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The Urban Cloud: Linking city services, cloud computing, and the Physical Internet to achieve smart city objectives

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Keywords: *urban logistics, last mile delivery, infrastructure as a service, Internet of Things, Physical Internet, cloud computing, sensors*

Conference Topic(s): *last mile & city logistics*

Physical Internet Roadmap *(Link): Select the most relevant area for your paper: ☒ PI Nodes, ☒ PI Networks, ☒ System of Logistics Networks, ☒ Access and Adoption, ☒ Governance.*

Abstract

Urban logistics operations have become more complex and problematic for cities. The last mile delivery situation, driven by the growth in eCommerce purchases, is creating congestion and sustainability problems that cities must address if they are to meet the expectations of their citizens for a socially enjoyable and sustainable living space. This working paper explores the potential restructuring of how cities manage their infrastructure to achieve these objectives. Building on the fact that cities have increasingly built intelligence into their infrastructures through the installation of sensors, the paper examines the potential for reorganizing the management of this infrastructure using cloud computing three layers of Infrastructure, Platform, and Software as a Service architecture as a model.

1 Introduction

Cities are complex entities composed of multiple interacting networks of actors, systems, technologies, and regulations (Batty, 2013). As a structure built from the interaction of multiple networks, a city is not a planned construct, but an emergent concept reflecting the multitude of interactions between its underlying components (e.g., Fromm, 2004). Historically, the approach cities have taken to managing this complexity has been to organize functionally and, within function, to focus on either technical or geographic components of the function (Minett, 1975). Unfortunately, such a structure has encouraged the development of "silo" thinking, which ignores the interconnections of the various networks that operate within a city. As Christopher Alexander noted in the article that John Minett was responding to in his 1975 article, a city is not a tree, i.e., it is not a hierarchical construct that can be neatly laid out and managed as if what happens along branch 'x' has no impact on things going on along branch 'y' (Alexander, 1966). The complex interactions that people, organizations, services, etc. have within a city preclude this tidy tree like thinking (Jacobs, 1961).

Complexity makes the management of a city's infrastructure a difficult task. An urban street, for example, may have retailers located along it who need to be resupplied with goods for sale, parking for people to come by and shop, electricity to operate lights and internal systems, sewage to provide for the comfort of employees and shoppers, telephone lines to make calls, Internet access to order supplies and replenish stocks, garbage collection to pick up waste and recyclables, gas for heating, street cleaning to entice shoppers to a neat shopping district, police and fire personnel to ensure safety, etc. The myriad of interacting systems operate to allow this retailer to provide services to their customers, rent to the building owner, pay its employees and taxes to the city. Numerous other sets of separate networks interact within the city to generate economic, social, educational, and artistic benefit for the city's citizens.

Overseeing the various services that are accessed by the entities that deliver services and benefits to the city's citizens are the city's public works department, the transportation department, the police and fire departments, the tax department, a building inspection department, a business license department, an education department, a social services department, a parks and recreation department, etc. In addition, water companies, electric companies, Internet service providers, gas companies and telephone companies all are also managing a set of services that allow these service entities to operate. And, of course, there is that logistics service provider who is being asked to replenish the stock of the retailer, deliver a package to the consumer, or deliver office supplies to the various city departments that enable the retailer to sell to the citizen who wishes to park their car in front of the retailer's shop and shop at the retailer.

As cities have grown the services that they are expected to deliver to their citizenry have also grown. As the example of the retailer indicates, these services, provided by numerous city functional departments and external commercial entities intersect, facilitate, and constrain the various recipients of the services in an emergent manner that no individual department or company can foresee or control. Given the city's inability to systemically control or understand what is happening at the operational level means that interventions are as likely to harm as they are to help in achieving higher level goals being set by citizens or regulatory authorities. Another approach to managing the operations of the city is required.

