A Systems Approach to Smart City Infrastructure: A Small City Perspective

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Abstract

This research examines how a smart city is defined and then compares these definitions to actual city mission/vision statements. This comparison revealed a disconnected between the technology focused definitions of smart city, and the focus of city leaders. A systems integration framework and generalizable model for smart project implementation are then developed to enable any small city to become a smart city with a focus on the goals identified in the city mission/vision statements.

Keywords: Smart City, City Small City, Systems Integration, Internet of Things

Introduction

There have been many efforts to describe how cities should be designed, and how people should interact with city infrastructure, in an effort to build cities where people want to work and live. City planners have been looking to build "Smart Cities" for over 2000 years from Plato's theoretical Utopia (Plato, Ferrari, & Griffith, 2000), to the middle ages that utilized the hub and spoke city designs urban planners used in the renaissance, to the industrial age and the Octagon city in Kansas, designed for vegetarians and built in 1856. In 1924 the architect, Le Corbusier presented Ville Radieuse (Radiant City), the machine city where daily life was controlled by machines (Merin, 2016). However, the advent of the internet, with ubiquitous compute power and fast computer networks, only now makes it possible to provide city infrastructure that will sense what is happening and report what is happening in real time. City designers now speak of smart cities, an evolution of the city that includes the integration of information communication technologies (ICT) to monitor city conditions in real time.

Much work has been done to define what a smart city is and to define what is required to make a city "smart". However, there is currently little agreement in the academic community as to a singular definition of what constitutes a smart city (Albino et al. 2015). For example, Lombardi et al define a smart city as "The application of information and communications technology (ICT) with their effects on human capital/education, social, relational capital, and environmental issues"(2012); whereas, Bakici et al define a smart city as "a high-tech intensive and advanced city that connects people, information and city elements using new technologies in order to create a sustainable, greener city, competitive and innovative commerce, and an increased life quality". These two definition focus on two different categories of city improvement and emphasize technology over everything else. This lack of agreement inhibits the ability of municipalities to design and build cities that fully leverage technology, as each municipality must go through a process of defining and designing all of the smart city components anew with each new implementation.

This paper uses a design science methodology (Peffers, et al. 2007) to bring together the common themes in many definitions of smart cities to create a framework that establishes a broad and robust definition of a smart city. Further, we identify the requirements and measures needed to assess the "smartness" of a city. While many papers identify technologies that can be used to build smart cities, none provide a comprehensive basis for comparing two or more smart cities with respect to their "smartness". Additionally, the lack of a comprehensive framework leaves practitioners with no guidance on how to make it all work.

This paper focuses on cities with fewer than 100,000 in population. Most smart city research has been conducted on large cities, leaving the much larger number of smaller cities left with trying to decide what parts of the larger city projects can be done with the resources smaller cities have available. We believe it is easier for large cities (with greater resources) to scale up a framework that succeeds in a small city context than it is for a small city (with fewer resources) to scale down a framework developed in a large city context. Thus, the framework developed in this paper takes into account the limited budgets and limited technical resources owned by smaller cities. In 2015 in the United States, there were 19,235 cities with less than 100,000 in population (National League of Cities, 2015), which makes this work immediately relevant on a wide scale.

Design Science

Design Science research in Information Systems is concerned with creating an IT artifact to solve an identified organizational problem (Hevner, March, & Park, 2004). The boundaries of this artifact or framework can be defined utilizing the information technology(IT) interaction model (Silver, et al, 1995), which focuses on the IT framework required within a managerial view of the municipality. Therefore, the information system framework will utilize "business need" as its driving input. For small cities, the business need is defined by the mission statement of the city. The resulting framework will represent the information system within this context.

