



Full length article

The next wave of innovation—Review of smart cities intelligent operation systems

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ARTICLE INFO

Article history:

Received 7 June 2016

Received in revised form

15 September 2016

Accepted 19 September 2016

Available online 4 October 2016

Keywords:

Complex and intelligent systems

Intelligent Operation Center

Smart cities

Smart citizen

Simulation

ABSTRACT

The use of new technologies in business models and infrastructure has been driven in part by the Internet and globalization. The next trend of innovations is likely to come from humans' ability to connect to machines and the data that comes from these connections. The IBM Intelligent Operation Center (IOC) is a "system of systems" that is not intended to replace an existing physical infrastructure that gathers raw data. Instead, it is intended to extract only the data necessary to optimize the operations of the organization. The types of data and integration into the IOC make efficient problem solving solutions readily available to city authorities. The user interface and standard operating procedure and the resource processing capabilities of the IOC indicate that this system is optimal for smart cities of the future with regard to improvement of quality of life and ease of navigation. The need for smart cities, universities, campuses, citizens, and students to drive growth of urban and regional economies is evident. In this article, a thorough analysis of the architectural design of an intelligent operational system is completed to present a smart solution for cities to unify departments and agencies under one umbrella.

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1. Introduction

Within the past decade, the increased use of technology in all sectors of society has created a push for cities to integrate the latest and greatest into their city development both economically and politically (Albino, Berardi, & Dangelico, 2015). As cities gain greater control over their development and progression into the 21st century, they face a range of challenges and threats to sustainability in a variety of ways (Dirks, Keeling, & Dencik, 2009). As cities play a prime role in social and economic aspects worldwide and have a huge impact on the environment, it is easy to understand why cities are the key elements for the future (Albino et al. 2015; Keeling & Mooney, 2011; Zhuhadar, Carson, Daday, Thrasher, & Nasraoui, 2016a).

The world is at an unprecedented level of urbanization (Keeling & Mooney, 2011). In 2008, the United Nations noted that more than 50% of all people lived in urban areas (Albino et al. 2015). With

urbanization of city centers, the world economy is now globally integrated and services-based, accounting for two thirds of all global trade, with these city centers being the hub of commerce and concentrated capital both human (qualified staff) and physical (telecommunications) (Bhowmick et al. 2012). Having a higher share of workforce participation with tertiary educational attainment allows cities to be the focal point of innovation (Bhowmick et al. 2012). Growth, economic and competitive differentiation of cities will be derived from people and their skills, creativity, instrumentation and the capacity of the economy to create and absorb the innovation through application of advance information technology, analytics and systems (Dirks et al. 2009; Keeling & Mooney, 2011). Therefore, in order to capitalize on the opportunities made available through technological advancements for prosperity, cities must become 'smarter' to attract, create, enable and retain citizens with skills, knowledge and creativity needed for competition on the world stage. But what exactly makes a city smart? The traditional 'bricks and mortar' drivers of city economic growth are losing ground to an economy in which 'education and creativity' are the grounds for competitive prosperity, based on the ability of the workforce provided to create and acquire skills and innovation (i.e. the talent pool) (Dirks et al. 2009; Keeling & Mooney, 2011). Cities being the new hub of global economy are the focal points in which this transformation

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from the secondary sector (industrialization) to the tertiary (services) and quaternary (intellectual activities) sectors is becoming reality. There have been numerous definitions given over the past decade for what smart cities are, but essentially smart cities are those cities that have the greatest quality of life and economic well-being for their citizens (Albino et al. 2015).

Building a smart city is a challenge. Ultimately this requires gaining additional insight into the core systems that cities operate off of which affect the decisions made; however, the key is the way in which these cities acquire access to the type of information required to help gather new insight (Carrato, Nesbitt, & Kehoe, 2012; Neirotti, De Marco, Cagliano, Mangano, & Scorrano, 2014). A key aim in creating a 'smarter' city is to provide real time information, the goal being to address new challenges and manage available resources as closely as possible (Carrato et al. 2012). A critical question facing cities is how do the cities incorporate technology in the most cost-efficient, and productive fashion? As Dirks, Gurdgiev and Keeling note there are four high-impact areas of improvement: reduction of congestion in transport systems, improvement of public safety through reduction of crime and increased emergency response times, streamlining and tailoring services with an emphasis on education and continuous training, and enabling appropriate access to healthcare data for increased population health (Dirks & Keeling, 2009). Cities will need to continue to build onto their core systems other agendas including energy, water and environmental sustainability, urban planning and (Dirks, Gurdgiev, & Keeling, 2010a). IBM defines these smart cities in terms of applying information technologies to various stages of planning, designing, building and operating a city's infrastructure.

Since 2010, IBM has offered a new initiative—IBM Academic Initiative,¹ where professors have full access to the 21st century technologies, resources, and platforms. This article provides a detailed analysis of the architectural design of IBM Intelligent Operations Center² (IBM IOC). The reason of focusing on the IBM IOC in this article is its availability for professors and students cost free. It provides solutions to environmental problems that can range from banking and retailers to energy providers and water management. As a result, students who have a passion for sustainable development or city planning will be better prepared for the 21st century challenges (Sarkar, 2016).

