

Towards a governance dashboard for smart cities initiatives: a system of systems approach

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Abstract— This paper introduces a decision-making tool, designed to enable governing bodies to maintain management of traditional metropolitan areas as they evolve into smart cities. As metropolitan areas such as New York, Paris and Singapore begin embedding smart technologies into their infrastructure, real-time data become available to citizens and governments. As a result, new challenges have emerged that raised questions about more optimal ways to govern and manage cities operating as systems of systems environments that are now more highly connected and dynamic than ever before. To assist governing bodies to effectively manage these quickly growing systems of systems, this paper proposes a conceptual framework with a set of core building block components required to develop governance dashboards for smart cities. A case study of Singapore Smart City Lamppost initiative is presented, which acts as a practical example of the development of these governance dashboards within the lampposts component of smart cities and serves as a possible blueprint for expanding this approach to the rest of the smart city infrastructure.

Keywords—System of Systems, Smart City, Governance, Dashboard.

I. INTRODUCTION

The significant increase in embedded technological and smart infrastructural development has given rise to more Internet of Things (IoT) devices being deployed across the new urban environment. Smart cities like New York City, Paris, Amsterdam, Boston, Seoul, Tokyo [2] are facing immense challenges in effectively managing the highly connected system of systems environment as they enter a new critical phase of development. To overcome these challenges, there is a need to harness highly granulated real-time data across the smart city's operations [3]. This presents an opportunity to apply a concrete smart cities system of systems governance framework [4] to develop a smart cities governance dashboard capable of aggregating and disseminating massive data before conveying holistic information to citizens [5] within a complex urban system that consists of constituents that are autonomous, connected, diverse and emergent [6].

This paper will first explore the rise of the terminology of smart city, followed the challenges faced by the rapid emergence of the adoption of smart city technologies within the existing urban systems. Finally, a case study is discussed, which demonstrates the use of governance dashboards in a segment of smart city infrastructure and future work in the area.

II. SMART CITIES

A. History / Evolution

The terminology used to describe the future of cities can be derived from a variety of perspectives including environmental, social, economic or governance. Even a combination of any number of these viewpoints. The most used terms used to describe these cities of the future provide broad and wide sweeping analogies. Such terms include 'future cities', 'sustainable cities' and as used in this paper, 'smart cities' [7].

These terms have seen a spike in usage over the last ten years [7] with Sustainable cities and smart cities taking top place in Google search interest making 'smart' among the most "popular adjective of cities in comparison with others such as sustainable, healthy, liveable, green and resilient" [8].

Mardacany [9] identifies seven characteristics of smart cities in his paper, Smart Cities Characteristics: Importance of Build Environment Components. The characteristics include smart politics, smart governance, smart people, smart science and technology, smart environment, smart living, and smart built environment. In summary, a smart city is defined as a municipality that increases operational efficiency, information sharing with the public and improves government service and citizen welfare through information and communication technologies [10].

B. Benefits

A smart city is a system of systems with governmental departments, infrastructure, communities, public and private services all operating together for a common purpose of a safe and sustainable metropolitan area connected by digital networks and devices. This highly integrated city provides for quicker response times for public services, greater access to information and innovation within enterprises, more sustainable environments, and more efficient use of resources. All these services aim to contribute to a better lifestyle for all the citizens of the city. [11]

The infrastructure enabled through smart cities also provides advances in how governing bodies are able to gather, interpret, and leverage data for improved decision-making. With real-time and near real-time data being fed into tools such as governance dashboards, responses that were highly reactive can now be proactive and time for approvals and actions can be greatly reduced [11],[10]. An example of smart cities gaining from interconnected systems can be seen from such innovative projects as MaCh eX Singapore smart light poles. Usage of these systems developed, by companies like MaCh eX, enable decisions about city security, health emergencies, social unrest and more can be more informed,

TABLE I. SMART CITY GOVERNANCE DASHBOARD ADAPTED FROM GOROD, ET AL. [20]