In this paper we will follow the design science research methodology's six activities as outlined by Peffers et al. (2007). Activity 1 will focus on problem identification and the value of a solution. Activity 2 will define the outputs of the system with respect to the problem definition. Activity 3 will define a systems framework that a city can follow to produce a "Smart City" outcome. Activity 4 will demonstrate how the framework can be implemented within a city and will show a prototype instance of the implementation and a set of limited results. Activity 5 will evaluate the framework based on a field study (Hevner, March, & Park, 2004) that utilizes previously defined metrics of smartness, from Activity 2. Activity 6 is this paper and future papers that will discuss the results of the designed framework and what the next steps in implementation of this framework should be. Figure 1 shows a conceptual framework for executing this research adapted from Hevner et al. (2004).

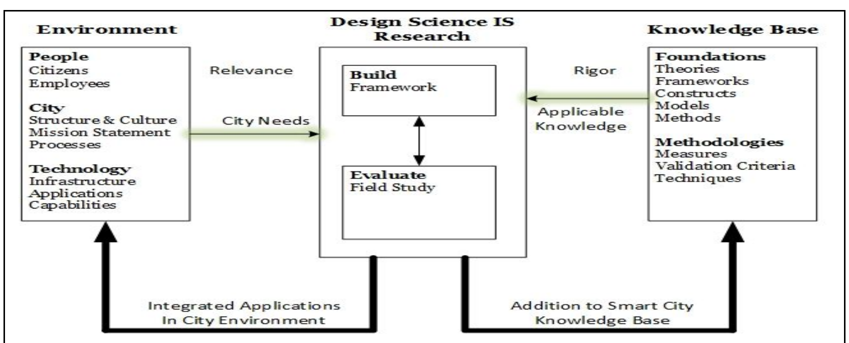

Figure 1. Conceptual Research Framework adapted from Hevner, March, & Park, 2004

Activity 1: Defining Smart City

The term Smart City has been in use since 1990's (Doran & Daniel, 2014) (Lombardi, et al. 2012) and in recent times the concept has also been communicated under other monikers such as digital city, intelligent city, cognitive city, and knowledge city. Unfortunately, many definitions of smart city have been promulgated. Albino, Berardi, & Dangelico (2015) identified a large list of definitions for smart city used in research papers in the last 5 years. These definitions of Smart City can be categorized in ways that capture the focus of each definition (Table 1). Some definitions have a secondary focus, so we identify a secondary category. The identified categories are:

- Technology – The focus of the definition is on how Information and Communications Technology (ICT) can be used to affect an artifact within the city or the focus could be on a specific technology implementation.
- Sustainability – The focus of the definition is on sustainability through the use of ICT. Sustainability can refer to resource use, financial responsibility, or environmental control.
- Economic Development – The focus of the definition is on how ICT can improve the growth and economic output of a city.
- Quality of Life – The focus of the definition is on how ICT can improve the quality of life to citizens living within the city. Quality of Life includes public safety, education, and facilities.

Table 1. Categories from Smart City Definitions Review		
	Category 1 Count	Category 2 Count
Technology(ICT)	18	1
Sustainability	2	3
Economic Development	0	3
Quality of Life	1	3

Table 1. Identified Categories from Smart City Definition Review

As can be seen, the overwhelming majority of smart city definitions focus on ICT.

When considering the focus of city mission statements, we believe the overwhelming focus on ICT in the smart city definitions is unfortunate. Table 2 in Appendix 1 shows a review of city mission statements from cities in North America. The prototype system model is a computer systems model that has been developed for a City in the Southern United States, and is specific for cities in the United States. Using the same categories as was used to identify the focus of the smart city definitions, we get a very different idea of what is important to city planners and leaders.

Table 2. Summary of Identified Categories from City Mission Statements		
	Category 1 Count	Category 2 Count
Technology(ICT)	0	0
Sustainability	5	3
Economic Development	0	5
Quality of Life	18	1

Table 2. Identified Categories from City Mission Statement Review

As can be seen from this sample of City mission statements from North America, in Table 2, when it comes to the guiding principles of cities and their raison d'etre, technology is not mentioned. Smart city definitions focus mainly on Technology while the focus of cities, as set out in their mission statements, is on quality of life, sustainability, and economic development. This disconnect may inhibit the development of municipal technology infrastructure to build smart cities because the purpose of the technology does not appear to be at all aligned with the purpose of the city.