While the focus of this article is on the IBM IOC, IBM is not the only company to notice. Similar projects to the IBM IOC are also available for improved housing (Matayoshi et al. 2016; Polenov, Kostyuk, Muntyan, Guzik, & Lukyanov, 2016), including the 3-E Houses and Beca projects,³ which provides tenants with an innovative energy efficient service via real time monitoring of the energy consumption, integrating renewable energies and creating resources to lower energy consumption.⁴ The project allows tenants to develop or enhance their relationship with the utility, the environment, with the objective that saving energy is saving CO2 emissions (Zhou et al. 2016). Other smart services for housing include E3Soho and EDISON (Energy Distribution Infrastructure for Ssl Operative Networks), which work to limit CO2 emissions as well.⁵ Projects such as green@hospital offer efficiency services for hospitals,⁶ while SMARTBUILD offers smart IT services for building infrastructure.⁷ Nevertheless, the *European Commission on Valuable*

*EneRgY School*⁸ (VERYSchool) produced an intensive survey-based report on sustainable environment for a smart school (Caragliu, Del Bo, & Nijkamp, 2011; Galata et al. 2014; Vaquero & Saiz-Alvarez, 2016).

2. Literature review

2.1. The internet of things

The rise of interconnectedness has created a redistribution of wealth and redefined the workforce of the future (Davies, 2015). The shift in globalization has been largely propelled by the Internet, which has increased the rate at which people and business are connected, as well as, created a larger realm of competition where challengers can enter and disrupt economic markets and supply chains (Davies, 2015). As Davies notes, the Internet of Things references the mass connectivity of machine-augmented systems, processes and people to create value. As with all advancements in society, the Internet's growth and subsequent influential position into both economic and political arenas has been met with a mixture of enthusiasm and skepticism from businesses and institutions whose power and influence have been threatened (Allen, 2016; Chakrabarty & Engels, 2016; Ramaswami, Russell, Culligan, Sharma, & Kumar, 2016). Smart cities are critical to the digital economy and for the nation's capacity to compete globally, being those cities that exploit hyper-connectivity to meet real challenges such as mitigating the effects of urbanization, addressing added pressure for infrastructure and quality of life, along with environmental sustainability, increased safety and economic opportunity (Bhowmick et al. 2012; Marsh, Molinari, & Rizzo, 2016).

2.2. Problems of cities

For cities, problems arise due to the fact that the city is managed under multiple separate domains with no real ability to be condensed into one entity (Bhowmick et al. 2012). City managers have no single place to interact in real time regarding status or historical reports for city events. The physical systems of a city that need to be monitored include roads, energy, water, and sewer lines; but there is a lot of intangible data that, when analyzed and combined with other factors, provide critical, additional insight. Since the core of a city is composed of different networks, infrastructures and environments related to key functions including services, citizens, business, transport, communication, water and energy, public safety, health and education are central to whether a city offers up the quality of life desired by citizens smart (Chourabi et al. 2012; Neirotti et al. 2014). Simply put, the daily operations of cities generate vast amounts of data from a multitude of sources that create an inability to visualize and extract meaningful information. Cities must address the increased number of service coordination and planning challenges as a result of urban sprawl (Scuotto, Ferraris, & Bresciani, 2016). Citizens face healthcare threats including infant mortality and disease (Davies, 2015). For businesses, cities must balance regulatory requirements with the need to decrease costly administrative overhead, not to mention the inefficient transportation systems, which continue to drive up costs (Katsigiannis et al. 2014). Increasing communication and connectivity demands challenge the ability of cities to meet the needs of its citizens and businesses effectively (Galata et al. 2014). Water resources fall victim to leakage, theft and poor quality; and current energy systems are often insecure and inefficient (Galata et al.

¹ <https://developer.ibm.com/academic/>.

² <http://www-03.ibm.com/software/products/en/intelligent-operations-center>.

³ www.3ehouses.eu.

⁴ www.beca-project.eu.

⁵ www.project-edison.eu.

⁶ www.greenhospital-project.eu.

⁷ www.smartbuild.eu.

⁸ <http://www.veryschool.eu/>.

2014; Zhou et al. 2016). As cities face these substantial and inter-related challenges, it becomes clear that the 'business as usual' model has become obsolete. The solution to these problems is to leverage information across all city agencies and departments and present the information in a single unified view on one platform. Coordinating resources to respond more immediately and effectively allows city organizations and agencies to anticipate and correct for problems, thus minimizing the impact of future disruptions.

A majority of developed societies are experiencing aging (Katsigiannis et al. 2014). However, in developing economies such as those in India and the Middle East, there are massive 'bulges' of young people working their way through the education and economic systems (Katsigiannis et al. 2014). As noted in previous research, pressures are mounting on the capacity of existing systems and institutions to respond (Davies, 2015; Katsigiannis et al. 2014). New demands for learning, skills, investment, growth and jobs are testing the limits of many countries to respond quickly enough and with solutions that work and endure (Katsigiannis et al. 2014). Technology's ability to connect everything and everyone is shifting the way individuals learn, work, do business, innovate, and entertain themselves (Katsigiannis et al. 2014). These are shifts that can easily be underestimated when they are over-hyped and simplified; yet things are changing.