SoS Governance Feature	Smart City Elements	SoS Governance Dashboard Component
SoS External Factors	Natural disasters, pandemics, adverse weather events, social unrest etc.	Interactive simulated events and environmental construct
Feedback from SoS	CO2 levels, noise levels, traffic numbers, pedestrian numbers, security video feeds etc.	Interactive indicators and charts
Constraints on Governing Body	Budgetary funding, public opinion, natural resources capacity, international law etc.	Interactive parameters
SoS Governance Levers	Public policies, budgetary spending, fiscal policy, legislation etc.	Interactive variables

and made quickly, using high quality, streaming data straight from the field.

C. Challenges Relating To Governance And Management

Governance and management of smart and traditional cities alike are how to respond to challenges that occur daily when operating a SoS. The decisions of which have direct, and in-direct, impacts on citizens well into the future. The results of such actions may not be experienced for months, or years from the day they were taken. An example of such challenges is the governance of city-wide transportation systems. Specifically, the lack of credible public transportation options for integration, a need for centralization of the transportation system, safety and security concerns of increased internet connectivity of public facilities and the need to ensure the sustainability of the transportation system during and post upgrade [4].

III. GOVERNANCE DASHBOARDS

One of the common methods of providing information to decision makers are concise, interactive dashboards that are made available to multiple levels of management through various perspectives. The term ‘dashboard’, as a decision making tool, has been officially around since 1990 when Oxford dictionary recorded its definition as “screen giving a graphical summary of various types of information, typically used to give an overview of (part of) a business organization.” [12] The use of dashboards has been increasingly popular as it enhances end users’ process of decision-making ability. Due to the demand for interactive multi-system dashboards, many industries and academia are investing heavily into their development [13]. The purpose of a dashboard is to allow users to effectively view large amounts of data, structured into multiple perspectives to guide users through vast information effortlessly. The displayed features on the dashboard will allow users to immediately identify key information, with the options to drill down to details [13].

Dashboards can be used for planning, monitoring, communication, consistency and analysis and must be intuitive, concise, complete and yet, expressive. Dashboards can be categorized based on common features or three managerial levels i.e. strategic, tactical and operational levels [14]. The introduction of smart cities initiatives into the urban area is a recent phenomenon, where smart devices like high quality sensors, cameras and transponders are used to capture real time data. The synthesis and analytics performed on these collected data will improve the existing lifestyle of people,

hence a more effective way to govern the new urbanized landscape [15].

IV. GOVERNANCE DASHBOARDS IN SMART CITY INITIATIVES

Meijer and Bolivar performed a literature review of 51 publications on smart city governance in their paper “A review of the literature on smart urban governance”. They observed and documented variances and commonalities of the perspectives held by these publications. Although, their research identified that there is fragmentation among academic work regarding how governance of smart cities is applied, they did manage to identify four perspectives and focus; government of a smart city with a focus of good administration and good policy, smart decision-making with a focus on innovative decision-making processes, smart government administration with a focus on innovative organisation and administration, and smart urban collaboration with a focus on innovative governance networks [16].

To enable governance of smart cities of the future to achieve these maintain these perspectives and areas of focus, this paper proposes that governance dashboards capable of capturing, consolidating, analysing and presenting real-time data of these large SoS are required.

V. SYSTEM OF SYSTEMS APPROACH AS A GOVERNANCE DASHBOARD

Typically, smart cities incorporate multiple distributed systems which share complex relationships. These relationships generate new functionalities through integration and subsequent interactions. This structure of smart cities allows them to be classified as ‘system-of-systems’ (SoS) [17]. Sauser, et al. [18] identifies five characteristics of SoS that are common to smart cities. These characteristics are autonomy, belonging, connectivity, diversity, and emergency. A smart city, as a SoS, is built of autonomous departments, that share a common purpose, are connected via networks and information sharing, are diverse in nature and demonstrate emergent behaviour as they adapt to the environment of the city. Governing a smart city as a system of systems requires a framework and tools designed to support management decision-making. Darabi, et al. [19] provides a SoS governance framework developed around five pillars, purpose integration, belonging regulation, incentivising device, interactions protocol, and principle & perception. These five