Rather than propose yet another definition of smart city we focus on the action of being smart. In the same way a business follows its overall mission statement and strategic plan, a smart city is simply a city that follows its mission statement and initiates projects based on the overall mission of the city. This approach captures the "smartness" of the system, rather than a focus on any "smart" initiatives.

Activity 2: Smart City System Outputs

Given that Quality of Life appears in a majority of city mission statements, we will use it as a guiding factor in developing our framework. Where quality of life is not a focus for the city, the appropriate focus could be used instead.

In government information systems, the information and applications tends to exist in silos, with little information sharing due to the hierarchical nature of government organizations (Bigdeli, et al. 2013). For a smart city to be successful an operational framework needs to be developed that ensures ICT systems are integrated. Municipal information governance must therefore be defined as a collective set of systems and processes that work together to increase the quality of life of citizens, the economic opportunity of citizens, and can provide for resource sustainability. Each link in the system must be shown to service these end goals, otherwise it is not critical to the municipal organization's success.

When developing metrics to measure the success of a smart city initiative, the analysis of city mission statements in the United States showed quality of life to be the overwhelming guide for city leaders. The World Health organization defines quality of life as *an individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns* (World Health Organization, 1997). Economic development is defined as the level of business activity in a community (Wassmer, 1994). Cities must therefore attract business and offer economic opportunities to its citizens. Today, the opportunities must be in the finance or technology sectors for young people to either stay in a city or to choose migrate to a city (Bartley, 2006). Sustainability relates to the conservation of natural resources, usage of land through planning policy, and the control and monitoring of pollution (Ramaswami, et al. 2016) (de Jong, et al. 2015). Chosen metrics must measure some artifact summarized in Table 2.

Smart city definitions focus on the whole city including government agencies, Non-Governmental Organizations, schools, private business, and citizens. A municipal government cannot affect the systems and procedures of non-municipal entities. The system we propose will be for municipal government and its agencies (Stratigea, Papadopoulou, & Maria, 2015). All integrations within the framework must contribute to an identified focus of city leaders. However, qualitative indicators must be defined to measure the effect of a city project or initiative on the categories identified in table 2 and table 3. Measuring the success of a project in terms of the city's mission statement relates the value of a project back to the mission of the city, rather than some vague smart city definition. Lombardi, et al. (2012) propose a modified Triple Helix model with indicators for measuring smart city initiatives. The four helix model can be operationalized by being linked to the three foci identified in Table 2 and then summarized in Table 3, thus providing a framework for classifying the smart city indicators in the terms of the city mission statements. Table 5 in Appendix 1 shows the city focus category, the associated helix, and the chosen indicators to measure a cities level of success. The revised triple helix model contains four helices: university, government, civil society, and industry. Each city can choose from measures identified by Lombardi, et al. (2012) based on the project it is implementing and the definition of project success with a focus on the city mission statement.

Activity 3: Smart City Systems Framework

A smart city must build a collection of ICT infrastructure solutions that include an integrated data center, integrated applications, and an advanced communications network capable of collecting data from a myriad of internet of things (IoT) sensors (Dirks & Keeling, 2009). The systems integration model should show each city system, and the links between systems should be identified with indicators.

Cities' structures usually contain sets of departments that manage the various tasks of the city. While the names of the departments vary from city to city, the functions they perform are similar. Cities may order their tasks differently, however, the model of the systems in use can be adjusted for individual instances to fit the local nomenclature. The systems integration across departments, agencies and/or business units is important because it will provide citizens with a better quality of life, more economic development and better resource utilization and sustainability. Table 3 gives a definition of each system, which department may use it, and its function within a city.

