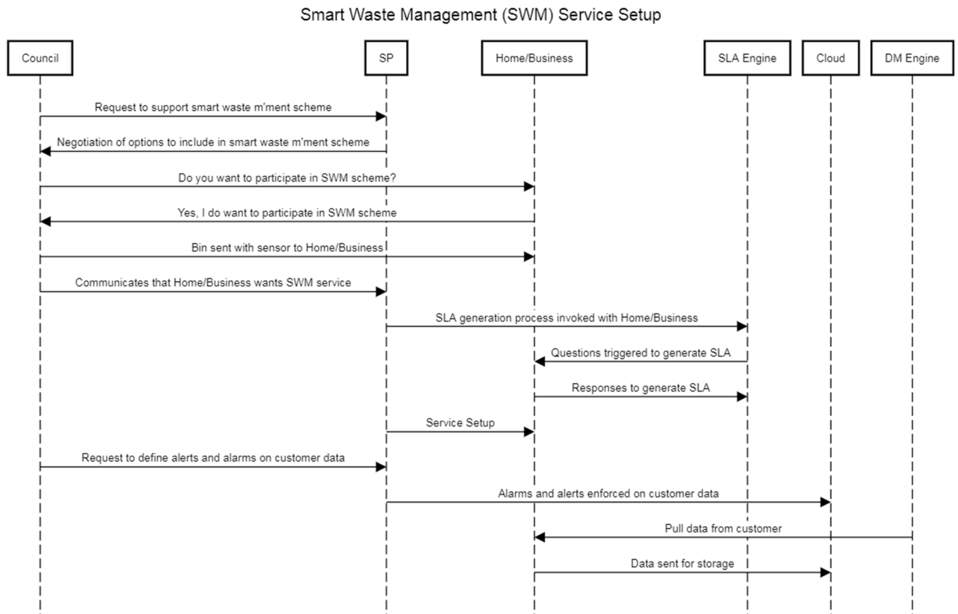

Figure 2. Smart waste management service setup process.

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.

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.

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
	Installation	Sensor installation in bins	£5-£10 per unit	-	-
Software	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

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.

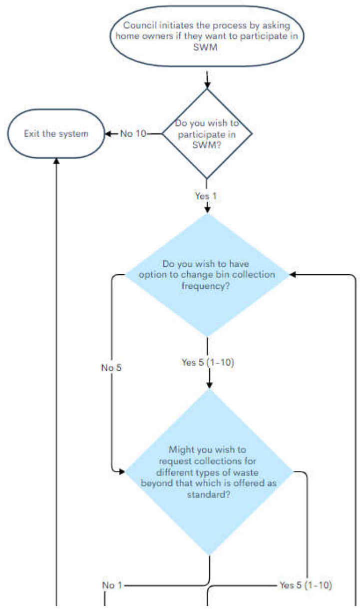

Figure 3. First phase of scoring a customer for SWM.

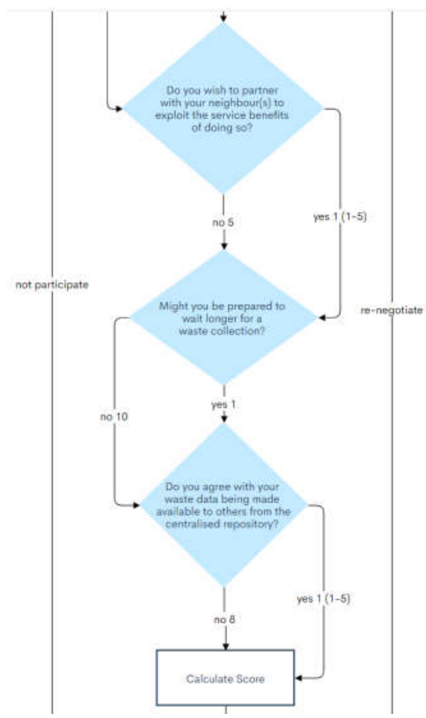

Figure 4. Second phase of scoring a customer for SWM.

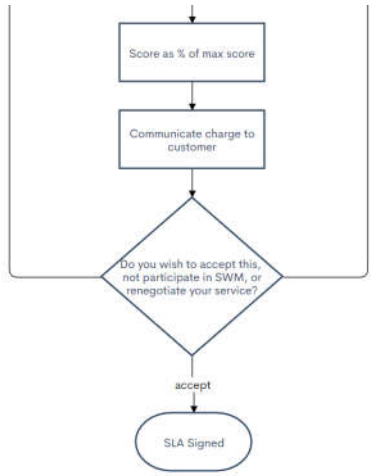

Figure 5. Third phase of assigning a customer SLA.

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 x 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

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).

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

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

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

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).

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

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

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

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.

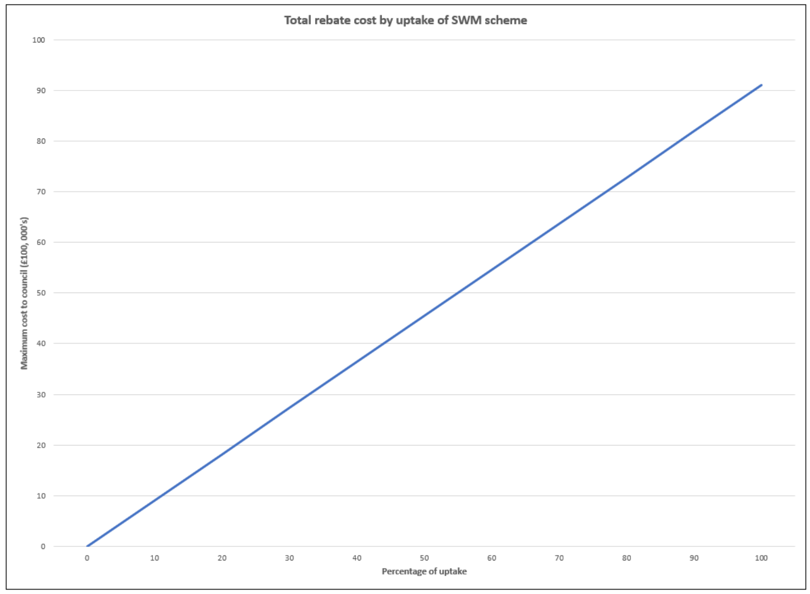

Figure 6. Total rebate cost by uptake of SWM scheme.

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

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

On the basis of the defined model, we expand upon the evaluation in Section 3.6 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.

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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