2.3. Investments of cities

Productivity now demands innovation which, in turn, requires the mobilization of an entire ecosystem that includes a solid knowledge infrastructure, a highly skilled labor force, creative workplaces, business models built with both customers and competition in mind, and engagement of global supply chains (Graham, 2016; Haidine, Aqqal, & Ouahmane, 2016). Investing in creating a smarter core system for a city creates cost savings and increased efficiencies while positioning the city for long term economic growth (Foth, Hudson-Smith, & Gifford, 2016). The shift towards a knowledge-based economy has increased the need for superior talent in the city center embodied by higher education, training, skills, creativity and innovation capacity (Anthopoulos, Janssen, & Weerakkody, 2016).

The increasing demand for more diversified workers is becoming a crucial contributor to economic growth (Davies, 2015; Dirks, Gurdgiev, & Keeling, 2010b). Therefore, as cities begin to face increased competition for both highly skilled labor and a diverse mix of talent necessary for growth in a global market, the need to optimize core systems of a city plays a critical role in attracting both skills and innovation to the region, equating to better public service delivery and a better overall standard of living (Davies, 2015; Dirks et al. 2010b).

2.4. Education as a key

As previously mentioned, education is a focal point in a city's journey to becoming a 'smart city.' Yet, instrumentation does not always have to be hardware; it can also be people. An estimated 75% of the fastest growing occupations will require STEM related skills and knowledge (science, technology, engineering and math) (Carey, 2015; Katsigiannis et al. 2014). The need for an increased emphasis on computer coding, computational thinking, problem solving and design thinking into pre-primary and primary educational institutions cannot be avoided (Carey, 2015).

The learning, knowledge and teaching roles of universities and the enduring role of cities as spaces and places for commerce, creativity and community are both being challenged (Katsigiannis et al. 2014). The relationship between smart cities and connected

universities is increasingly important to drive growth, sustainability and inclusion for stronger and more resilient urban and regional economies (Davies, 2015; Kaplan, Slivecko, Gardner, & Turner, 2014; Marsh et al. 2016). Leaders from both educational and governmental institutions strive to meet rising expectations from students, communities and employers with limited and increasingly constrained resources. Education is the critical determinant of success for communities in the 21st century just as land was important to agrarian societies and capital investment was paramount for industrial economies; (Katsigiannis et al. 2014). In the future, the education industry will continue to face evolving challenges in its relationships with constituencies. Trends for the future of education provide indicators of new models and signal significant changes to all segments of education and funders. As a result, a new and transformative paradigm that IBM calls the "educational continuum" has emerged (Davies, 2015; Kaplan et al. 2014; Marsh et al. 2016).

What are the trends that are creating the educational continuum? IBM has identified five: technology immersion of students (requiring critical thought, information literacy, etc.), data analytics for analysis of student and institutional data and performance metrics (serving as a foundation for improving allocation of resources, creation/delivery of curricula, etc.), personalized learning paths (selection of individual learning opportunities), knowledge skills for service-based economies (job-based skills) and economic alignment (governments responding to growth opportunities) (Scuotto et al. 2016).

These five trends are dramatically affecting students, workers and institutions now; and their impact will continue to increase. Education systems that adapt and respond accordingly are critical to a successful return on government education investments (Davies, 2015; Kaplan et al. 2014; Marsh et al. 2016). Those that can best demonstrate their adaptability and responsiveness will be the ultimate winners in receiving favorable government treatment and funding. In the educational continuum, the vast majority of students will follow more dynamic and individualized courses throughout their lifetimes (Davies, 2015; Kaplan et al. 2014; Marsh et al. 2016). Their courses of study would start with an emphasis on foundational skills then advance toward specialized competencies that correspond to their strengths, passions and employment opportunities and continually provide for retraining as the employment market changes (Davies, 2015; Kaplan et al. 2014; Marsh et al. 2016). As government leaders worldwide increasingly begin to view education as a key component to a sustainable foundation for economic recovery and long-term health, educational systems such as (Zuhadar et al. 2014; Zuhadar et al. 2015; Zuhadar et al. 2016b) will transition from outcome metrics that assess the performance of individual institutions to measuring the efficacy of the entire system in contributing to economic goals (Davies, 2015; Kaplan et al. 2014; Marsh et al. 2016).

2.5. Consumer IT and the cloud

It goes without saying that the increased use of mobile technology and devices for IT functions continues to grow. Consumer IT and cloud technologies have driven down the costs of hardware and software infrastructure (Davies, 2015; Kaplan et al. 2014; Marsh et al. 2016).

Computing services, storage and networking bandwidth are approaching prices that shift the balance from scarcity to abundance (Sun, Liu, Ma, Liu, & Sun, 2016). This has changed the economic dynamic of IT to focus on the scarcity of other factors: power and cooling costs, IT supports staff, floor space, management time and others (Davies, 2015; Kaplan et al. 2014; Marsh et al. 2016). The growth of bandwidth and Internet scale computing capabilities

spell the end of distributed computing. Computing is shifting 'into the clouds' and will be available whenever, wherever it is needed (Neirotti et al. 2014).

Cloud computing uses a utility delivery model to improve user services, thereby lowering costs because companies no longer need to acquire and maintain storage and computing power to run cloud applications (Dirks et al. 2010a). In the future, institutions and communities will build their own private clouds to provide unique services to their constituents (Dirks et al. 2010a). Cloud computing will enable educational institutions and governments to create shared services that can span regions and systems. According to (Shapiro, 2006) this will improve access to both urban and rural communities, improve the quality of services from providers, reduce duplication, and enhance efficiency.