Table 3. System Definition, Main City Department User and Functions

System	Department(s)	Function
911 – Computer Aided Dispatch (CAD)	Public Safety	911 Calls Dispatch Police/Fire/EMS
Police/Fire Mobile Data	Police and Fire	Provide GPS co-ordinates to CAD, track historical vehicle behavior, and provide real time alerts to staff.
Police Records Management	Police	Crime reporting and documentation
Traffic Management	Engineering Public Works	Provide centralized traffic light control and intersection monitoring
Public Works	Public Works	Vehicle fleet management, infrastructure maintenance work orders, waste water management, city building maintenance, street cleaning, street signs, cemetery, and grounds keeping.
Environmental Management	Environmental Management	Garbage pickup, recycling programs.
Parks and Recreation	Parks and Recreations	Manage municipal sports complexes, leisure programs, organized activities, and sports. Manage municipal event/conference space.
City Engineer	Engineering	Postal address creation. Infrastructure improvement and build plan review and inspections. Storm water management.
Planning Permitting and Inspections	Revenue(Permits) Code Enforcement Bldg Inspection Fire Inspection Planning Public Works	Business licensing, building occupation certificates, manage planning application process. Work orders to public works for street changes, code enforcement inspections, and citations.

Table 3. A System Definition, Associated City Department and Function Description

Many of the technology based definitions of smart city discuss city systems or collections of systems (MIT, 2015), however, they do not link what the system task is to the strategic vision of the city. Figure 2 shows the proposed systems framework model for a smaller city. This framework has many links. Each of these links must have a purpose and must be tied back to the categories identified in city mission statement focus summarized in Table 2. Much research has been done on spatial analysis, utilizing Geographic Information System (GIS) (Theodoridis, et al. 2013); (Doran & Daniel, 2014). We place three modules we feel are critical to the successful operation of a city at the center of the model. GIS is required to show that all city assets, systems, and sensors will track city artifacts on a map. By providing map based recognition of events and city actions, city staff will be able to report usage by area, by planning zone type, or by voting districts. This spatial information is the base information that all city systems use. Maps provide the most meaning to reported data that shows an effect on a citizen's quality of life (crime heat maps, and school zone maps), for economic development (traffic counts and infrastructure investment), and for sustainability (pollution heat maps and recycling counts by location). Map based city information provides an easy to understand, dynamic report that is visual, rather than a table of numbers (Chapin, 2003).

The second module essential to the building of a smart city is a network that can allow IoT sensors a way of sending data back to the city data center for processing. Each city's topography, infrastructure, and capabilities differ, so we cannot prescribe a specific networking technology to achieve this goal. For monitoring of city infrastructure, pollution, fluid systems (water, waste water, and storm water) and traffic data must be sent to the event management system located in a city data center or cloud data center. From the event management system, event data is transferred to the appropriate module for processing and action by city staff if required. The significance of being able to access the data in real time is that actions by the city can be proactively initiated as events are detected rather than the city passively waiting for them to be reported by citizens or city employees (Salim, 2012).

The third module is the ERP system which provides purchasing, human resource, inventory control, revenue, permitting, inspections, and web based access for citizens to request services from the city. This system provides the governance and control required by governmental organizations to ensure, the city is in compliance with ethics laws, procurement laws, and other general regulations enacted by the Federal Government, State Government or even local ordinances enacted by the City itself. By providing rules and controls that are auditable, the city cannot act or spend money without following the correct procedures enforced by the ERP system. For example, a work order created automatically by the street light system, to clear a storm drain based on the detection of pooled water, must go through the same approval process a manually entered work order goes through based on a call from a citizen.

Table 4 shows each module within the framework and defines each link and which indices it should affect, according to the modified triple helix model.