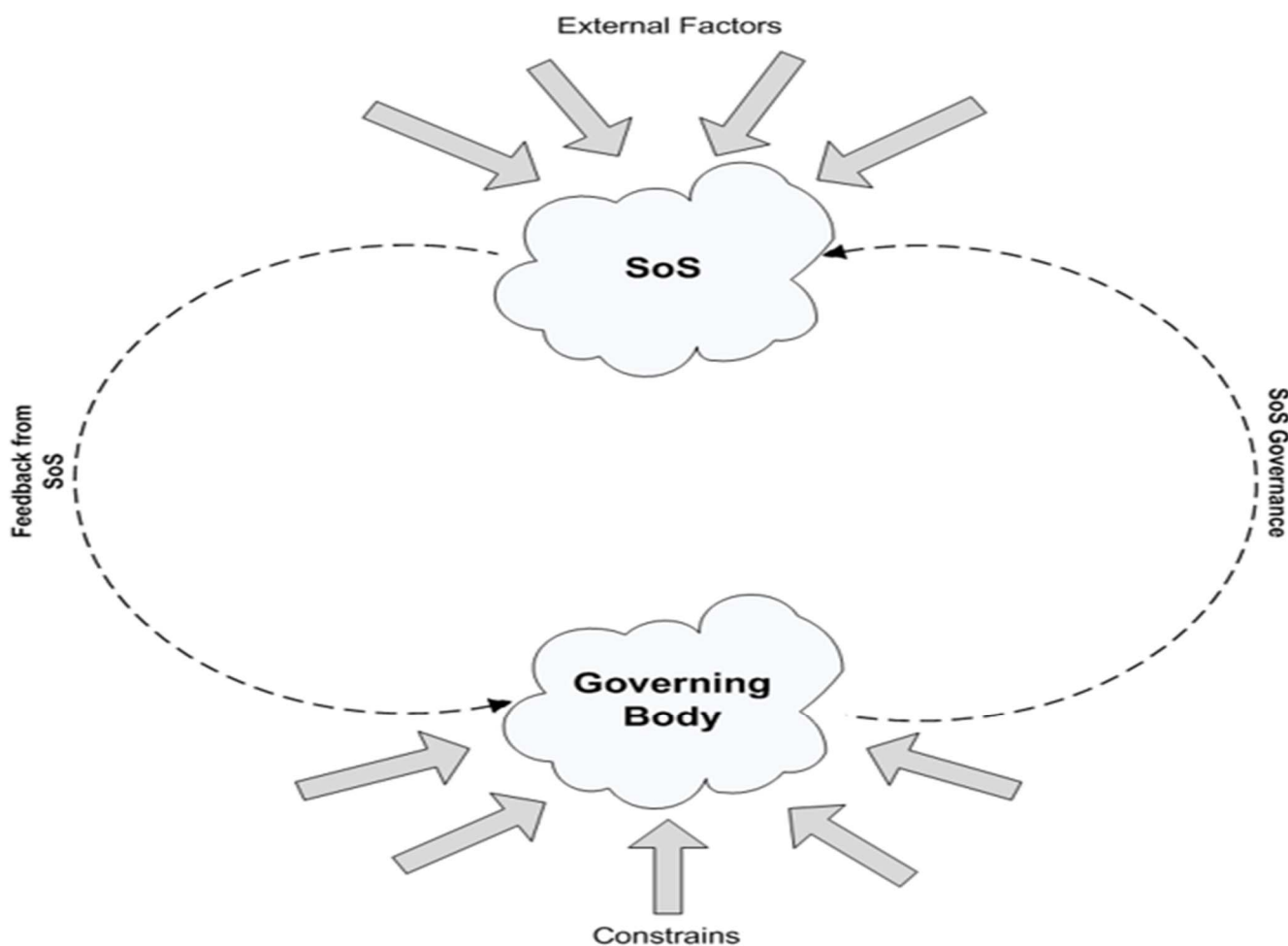


Fig. 1. System of System Governance Gorod, et al. [20]