2.6. Smart campuses

The key to transforming education is collaboration. Yet, as Carey points out, higher education is reaching a crisis in terms of the mounting numbers of student debt (Carey, 2015). Carey discusses the role that technology will have in education, stating that the hybrid college that is the backbone of higher education today will soon be compelled to make way for a technological revolution that will make high quality, affordable education available to students everywhere (Carey, 2015). How is this possible? Deakin University⁹ is an example of a university that is committed to working at the digital frontier, applying new technology and wisdom to all aspects of its operations (teaching and learning, research and administration) (Davies, 2015). Deakin is a regional university faced with servicing students who are geographically dispersed; thus, the university pushed for a digital focus (Davies, 2015). In doing so, Deakin has the potential to leverage its Smart Campus for the betterment of the broader community and city as a major driver of engagement, attainment and achievement. There are three broad motivations for Deakin's Smart Campus initiatives that relate to the "three brains" framework (Davies, 2015). The first represents the industrial brain dimension: a set of imperatives centered on improving costs and productivity (i.e. deployment of smart lighting, smart waste management and smart systems and processes such as the optimization of building scheduling) (Davies, 2015). The second represents the customer-centric brain dimension: opportunities related to technology's capacity to drive the student experience (e.g. how to better understand student learning and response to different situations). The third dimension represents the Meta brain dimension: the hyper-connectivity of 'things' (Davies, 2015). As noted, since a majority of universities (particularly in regional centers) anchor a city, these smart campuses should be a mode of transition for a city's journey to becoming a smart city.

3. Case study: IBM's Intelligent Operations Center

3.1. A smarter city solution

Some of the key benefits of the IBM IOC solution include automatic alert to conflicts between city agencies, optimization of planned and unplanned operations using a holistic reporting and monitoring approach, adjusting systems where needed to achieve results that are based on the insights gained. These benefits enable the building of a convergence of domains in an organization through communication and collaboration, thereby improving the quality of service and reducing cost by coordinating such events (Bhowmick, 2012). Traditionally, information involved many

disconnected and conflicting data sources; today, data is integrated with sensors, video and voice. Traditionally, anticipation included long-range predictions for trends and directions. Yet, with systems like the IBM IOC, detailed action is given in real time. Furthermore, coordination was previously complex and complicated, with each department operating as a disconnected silo. Today, departments are interconnected through coordinated processes across city stakeholders (Bhowmick, 2012).

For example, relative to attending an athletic or entertainment event at a stadium, the IBM IOC can improve overall navigation to the stadium, ease of parking, and waiting in line. In addition, the IBM IOC can provide a complete interconnected view of stadium activities such as weather alerts, real-time security, traffic flow to the stadium, etc. Specifically, the event manager handles event messages that are received through the service bus. It is capable of handling large volumes of events from various sources and applies policies or event rules to the messages. The workflows engine helps automate and track standard operating procedures for consistency and audit ability. All the information is displayed through dashboards, reports, and advanced features such as video feeds and unified communications. Advanced analytics can analyze the data, identifying optimizations and predictions that can help guide decisions and develop policies for future ease of use (Bhowmick, 2012). The use of the IBM IOC requires skill and training and an increased knowledge of a diversified and talented workforce.

Transportation, for example, is the vital means of connecting people, goods, and services; and the smooth operation of a transportation system can directly determine the level of economic activity and output of a given city. Consequently, it has the potential to affect both the quality of life for citizens and the economic vitality of a city. Significant increases in urbanization over the last 50 years have placed an overwhelming burden on city transportation systems. Clogged roadways not only delay the delivery of goods and the movement of people, they also contribute to pollution as cars and trucks sit in traffic (Bhowmick, 2012). Traditionally, cities have attempted to solve transportation challenges by expanding the infrastructure—building more roads, tunnels and bridges. But for many cities today, poor financial conditions and land constraints make that approach impossible. IBM IOC helps city traffic managers visualize and analyze traffic conditions so they can better manage incidents, increase performance, improve the commuter experience, reduce pollution and maximize the utilization of transportation assets (Bhowmick, 2012).

Growing awareness of global climate issues among citizens and an increasing focus on health, safety, security and the environment in the media have brought the water crisis into sharp focus for cities. Cities need ways to ensure the availability and quality of water for residents while also working to balance the needs of industry and agriculture. Software such as IBM IOC offers analytics solutions to help cities and utilities develop full-cost pricing models, target conservation efforts and improve demand (Bhowmick, 2012). These solutions can help organizations improve water efficiency and enhance water use management. They can also help cities' public safety services provide real-time information and situational awareness to help avert crimes and emergencies, provide greater energy efficiency, and help with healthcare (Bhowmick, 2012), as well as a safe, healthy environment for their families to live, learn and grow (Dirks, Gurdgiev, & Keeling, 2010c). Yet, as population demographics change and budgets shrink, many cities are finding it difficult to provide the services and environment that their citizens require (Galata et al. 2014). Increasing demand for services from aging and chronically ill individuals, for example, can hinder a city's ability to provide services to all citizens. New technology solutions can help health authorities and city agencies deliver the right lower-cost care when and where it's

⁹ <http://www.deakin.edu.au/>.

needed, while enabling patients to play more active roles in managing their care (Davies, 2015). By adopting new solutions, cities can make health and social services information readily available, proactively manage health threats and emergencies, rapidly alert the public, efficiently mobilize resources and take preventive measures when needed, and deliver more cost-effective, quality care at local hospitals while supporting the collaboration among public and private hospitals and care providers (Bhowmick, 2012).