Table 4. Framework links and the affected Output Indices

Module	Linked Module	Indices
911-CAD	Police/Fire Mobile Data System, Police Records Management, IoT, Event Management.	Crime Rate - percentage per capita for various types of crime. (Quality of Life) Law Enforcement Accountability Assessment (Quality of Life)
Traffic Management.	Event Management, IoT.	Accident Detection all traffic signal timing changes. (Quality of Life)
Public Works.	Event Management, IoT.	Automatic detection of Infrastructure problems allows fast response to maintenance issues (Economic Development and Quality of Life). Storm Water System monitoring and repair. (Sustainability). Waste Water System Monitoring. (Sustainability)
Environmental Management.	IoT and Event management.	Track recycling centers and customer counts. GPS location information showing pick up times. (Quality of Life) Manage citywide recycling programs (Sustainability)
Parks and Recreation.	IoT.	Provide Sports and leisure facilities, activity programs (Quality of Life) and conference and event centers (Economic Development)
Planning Permitting and Inspections.	ERP, City Engineer.	Provide e-Government processes to ensure a consistent approach to planning, and permitting with the City. Allow inspection process to be monitored online (Economic Development)
City Engineer.	IoT.	Storm Water Control (Sustainability). Energy efficiency programs (Sustainability). Pollution monitoring (Quality of Life). City infrastructure planning and approval and inspection. (Economic Development)

Table 4. Explanation of the links within the developed framework (Figure 2.)

While each information system within the city helps improve the stated goals, there are also other city government internal tasks which are not represented on this model. This model attempts to define the systems integrations necessary to provide the ICT infrastructure that can support smart city projects. It can be seen from the following examples utilizing the model in Figure 2 that the collection and sharing of information between city departments through integrated information systems will allow the development of smart city applications shown in prior literature. Example 1, shown later in Activity 4, shows the implementation of a prototype dynamic street lighting system. This system requires the use of GIS to mark the location of each device, and an IoT infrastructure to link all the street lights together to ensure they work together to dim and brighten as people and cars are detected. Video data will also be streamed back to the city's servers for analysis with traffic and pedestrian information to be fed into the traffic management system. This information will also be retained for use in maintenance decisions, for example on when road resurfacing and sidewalk maintenance needs to occur. This video can also be moved to the police evidence management system if a public safety related event has been captured. Example 2 seen in Activity 5 shows an automated traffic management system. This system uses video to measure traffic counts at intersections and the directions cars take as they pass through the intersection. This information is passed to a central management system to enable management of traffic across multiple intersections based on traffic counts and vehicle direction data. Data from this system will be shared in real time with 911 dispatch if a car crash or pedestrian accident events are detected. This will allow faster response times from medical services and police units. This video can also be moved into the evidence management system in the event it is needed by public safety officials. It can also be seen from this design that an initial requirement for a smart city is an appropriate GIS system with the necessary information on city infrastructure collected (Venigalla & Baik, 2007). If a smaller city does not have the resources to complete a GIS project, then a partnership with a local university maybe an option. This arrangement would supply the necessary expertise, while also offering an educational opportunity to students (Dawe & Sankar, 2016).