pillars provide an understanding on what points of leverage governance of a smart city has available to them and what they can use to guide its management. Any smart city governance dashboard must be able to provide a consolidated view on the effect of these pillars being applied. Gorod, et al. [20] developed a SoS Governance framework which represents the cycle of the SoS as shown in Fig. 1. Feedback from the SoS to its governing body, constraints applied to the governing body, the levers or areas of influence that can be used by the governing body onto the SoS and back to reviewing the feedback. This model forms the basis of how a smart city governance dashboard operates. It allows decision makers to view, in real-time or via simulation, the environment they are operating in, the impacts of their decisions, and possible future outcomes from simulated decisions by using the interactive controls as shown in Fig. 2.

VI. SMART CITY GOVERNANCE DASHBOARD

Although every smart city may have differences in culture, geographic area, demands of citizens etc; they are unified by their common attributes, or pillars, that enable governance of SoS. Smart city governance dashboards are designed around these common governance pillars. These pillars provide a framework for governance of traditional and smart cities alike however, how to practically make use of their value has yet to be clearly demonstrated in a tangible manor. The concept of a smart city governance dashboard is the attempt at providing this tool that connects the smart city governance framework with real tools that can be used by decision makers.

The ability to use smart city governance in a dashboard is possible when the framework from Gandhi, et al. [1] is merged with the purposes and features of dashboards as presented by Rahman, et al. [14]. These two insights are what enables the ability to develop smart city governance dashboards as summarised in Table 1. Rahman, et al. [14] splits the governance into three distinct yet related levels, or systems. Level one is the strategic view of the city which allows the user to evaluate current strategy as well as test / simulate changes in policy at the strategy level. Level two is the tactical level which allows the user to interact with and evaluate tactical decisions that are typically applied to suburb or district. Level three provides operational insight, allowing the user to monitor and interact with operational components of city governance and services [14].

VII. CASE STUDY

In this case study, we will explore how a governance dashboard can contribute to the success of smart cities initiatives, specifically to the smart lamp pole project in Singapore. Singapore is gearing up to transform into a smart city aggressively. A plethora of measures have been put in place, with the digital economy being named as a key pillar of Singapore's Smart Nation goal [21]. As the nation progresses towards this direction, the importance of dashboards as a tool to feed, and monitor, decisions made by governing bodies becomes magnified. The effectiveness of communicating information, improving data accuracy and efficiency also becomes heightened [22].