3.2. IBM smarter cities prototype

IBM's smarter cities drive sustainable economic growth by being able to anticipate problems and proactively assess and minimize the impact of disruptions. The dimensions of Human, Planning and Management, and Infrastructure are intertwined, thereby improving decision-making by analyzing information and coordinating resources at all levels across city agencies and departments (Dirks et al. 2009).

IBM IOC is a one-stop shop program with a user interface that allows organizations and/or institutions to facilitate effective supervision and coordination of various operations (Dirks & Keeling, 2009; Dirks et al. 2010a). Coordinating resources to respond immediately allows city organizations and agencies to better anticipate and correct for problems beforehand. The IBM IOC for Smarter Cities is a solution that synchronizes and analyzes efforts across sectors and agencies; this gives decision makers consolidated information that allows for anticipation, rather than reaction, to problems (Dirks et al. 2010c). Not only does the IBM IOC provide a unified view of all city infrastructure and departments, but it also processes all data feeds and event information to improve operational efficiency, monitoring services and operations to facilitate insightful decision-making and providing effective event response management and coordination (Dirks et al. 2010b).

3.3. Components of smart cities

The executive dashboard depicts the overall status of city operations, thus providing the ability to gain insight into the city environment through a centralized gateway of information management (Bhowmick et al. 2012). For example, the intelligent transportation solution offers greater traffic awareness, traffic analytics, and traffic prediction capabilities so that greater solutions for traffic congestion can be addressed. In addition, this solution enables visibility of traffic performance, management of traffic conditions, and visibility of incidents across a diverse set of traffic systems.

The IBM IOC is mainly implemented for complex systems such as airports, city operations, emergency management, energy, healthcare, parks and recreation, ports, stadium operations, transportation, and water utilities. The IBM IOC helps city officials monitor and manage services to a greater degree than ever before, providing insight into daily city operations through centralized data intelligence. The IBM IOC aids agencies in preparing for problems before they arise, coordinating and managing problems when they do, and enabling officials to communicate instantly to discuss and synchronize rescue efforts. The IBM IOC essentially maximizes the efficiency of departments, sending the right people and equipment to the right places at the right time. In the following sections, we introduce an Intelligent Operations Center (Carrato et al. 2012).

3.4. Benefits of IOC

Some of the key benefits of IOC solutions include automatic alerts to conflicts between city agencies, optimization of planned

and unplanned operations using a holistic reporting and monitoring approach, and adjustments to systems where needed to achieve results that are based on the insights gained. An IOC solution enables the convergence of domains in an organization through communication and collaboration, thereby improving the quality of services and reducing costs (Bhowmick et al. 2012).

The IOC improves the overall customer experience through ease of infrastructure navigation (Carrato et al. 2012). This is accomplished because of the types of data received through the IOC. The IOC receives and processes events (happening or occurrence) and categorizes each event based on importance. The events can be used to trigger a response based on pre-defined plans (i.e. a fire) or a custom plan (i.e. traffic in case of a hurricane). The key performance indicator (KPI) is a measure designed to track the critical success factors of a process or operation used to evaluate conditions of a particular event or set of circumstances for an event.

The Common Alerting Protocol (CAP) provides open, non-proprietary digital message formats for all types of alerts and notifications (i.e. public warnings). CAP events are self-contained data messages that can be sent or consumed by the components and published to topic queues to be read by the IT systems. CAP events have a standardized data and structure so that multiple domains can send and receive events in a common format using common conventions, as shown in Fig. 1 (Bhowmick et al. 2012). The Alert segment provides basic information about the current message: its purpose, its source, and its status. It also has a unique identifier for the message and links to any other related messages.

The data from various sources are received through gateways that can forward events, alerts, and notifications into an interface for the exchange of data and operations in a service-oriented architecture, as shown in Fig. 2. Specifically, the event manager handles event messages that are received through the service bus. It is capable of handling a large volume of events from various sources and applies policies or event rules to the messages. The workflows engine helps automate and track standard operating procedures for consistency and audit ability. All the information is displayed through dashboards, reports, and advanced features such as video feeds and unified communications. Advanced analytics can analyze the data, identifying optimizations and predictions that can help guide decisions and develop policies for future ease of use (Bhowmick et al. 2012).

3.5. The user interface

The IOC User Interface, as shown in Fig. 3, contains six viewing windows, including Supervisor: both status and operations views and reports; Operator: both operations view and reports; and a Location Map view. The IOC is composed of the following five logical servers: the application server (responsible for overall web infrastructure and obtaining access to the entire set of functions available in the solution when users log into the portal), the event server (connects external data sources, processes incoming events, manages response processes, implements standard operating procedures and collaborations during a crisis), the database server (directory repository used for securing access to different functions and implements key security functions including identity management), the management server (provides capabilities to monitor infrastructure including hardware, operating system, databases and web infrastructure so that each is performing as intended), and the installation server (allows center to run most of the tests needed to determine the health of the overall system and components) (Bhowmick et al. 2012).

The IOC provides a 'must gather tool' that allows the user to gather log files and other information required to analyze problems with the installation or usage of the solution (Bhowmick et al.