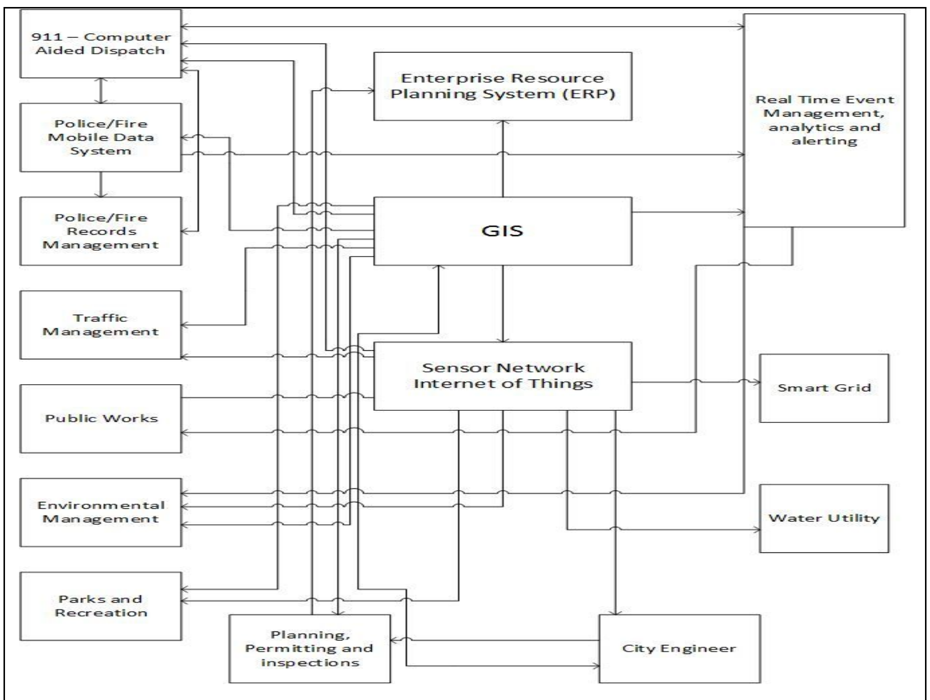

Figure 2. A Small City Systems Framework

System Connections

Each system has various connections to the other systems for integration purposes. The GIS system is connected to 911-Computer Aided Dispatch (CAD), Police/Fire Mobile Data System, Traffic Management, Public Works, Environmental Management, Parks and Recreations, Planning, Permitting and Inspections, City Engineer, Water Utility, Smart Grid, ERP system, and the Real Time Event management, analytics and alerting. This is because all these systems, require spatial data and maps to operate. By utilizing maps, events can be placed in a specific location so personnel can be directed there and map based reporting can be conducted based on the city's needs. The Sensor Network, IoT is connected to CAD, Traffic Management, Public Works, Parks and Recreation, City Engineer, Water Utility, and Smart Grid. These systems utilize sensor data to proactively maintain city infrastructure. For example, the Smart Grid utilizes electrical sensors to monitor equipment performance, and to monitor the grid for failures, allowing the system to self-heal if a failure is detected. The Smart Grid sensors also creates work orders for crews to fix problems or replace/repair equipment that is showing a predicted failure alert. Parks and Recreation utilize ground water sensors in the ball parks and soccer fields to enable water savings by only activating the water sprinklers if the amount of water in the ground reaches a certain level. The ERP system governs rules for purchasing, inventory usage, permitting, and billing. The City Finance department tracks all public expenditures and incoming payments via the ERP system. The ERP system also generates all work orders, so equipment usage and labor hours can to tracked, and linked to map locations via GIS.

The Real Time Event Management, analytics and altering system provides connectivity between the applications and generates warnings that require a human response. This system also handles the analysis of video data to provide event warnings to either public works, in the case of identified city infrastructure failures, or to 911-CAD in the event the camera systems detect vehicles that have been flagged by the local law enforcement agencies. The Water Utility utilizes GIS to track all underground infrastructure and the Sensor Network IoT to provide water flow information, meter reading and leak detection. The 911-CAD system utilizes GIS to provide mapping data and address information, to locate calls to 911. This system also, passes the 911 call center notes to the Police/Fire Mobile data systems, so the officers have the 911 location, directions and transcripts of the call(s) in real time. The Police/Fire Mobile Data Systems also updates the 911-CAD center with the location of officers and public safety vehicles. Officers can see the locations of all other units and personnel responding to an incident. The Police/Fire records management system(RMS), take the data from 911-CAD and the Mobile data system to create the written reports for each event an officer responds to. This system is also responsible to reporting crime data to the relevant federal agencies for national statistical reporting.

Public Works and City Engineering utilize the Work Order system within the ERP system to respond to city building issues or to infrastructure issues reported by citizens or identified by the Real Time Event Management and Analytics System. Public works also operates the sewer system and uses the sensor network to ensure the sewer system is working correctly, by monitoring flow data at each pumping station and ensuring all the waste water arrives at city treatment facilities. City Engineering also provide design reviews and inspections of new city infrastructure, including roads, bridges and city owned buildings and facilities. City Engineering is also responsible for monitoring storm drains, Traffic Management uses GIS to provide mapping and location information and the sensor network IoT import real-time traffic statistics to control traffic light hold and release times. Video analytics also provides intersection accident data to the 911-CAD system for dispatch of emergency services.