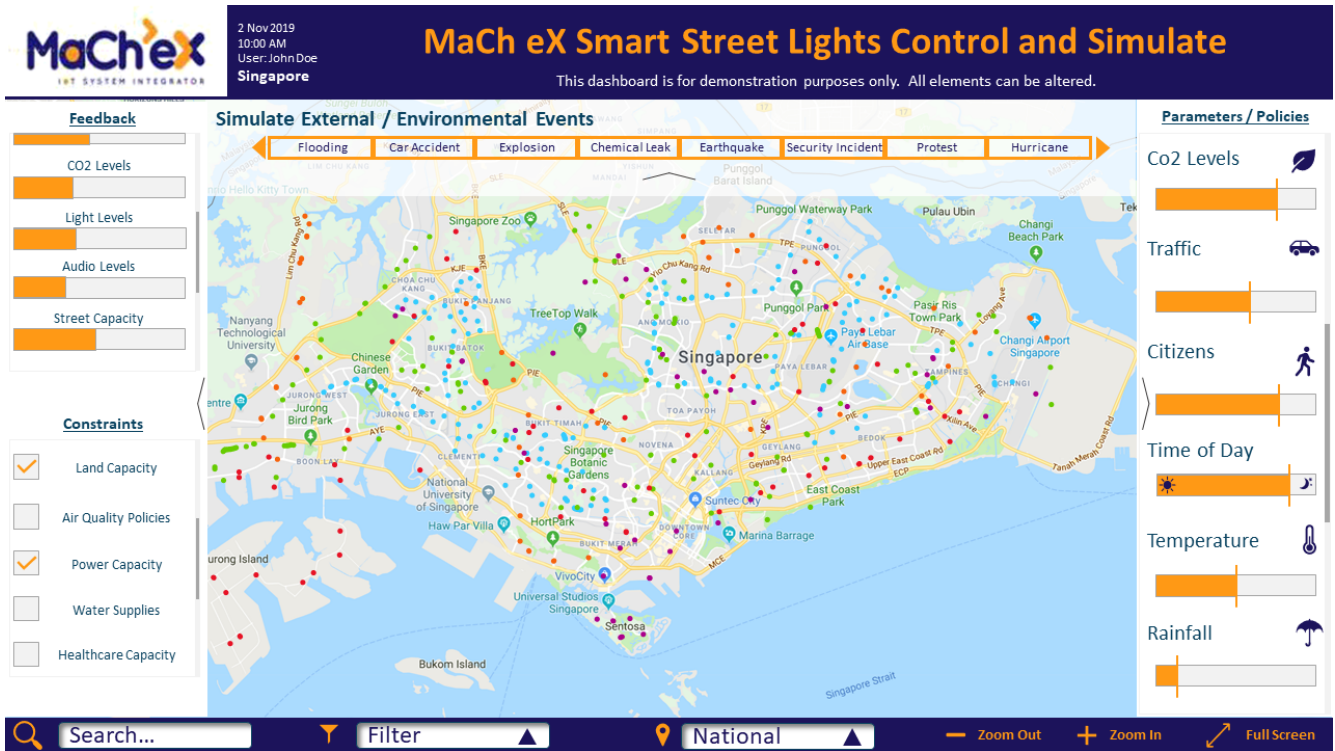


Fig. 2. Smart City Governance Dashboard - Strategic View

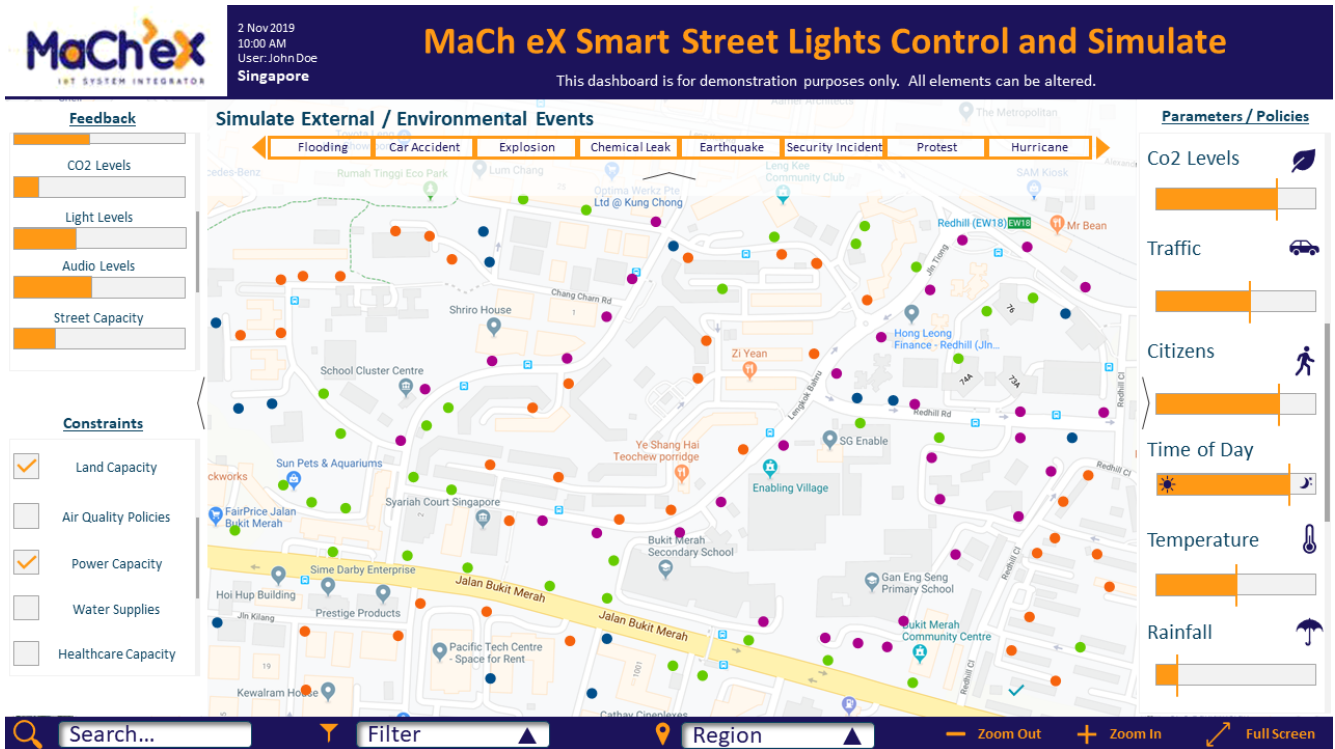


Fig. 3. Smart City Governance Dashboard - Tactical View

One of the technologies enabling the capture and display of real-time data in governance dashboards is performed by smart lamp poles. The idea for the next generation lamp poles arose from the need to have faster responses to traffic and emergency situations in Singapore. MaCh eX Pte Ltd, specializing in ‘Internet of Things’ (IoT) system integration, was engaged by a lighting company to transform a typical

lamp post into a smart lamp pole by developing the “brain” on an IoT platform, which encompass the below smart features:

- Automatically detect intrusion and report incidents.
- Energy and cost saving as it works with sensors to turn on and off.