2 The Smart City

Several proposals have been put forward to try and address the problematic nature of managing a modern city (e.g., Batty, 2018). No single approach has gained more attention in the last fifty years than that encapsulated in the term "smart city."[1] Smart cities are defined in many ways (Dameri, 2013; Albino et al., 2015). For this paper we use a definition employed by the European Commission. This definition states that[2]:

> A smart city is a place where traditional networks and services are made more efficient with the use of digital solutions for the benefit of its inhabitants and business.

This definition recognizes that cities are composed of multiple networks that interact and that the purpose of applying digital technologies is to make these interactions more efficient so that citizens and businesses benefit. The smart city concept has evolved from its early days in the 1960s to a sophisticated view of citizen centric and ecosystem focused service deployment enabled through platforms, sensors, and artificial intelligence. This evolving viewpoint posits many benefits to citizens, society, commercial enterprises, and the environment. Unfortunately, analysis of the numerous projects that have been reported as part of smart city implementation

[1] Note that the actual smart city concept, although not called a smart city, was probably in the minds of individuals in the early 1950s as can be seen in an article by Norbert Wiener in a December 1950 Life magazine article where he spoke of the city as a "communications net" (Kargon & Molella, 2004).

[2] Smart cities (europa.eu), accessed 15 April 2023.

efforts show that benefits have been limited (e.g., Lim et al., 2019). This fact is partially due to the primarily technical focus of these implementations, but also is a result of the relatively ad hoc nature of the implementations and their lacking integration into an overall smart city governance structure.

To date most smart city efforts have focused on applying technology to solve a particular problem. Classic examples of these efforts are the application of video cameras and sensors to control traffic flow, cameras and microphones to control and potentially predict crime, sensor deployments to measure pollutants, moisture levels, and noise levels, and RFID tags to allow vehicles access to roads and areas within the city (Law & Lynch, 2019). Some efforts have been undertaken to structure and integrate the various digital sensors that have been implemented to both better control the operations overseen through the sensors and to analyze the large datasets that result from real time sensing of city activities. Most of these efforts have focused on developing technical architectures that facilitate the interconnection and management of the multitude of sensors, cameras, IoT devices, and control systems that cities have implemented over the years to address various point problems in their operations (e.g., Miladinovic & Schefer-Wenzl, 2018; Haque et al., 2021).

While the primary effort for most smart cities has been in deploying technology to address problems in an ad hoc manner, some cities have recognized the problematic nature of this approach and implemented efforts to integrate their disparate systems. Cities such as Barcelona and London both have worked hard to address the integration of data flows and the management of the systems being controlled or monitored through their smart sensing infrastructures (Bibri & Krogstie, 2020). These cities use the data generated through the various sensors they have deployed to inform citizens about the state of the city and to manage various systems in a more integrated and efficient manner (Bibri & Krogstie, 2020). Unfortunately, even these two cities, given the efforts that they have put into both collecting and integrating their disparate data streams, have not rethought how they might utilize this information to leverage their infrastructures in a more effective manner. This fact can be seen by examining the architecture of Barcelona's smart city infrastructure (Sinaeepourfard et al., 2016).