Environmental management uses GIS for route planning of trash pickup and for tracking recycling drops and the type of materials being recycled at different locations. GPS is also used to track each trash truck as it follows its route so citizens can see where the truck is, if their trash has not been picked up.

Planning, Permitting and Inspections uses GIS to management the planning process for land usage throughout the city. The permitting process utilized with the ERP system allows permits to be requested online, and then the citizen or business can track the permit and inspection process as it is completed. Permits are issued online via the ERP permitting web portal. The permit process includes inspections of retention ponds throughout the city. The Sensor Network IoT will be utilized to provide water quality information and foliage growth data.

Generalizing the Small City Systems Framework to define a model for a Smart project

Figure 2 represents a systems view of a city's ICT infrastructure; a generalizable framework needs to be generated for smart city projects. Figure 3 represents a generalizable model that shows what a project undertaken by a city should require for inputs, the general functional operations of a city that could be affected and based on our analysis of city mission statements, and the outputs that should be measured.

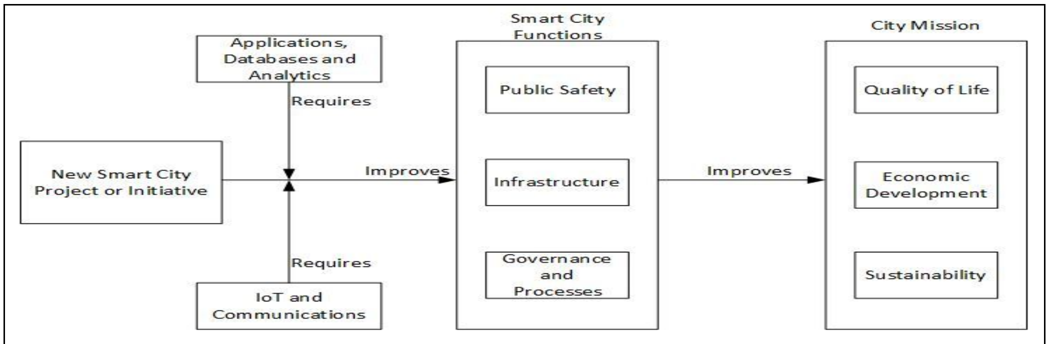

Figure 3. Generalized Smart City Project Framework

Each smart city project should be measured on how it improves a citizen's quality of life, the economic development opportunities offered to citizens and how it provides for more sustainable use of resources by the city. A city has three basic categories of functions: First, public safety, which includes police, fire, emergency medical response and emergency management; second, infrastructure, which includes streets, signage, engineering, grounds, environmental management, and building maintenance; third, governance and processes, which are the ordinances and management processes of the city defining how citizens and businesses interact with their city government.

Limitations

The limitations to this design research are that this systems model is built within one city. This model needs to be implemented and studied at several other cities to prove its theoretical generalizability and its overall practical usefulness. Also, this paper does not assess any other affects these systems may have on the citizens of the city. The systems added to this city and integrated together in this city will have other affects whose contribution to the success of the city mission needs to be quantified and measured. Longitudinal case studies should be conducted to ensure that the contributions of these systems is consistent over time, and to measure any changes to the results that occur over time. This will give a more accurate assessment to the benefits of the systems added in Activity 4 and Activity 5. The prototype streetlight system added in Activity 4 needs to be expanded, and the results recorded to show whether the power savings benefits of the system match those predicted. If the predictions are accurate, then this system could be implemented in other cities with an accurate prediction of power savings and return on investment for those cities.

Conclusion

This paper provides a practical systems framework, shown in figure 2 that allows a city to design an ICT infrastructure that supports the necessary ICT systems and system integrations required to initiate smart city projects. The generalized project framework shown in figure 3, can be used by any city to design a smart project. This theoretical project framework ensures that smart projects have an output that has been identified in the city mission statements. By recognizing that each city has its own mission statement, the generalized project framework coupled with the metrics identified in prior literature allow city leaders to design, approve, and invest in smart city projects that have measurable outputs that can be interpreted in terms of the city mission.

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