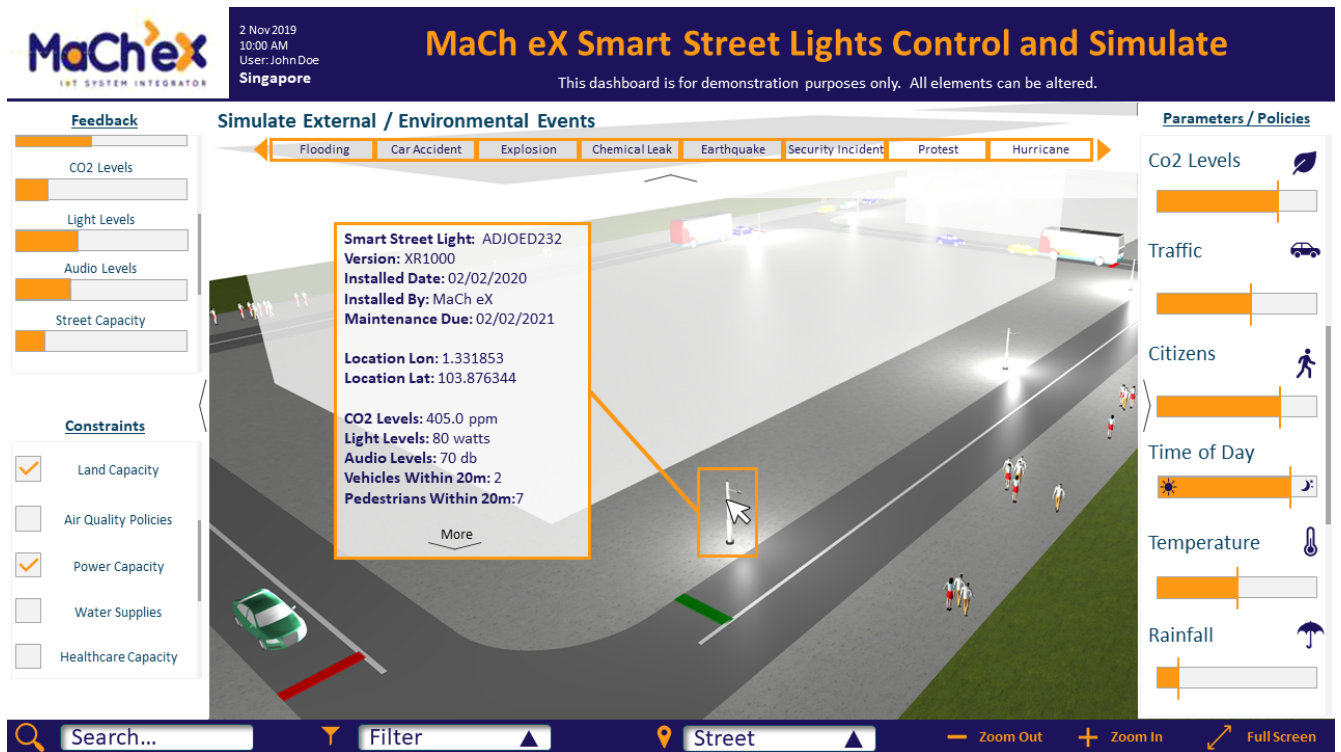


Fig. 4. Smart City Governance Dashboard - Operational View

- Video Streaming/Analytics to ensure and maintain public safety.
- Panic button in case of any emergency or danger to raise an alarm.
- Adaptive Lighting with intelligent monitoring system based on environmental sensors.

The smart lamp pole will auto-adjust the brightness level through sensing of the environmental lighting. If the environmental lighting falls below certain threshold level, the smart lamp pole will start to sense for movement in the surrounding. The brightness level will be auto-activated from the default brightness setting of 30% to 100% if movement is detected. This increase in brightness will auto-activate the adjacent smart lamp poles to increase the default brightness level of 30% to 50% level. The adjacent smart lamp poles will then display the same repetitive cycle to create a consistent environmental lighting to the person or vehicles moving in the surrounding.

To begin enabling the governance of the smart city through smart lamp a concept dashboard was developed which allows the five pillars of SoS governance to be monitored and experimented with to understand the city's strategic, tactical, and operational systems. Simulation modelling is built into the dashboard allowing the user to interact with the city and experiment with changes to city policies or events based on the real-time data being fed from the smart lamp pole devices. This combination of governance pillars and dashboard features enables insights to be discovered in how to improve traffic management and emergency services response times etc. The governance dashboard features have been critical to this project as it draws the data generated by the IoT devices and turns it into knowledge on a screen.

Fig. 2 is an example of the dashboards developed to assist in governing the city via smart poles. Fig. 2, Fig. 3, and Fig. 4 demonstrate the three systems, or levels, being viewed. These three perspectives include the strategic view of the smart city (Fig. 2), Singapore utilising a network of smart lamp poles; the tactical view of the smart city (Fig. 3); finally, the operational systems of the smart lamp poles (Fig. 4). This development work was isolated to how the smart lamp posts contribute to the infrastructure enabling smart cities however, future research will expand the smart city governance dashboards to more constituents of the SoS.

VIII. CONCLUSION

Cities around the world are becoming more complex with traditional management techniques no longer being enough to keep up with the developments. Cities are evolving towards becoming even more highly connected via technological advances being applied to new and existing infrastructure that provide real-time and simulated data to decision makers. To equip smart city management to maintain governance new tools are required. This paper promotes the new decision-making tool of smart city governance dashboards. These dashboards merge real-time data with simulation allowing users to not only monitor the five pillars of SoS governance but also interact with them to experiment with new policies and city investment decisions. Future work will expand the implementation of smart city governance dashboards from one constituent part of the system to others, eventually encompassing the complete future of metropolitan areas known as, smart cities.

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