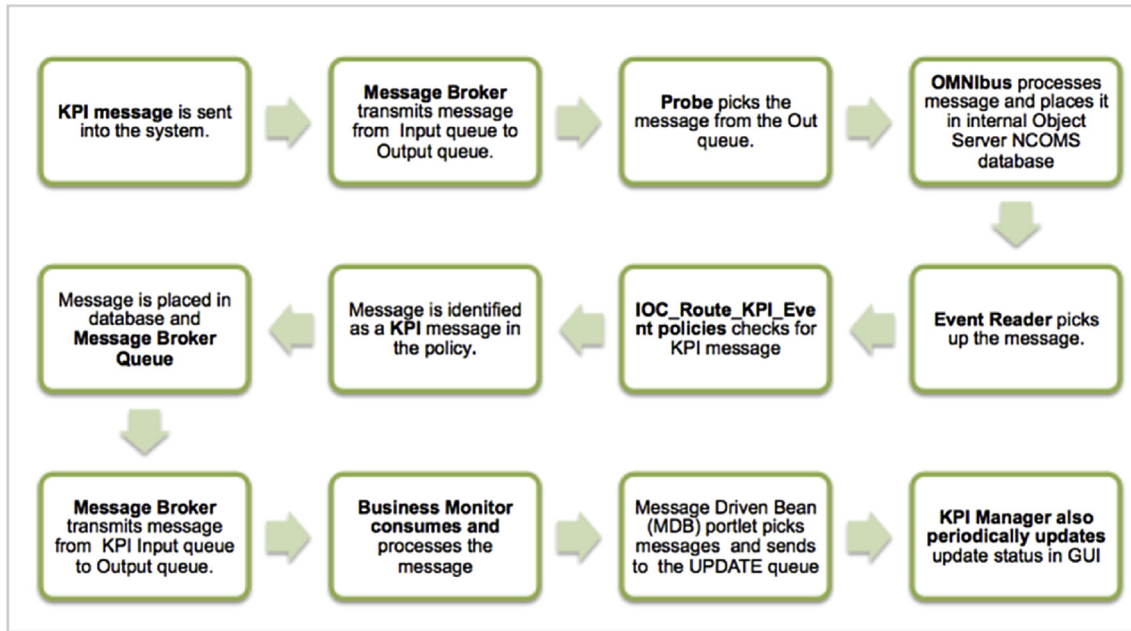


Fig. 1. Overview of Key Performance Indicator.

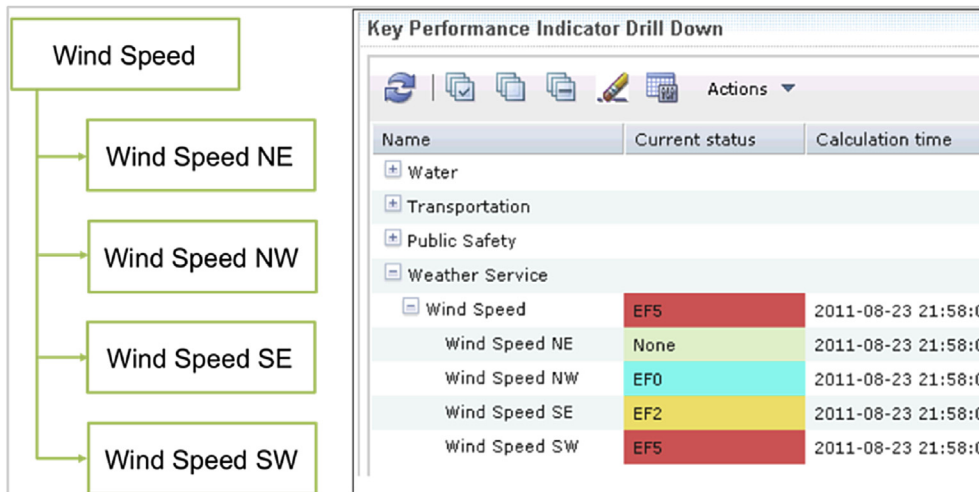


Fig. 2. KPI Hierarchy.

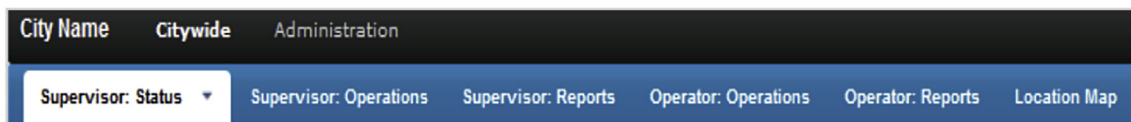


Fig. 3. User Interface.

2012). The data extracted comes in different forms based on the nature of the operations and domains, which can include city, region, government agency, office or health care complex, stadium or major entertainment venue. The IOC architecture provides a consistent framework for the incoming data; however, customization will be required for each solution, depending upon the data needs. Data from a variety of configurable sources can be provided through gateways into an open interface, which can forward alerts and key performance indicator (KPI) metrics and initiate directives.