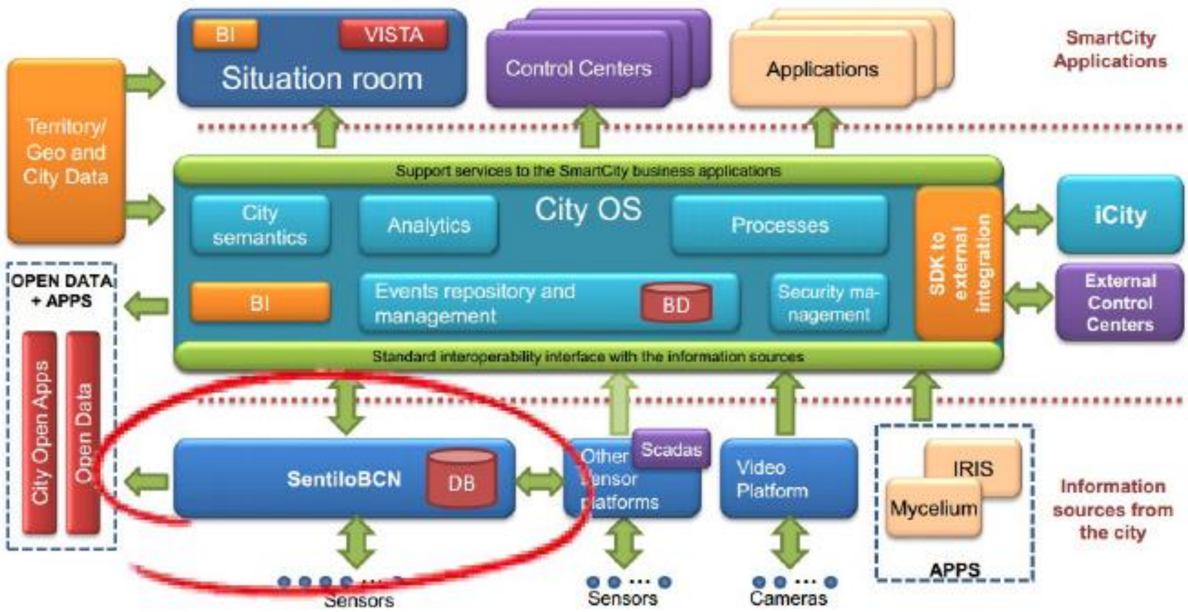

Figure 2-1 Barcelona Smart City IT Architecture (Sinaepourfard et al., 2016)

As noted in Sinaeepourfard et al. (2016), Barcelona developed its architecture with the goal in mind to better manage the disparate population of sensors it was deploying and integrate their data for use in providing its citizens and businesses with more informative and beneficial services. The three-layer architecture follows the standard enterprise architecture approach of creating a data interaction layer to interact with sensors, a middleware layer to act as an integration and publish/subscribe layer, and an application layer upon which various management and citizen facing applications can be deployed. City departments use the platform to monitor the services under their control to ensure that their departmental goals for the city, its citizens, and businesses are being achieved. Using the IT platform thus developed to rethink how the city could manage the complexity of its infrastructure in a more wholistic manner was not a design element of the platform or its implementation.

3 The Evolution of Cloud Computing

While the smart city concept has been undergoing its evolution, advances in digital and communications technologies have revolutionized how distributed computing and application delivery are performed. The late 1990s and early 2000s model of server hosting in external locations began to have problems as the number of users began increasing, forcing new servers to be purchased as individual server capacity became constrained. Google found it could no longer manage its server farms in this manner and started developing operations around what it called “warehouse scale” computing (Barroso et al., 2009). This type of computing operation linked hypervisor (virtual machine) management techniques with virtual machines running on a type of “bare iron” processors that allowed processors to be shared and scaling to occur in a planned manner. This early approach to on-demand scalable computing would be called “cloud computing” later in 2006.[3]

Cloud computing’s model of on demand scaling and pricing has enabled the abstraction of software application developers from having to worry about infrastructure support and management (Mell & Grance, 2012). Software as a Service applications have become commonplace and are providing distributed users with access to application services on an anytime/anywhere basis. In addition, cloud computing’s three-layer architecture, providing Infrastructure as a Service for computing resources, Platform as a Service for application development, and Software as a Service as a hosting layer for applications has enabled developers to create innovative solutions for distributed business users (Mell & Grance, 2012).

The development of Infrastructure as a Service (IaaS) capabilities enabled the warehouse scale computing concept employed by Google to manage the extremely large workloads its search engine was attracting. It also helped Amazon to address its growing need to integrate and manage the diverse frontend and backend systems required to handle its global online retailing business. While Google focused on building out efficient infrastructure for itself, Amazon saw the potential for other global companies to use its infrastructure services and released its Simple Storage Service (S3) and Elastic Compute Cloud (EC2) in 2006. Amazon’s commercialization of cloud services in 2006 created the market that is today recognized as cloud computing.

The key to the success of the cloud computing market has been its transformation of computer processing power from an individually onsite managed operation to a scalable utility in which a business pays for only what it uses. The ability of cloud computing companies to employ large datacenters composed of relatively inexpensive servers and allocate processing time dynamically across these servers utilizes technology that extends back to the late 1950s.

[3] Eric Smith of Google is generally credited with using the term Cloud Computing first at conference in 2006. This credit is controversial as a University of Texas professor, Ramnath Chellappa, claims to have used the term in 1997.

In the late 1950s computer scientists began looking for ways to allow individual users to interact dynamically with the large and expensive computers available at the time. This need arose because computer users, primarily academics and developers, did not like waiting to run simple tests on programs that they were working on. Unable to interact in real time with the large computers available to them, they had to submit their programs to be run in sequential batches, which meant waiting long periods of time to see whether a simple algorithm or program change would run. Computer scientists at MIT developed a prototype time-sharing system in the early 1960s (Corbato et al., 1962). Concurrently with the research work going on at MIT, IBM began developing its own time-sharing system for its soon to be released System 360 (Adair et al., 1966). To make such a system work required development of a concept that has come to be known as a “virtual machine.” This idea was required since the use of a single processor needed to be managed in such a manner that a computer program would believe it had sole access to the processor when in fact it was sharing the processor with many other programs.

Virtualization became a standard in shared computer systems in the years following its development. Users could now run their programs without worrying about having to manage all the intricacies of memory, loading, unloading, etc. However, virtualization was a process applied to a single processor, not to managing a host of processors running on different machines. Addressing this problem required a supervisory program for the operating system supervisor, a hypervisor. The first formal use of this term appears in an article by Popek & Goldberg (1974) where they introduce the concept of a virtual machine monitor, a hypervisor. The hypervisor, or virtual machine monitor, is the management technology that allows cloud service companies to abstract the physical hardware and operating systems they employ from users allowing users to focus on developing their applications and not worry about deployment or scaling.

IaaS services allow users to have access to scalable compute resources without having to manage the resources or worry about scaling. The ability to abstract users away from managing or worrying about the underlying physical technology has allowed the user community to increase its use of software for business operations while reducing its costs. Today there is little worry in most businesses about system response time or system crashes. The Quality of Service provided through IaaS services is significantly more reliable than on premise operations simply because of the scale and operational control that modern virtual machines and hypervisors provide in dynamically allocating compute resources to tasks. Failure of a compute resource is managed seamlessly and user applications continue to run as they are redeployed dynamically to run on other operating hardware.

4 The Physical Internet

While cloud computing was gaining traction in the computing world, the Physical Internet (PI) concept was also taking shape. The Physical Internet is an approach to mobility that uses the digital Internet as a metaphor (Montreuil, 2011). If every physical entity is instrumented with a real time trackable device, why can’t these physical entities be managed on their trips from origin to destination like packets over the Internet? The Physical Internet concept is a particularly useful model when the entities being tracked are freight packages, which are very close conceptually to packets being sent over the Internet.

Using a PI model for addressing urban transportation issues, particularly urban logistics, has been shown to provide considerable benefits (Kim et al., 2021). The basis of the PI model is the collaborative sharing of logistics assets to improve logistics efficiency, effectiveness, and environmental impact. The PI has been demonstrated to lower overall costs in a network through efficiency improvements while also lower emissions (Pan et al., 2013). In the urban context a PI structured logistics model would incorporate shared consolidation centers and microhubs ensuring that vehicle loads were optimized and that vehicle journey lengths were minimized (Kim et al., 2021). The use of low or no emission vehicles (electric vans, cargobikes, etc.) would further lower the emissions from logistics operations.