Advanced analytics can be performed on the data, identifying optimizations and predictions that can help guide decision-making and governance policies. Data providers are typically source-specific handlers for the data required by a use case. Therefore, the data providers encapsulate all data from a given input type. For example, a provider dedicated to a given Point of Sale (POS) system may have the ability to monitor a remote file location (as configured by the administrator), identify POS extracts from the system, and perform parsing of those files to extract required details to be

delivered to the receiver. The rest of the framework has no knowledge of the complexities of the source POS system – this knowledge is fully encapsulated within the input flows.

Data receivers (Bhowmick, 2012) receive data from the providers and format it into the specific representation required for integration into the IOC. Data receivers control the output of acquired data to a defined data target. The flexibility in the framework allows a range of receivers to be used to deliver acquired data in different ways, such as traditional publishing to the IOC of CAP messages or delivering data to a known database or other format (Bhowmick, 2012). A Data Integration Broker (Bhowmick, 2012) is a controller that coordinates, or brokers, the interaction between the providers and receivers. Within the IOC, these requirements may be satisfied through the use of the IBM MQ Message Broker platform, a basis for the Data Integration Broker (Bhowmick et al. 2012). For example, in maximizing a football stadium, sources would include data used to monitor the gate entry rate, crowd patterns, unauthorized entries, etc.

The IOC supports bi-directional data integration, which allows the center to function in an industry domain or cross-domain. This support can include systems reporting on public safety issues, systems reporting on traffic events, systems reporting on water quality and usage, and systems providing data on outages and the status of related work orders (Bhowmick et al. 2012). The Information segment describes an anticipated or actual event in terms of urgency (the time available to prepare), severity (the intensity of the impact), and certainty (confidence in the observation or prediction) (Bhowmick et al. 2012). It also provides both categorical and textual descriptions of the subject event. Multiple Information segments can be used to describe differing parameters, such as different probability or intensity bands, or to provide the information in multiple languages. The Resource segment provides an optional reference to additional information related to the Information segment, which could be a digital asset such as an image or audio file. The Area segment describes a geographic area to which the information segment applies; this could be in the form of postal codes; geospatial shapes; polygons; circles; or an altitude or altitude range expressed in standard latitude, longitude, and altitude terms in accordance with a specified geospatial datum.

Yet, there are limitations to CAP which include limited support for CAP format to the IOC, as well as, limited representation to certain domains (Bhowmick et al. 2012). Specifically, CAP does not allow the extension of any defined enumeration type (e.g. category, severity, etc.) Only the enumeration types supported by CAP can be used. To enhance the ease of use, support for non-CAP message formats has been incorporated in the IOC (Bhowmick et al. 2012). The IOC uses the same event flow subsystem for CAP messages and non-CAP messages. The common data and the reference data are maintained in common tables. Products such as Web Sphere Operations Decision Manager (WODM) and Tivoli Service Request Manager (TSRM) work with CAP and non-CAP events.

Basic threshold events compare two or more measures and report a trend. These threshold events help determine when the measurements obtained from a sensor or other source have moved outside the normal range. More importantly, sophisticated threshold events can compare measures against a threshold created by historical information. Some examples of these events include over and under temperature alarms, high and low water levels, air quality and water purity breaching environmental standards, and excessive power consumption. The IBM IOC can manage threshold events in the form of KPIs, all of which are indicators that monitor city functioning and breakdown (Bhowmick et al. 2012).

Events that are entered manually are especially important to cities. Some of these are observed incidents, such as crimes and traffic accidents. Other examples of events entered manually are

those generated from emergency calls from citizens, from reports made by city officials, or from management systems that report on city status. The most common types of events entered manually include severe weather warnings, crime reports, fires, road traffic incidents such as accidents and congestion, and upcoming events such as rock concerts or parades. Complex event processing allows a city to identify exceptions to city systems easily, sometimes noting trends from unrelated data, and to predict future issues.

Furthermore, the IBM IOC uses the sample publisher portlet (an automated test tool for administrator use) to publish CAP events (Bhowmick et al. 2012). The activities that can be performed in the sample event publisher include creating new events with XML, creating or updating events without XML, and creating test notifications (Bhowmick et al. 2012). The detection of an event in the IOC can be automatic or manual, based on the situation or conditions. The IOC supports data sources that can generate either type of message. WebSphere Message Broker is a powerful information broker that allows business data, in the form of messages, to flow across multiple hardware and software platforms. Rules can be applied to the data that is flowing through the message broker to route, store, retrieve, and transform the information (Bhowmick et al. 2012). WebSphere Message Broker facilitates interaction and data exchange with other applications in a flexible, dynamic, and extensible infrastructure, supporting a wide range of protocols such as WebSphere MQ (a robust integration platform that is based on queues and facilitates messaging between the brokers, and business applications), JMS 1.1, HTTP, HTTPS, etc., (Bhowmick et al. 2012).

In the IOC, the core event management process is performed by the IBM Tivoli Netcool family of products, which includes the IBM Tivoli Netcool/Omnibus (consolidates enterprise-wide event and alarms information in real-time from data sources, processes, stores and transforms messages and notifies reader) and the IBM Tivoli Netcool/Impact (defines what actions are performed on the incoming event and processes events based on the configured policy chain) (Bhowmick et al. 2012). Consequently, the Integration points for CAP Event Data in the IOC include WebSphere Message Broker (routes messages in queue, transforms non-CAP messages into CAP messages, publishes events in the IOC) built on the IBM Rational Application Developer platform and publisher Services (impact policies – aid in decisions making about the incoming and in-flight events and can also help with handling them under specific conditions). The Message broker toolkit can be used to create the broker flows and view a graphical representation of the flow (a map). Message Broker patterns are used to generate customized solutions to a recurring problem in an efficient way, offering guidance for the implementation of solutions because resources are generated from a set of predefined templates (Bhowmick et al. 2012). The end result is higher quality solutions through the reuse of assets and a common implementation of programming approaches, such as error handling and logging. Publishing services can be used to direct the events and enhance the events by using correlated information from other components, for example, automatically notifying individuals through email or SMS text message when a situation is detected.