While the PI offers many advantages by increasing logistics efficiency, lowering costs and emissions, and potentially improving quality of service, it requires logistics service providers to collaborate in delivering their loads. In a highly competitive low margin business like logistics, this is a difficult hurdle for companies to overcome (e.g., Basso et al., 2019). In an interesting article by Fawcett et al. (2015) looking at why supply chain collaboration fails, the authors found that a series of relational resistors create friction that impedes and ultimately causes failure of collaborative efforts between supply chain participants. They created a model of the various resistors that cause failure that is quite informative and shown in the figure that follows.

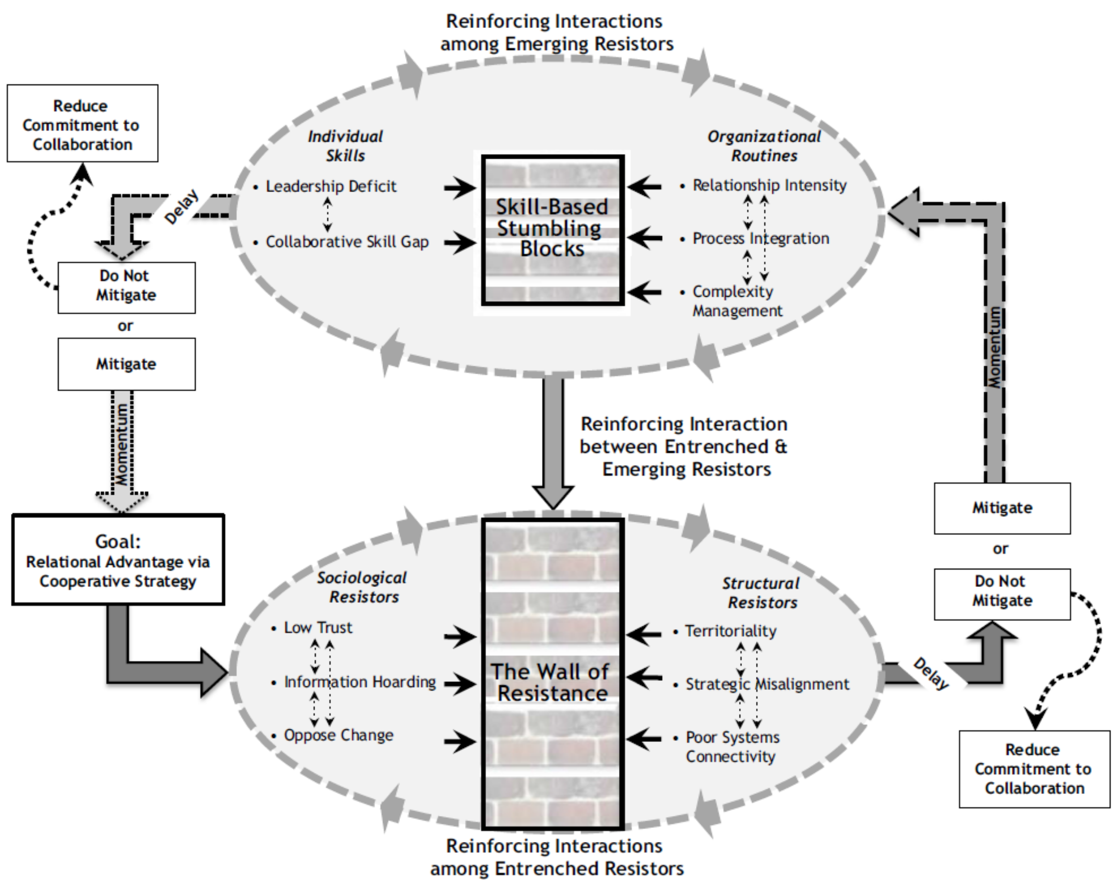

Figure 4-1: A Socio-Structural View of Resistors to Collaborative Capability (Fawcett et al., 2015)

The Fawcett et al. (2015) figure shows that resistance arises within two different groups of potential collaborators. The entrenched individuals see no reason to collaborate while the emerging resistors fail to get sufficient motivation from their leadership teams to overcome the friction caused by the entrenched resistors and the operational challenges that any new relationship brings with it. This study provides a very good overview of why, even when the benefits of collaboration are known, it is very difficult to get parties to collaborate. While it is not the intention of this paper to address the issues that get in the way of logistics collaboration, it is important to note that these issues do act to slow the implementation and adoption of the

PI, and similar issues create problems for city organizations to work in an integrated manner to deliver services to citizens and businesses (e.g., Pereira et al., 2017).

5 The Urban Cloud

The problems faced by cities as they attempt to achieve the vision of smart city operations can benefit from the linking of the cloud computing architecture framework discussed above with the Physical Internet construct. With respect to the cloud computing architecture, organizing smart cities around a model in which city infrastructure is managed as an on-demand service available to users could optimize the use of city infrastructure while eliminating overuse and congestion. In addition, building an urban "cloud" model for city services, where city platforms form a Platform as a Service layer upon which service providers (including the city itself) build applications to serve the city's citizens and businesses, would also enable cities to better realize the citizen centric service objective at the heart of the smart city concept.

The Internet provides an example of how urban cloud services, operating to manage a Physical Internet in which delivery and pickup of shipments within a city are consolidated and deliveries are optimized, could improve the utilization of city infrastructure, and benefit the city through more efficient logistics operations. Just as businesses use the Internet to access cloud-based services, cities employing an urban cloud model could deliver Logistics as a Service to their constituencies with the physical execution performed according to Physical Internet principles.

5.1 Urban Infrastructure as a Service

Managing city infrastructure as a service requires some clarification. Unlike the infrastructure models developed for cloud computing in which operations on silicon can be "virtualized" so that computing resources can be dynamically shared, and failure of infrastructure gracefully handled, it is very difficult to virtualize a vehicle occupying a curbside parking space so that another vehicle can also occupy that space. However, a city can dynamically manage and control the linear areas along its curbs using cameras or sensors. Using data collected in real time, the city can dynamically assign loading and unloading space to both passenger vehicles and logistics vehicles. It can enforce this assignment process by dispatching enforcement personnel to ticket offenders or by requiring all local vehicles to carry a sensor that identifies the vehicle and that can be used to automatically ticket the vehicle for offences. Certain issues with privacy would need to be addressed, although most cities require owners to register their vehicles to park in the city today, so adding a sensor requirement may not be as problematic as it may seem.

By abstracting the infrastructure through an IaaS system, the city would provide convenience to its citizens, businesses, and logistics operators. These users would no longer have to seek out open areas for parking, dropping off, or picking up items. They could schedule the abstract space through applications built on top of the IaaS services and be assured that they could use the space for the duration that they have scheduled it. These users could also be forewarned about issues with particular areas that they are interested in using through both predictive capabilities of the city's PaaS services and be given dynamic alternatives.

Beyond dynamic management of curb space, the Infrastructure as a Service model would allow cities to control access to areas that are congested by dynamically blocking access or controlling access flow based on congestion. Integrating this flow control with curbside parking management would reduce emissions and circling by both commercial and citizen drivers as they look for open parking space. Additionally, cities would have the potential to dynamically allocate open space areas to mobile consolidation hubs or parcel lockers based on demand. This capability would further reduce travel times for both logistics delivery services and customers as the distribution hubs and pickup points would be positioned as close to the demand locations as possible.

By dynamically managing its Infrastructure as a Service, a city not only is able to manage a scarce resource more efficiently and effectively, but it can also optimize its return on investment in that resource. Today cities generally charge fixed fees for parking and access. By being able to charge for actual use, and by employing demand based variable usage fees, cities can optimize the revenue they receive from the use of expensive and limited city resources. These fees can then be employed to better maintain or increase capacities thereby improving both citizen welfare and business economics.

It should be noted that while this paper focuses on a certain subset of a city's transportation infrastructure, the concept of urban Infrastructure as a Service is not limited to transportation. Cities have many different infrastructure components interacting in systems that support their citizens and businesses (e.g., sewers, water, communications, electricity, Internet, etc.). There is no reason that these types of infrastructure could not also be managed via an IaaS system as they are also highly instrumented today via different control systems and interact with transportation infrastructure in numerous ways.

5.2 Urban Platform as a Service

To develop services that would make use of an Urban Infrastructure as a Service requires the aggregation of sensor data from different urban systems. It also requires tools to make sense of the data being received and to develop new services that can be delivered to businesses and citizens. In an Internet cloud environment these tools and collection services are provided through the cloud providers Platform as a Service (PaaS) layer. For the urban environment such a layer would link to the sensors embedded in the city's infrastructure, integrate these data as required, feed management systems for controlling the infrastructure, link to digital twins for predicting future use and making decisions, and connect to strong non-repudiation monitors to ensure that events are properly logged and inevitable conflicts are resolved through clear establishment of what occurred, when it occurred, and who was responsible for the occurrence.

Employing a PaaS system for integration of data flows and management decision making increases the resilience of the city to disruptions. The PaaS services provide real time access to what is happening in the city's infrastructure. Failures are noted as they happen and, through the use of digital twin projections, city operators can determine the likely set of issues that such failures might cause. This information can be used to make informed decisions concerning what to do, how to minimize impacts, and, just as importantly, how to correct the failure. As cities face more stress due to increasing populations and environmental degradation, the ability to respond quickly becomes increasingly important. The structuring of a city's infrastructure technologies using the IaaS and PaaS models could help in addressing these rapid response needs.

5.3 Urban X as a Service

The urban PaaS would provide tools to developers, internal and external, to develop additional services that could take advantage of the city's infrastructure and be deployed through the PaaS. An example might be an urban Logistics as a Service (LaaS) model that implements on demand delivery of food or groceries for businesses within the community. A last mile delivery service could also be built as a LaaS service where consumers or business requiring delivery of goods could link to the delivery process and direct both the timing and location of delivery or drop off that would be most convenient for them. By connecting through the city sponsored LaaS service the city would be able to dynamically manage logistics flows and ensure that unintended problems did not arise. The city's Mobility as a Service operation could also employ tools from the PaaS to provide citizens with on demand mobility based on IaaS feeds that optimized their pickup and transport experience. Many other services could be developed such as Parking as a Service, Meetings as a Service, etc. All these services would provide citizens with more transparent access to city services and would help to improve the quality of delivery of these services to them.

6 Conclusion

Linking the Urban Cloud concept to city-wide logistics operations employing the Physical Internet model has the potential to create a controlled Logistics as a Service approach to city logistics operations. Such an approach, delivered through the on-demand scalability of the city's Infrastructure as a Service model and built on top of the city's Platform as a Service development platform, could lead to the elimination of logistics congestion and environmental problems that currently cause problems for city administrators and their constituencies.

This paper explores the potential for organizing city services in a cloud-like manner to achieve the smart city vision, optimizing the use of shared resources (city infrastructures). It examines how an Urban Cloud could be constructed in a three-layer model like Internet based cloud services. Using the Urban Cloud model as a foundation, the paper examines the development of a Logistics as a Service model built using the Urban Cloud's platform services, managed by digital twin services embedded in the platform, and employing its Infrastructure as a Service enabled by edge-based sensor technologies to control last mile delivery of parcels, accounting for interoperability, security, resilience and sustainability. The benefits of such an approach are discussed and the limitations of the model are identified. Finally, recommendations for how a city might move forward in the development of its own Urban Cloud are presented.

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