Another key component that IBM's IOC configures are correlated events (those happening in a city related by time, distance, and matching business rules) (Bhowmick et al. 2012). For example, events within 5 miles and within 2 h of time are noted on the dashboard. The event correlation rules application of the IOC is based in IBM WebSphere Operational Decision Management (WODM), a product which has the capability to integrate business events with business rules to enable decision making in real-time (Bhowmick et al. 2012). For example, when an event is found in the database that correlates with the source event, this event is called the target event.

Anytime a possible correlation is found, the notifications portlet sends an alert and the determination is unidirectional. This concept is important because the rules that determine the correlation do not have to be symmetrical. Consider a scenario of possible transportation obstructions due to road accidents on one of the roads used to get to an event in a city, as well as another road in which a fire accident has occurred. The city agencies need to know the possible obstructions to the event. This scenario requires an event correlation rule in the IOC. The correlation flow applies pre-defined rules to search for correlations among the incoming events. The purpose of this flow is to provide a mechanism to warn authorities, managers, or operators when a situation that demands their attention is identified (Bhowmick et al. 2012). The warning is triggered in the form of a notification sent when the inputs match the criteria defined in the rule. The default rule analyses time and location. So, as with the previous example, within a short duration a road accident also occurred along a parallel road to the fire, which is now limiting traffic flow to an event in town. The system administrator would use business rules based on WODM to create a correlation notification message for these events.

The IBM IOC uses the Netcool Impact policy to determine if an incoming event is a KPI event update determined by common alerting protocol (Bhowmick et al. 2012). The KPIs change information received as messages similar to events (Bhowmick et al. 2012). The information in the KPI message is evaluated against a target or a range specified in the KPI model. KPIs can be based on a single message, multiple messages, or multiple conditions and can be calculated based on a single message or based on the aggregation of the messages over time. KPIs are modeled as a hierarchy in the IOC. The Parent KPI values will reflect the status of the child KPIs. The IOC provides a top down approach from high-level indicators to low (Bhowmick et al. 2012).

3.6. Monitor model

The IBM Business Monitor is a business activity-monitoring environment that enables the display of KPIs and metrics through a dashboard, monitoring events from different applications (Bhowmick et al. 2012).

The monitor model describes how to gather information from events, structure the information, aggregate the information, identify business situations in near real time, and trigger resulting actions by sending out events. When a CAP message comes in, a monitoring context instance is created or refreshed, and metrics in the context instance are populated with values from the CAP message, a metric that holds information for a monitoring context such as sender, time, and parameters (Bhowmick et al. 2012).

The IBM IOC supports nested KPIs based on parent-child relationships (Bhowmick et al. 2012). With the Business Monitor however, KPIs are based on the value of another KPI, and a user cannot define parent-child relationships between KPIs. Defining the parent-child relationships in the IBM IOC database supports this feature. Parent-child relationships are used to “roll up” KPI values from a child to its parent; this is accomplished by using KPI expressions for the parent instead of an aggregation calculation.

The Business Monitor can generate and send outbound events when a business situation is detected via external message queues allowing event driven applications such as the IBM IOC to consume them. However, an outbound event is limited in the information it can send. It cannot, for example, send the same KPI information provided by the Business Monitor (Bhowmick et al. 2012).

3.7. Mapping events

The default security for the IOC is enabled with HTTPS protocol.

The HTTPS settings can be changed for the business monitoring service and the administration service within the IOC (Bhowmick et al. 2012). The three levels of access control are web resource permission (provide coarse grained access to web resources), portal resource permission (provide fine grained access to portal resources), and membership to user category groups (determines the events, KPIs, and alert data that the user can see). The standard categories include geophysical, transportation, meteorological, environmental, infrastructure, chemical, biological, safety, security, rescue, fire, and health (Bhowmick et al. 2012).

Map layers are created from the open layers component using custom Common Unified Rest Interface (CURI) adaptor. A Location Map is a map or plan with predefined areas for interaction, for example, seating areas in a major sports stadium. The Location Map portlet provides a visual representation of events in the position they occur. Some examples of location maps are buildings and facilities (stadiums, schools, city halls, etc.) and networks (water lines, transport Lines etc.). Filter widgets are used to filter events that are displayed. The Map option has a base map layer enriched with data on the server side and requires a Geographic Information System (GIS) server to display (Bhowmick et al. 2012).

A map can be selected from the installed ESRI GIS server or a publicly available GIS service. The location map is linked with Map and the details portlet to share input. The three interactive interface elements are location map (a diagram of the location with markers for events), select content (a filter form to select the categories of the event shown on the map), and the map menu (a list of the available location maps arranged by classification). The location map manager is a customization tool available to IOC administrators, which aids in the creation of classifications, location maps and specific areas (Bhowmick et al. 2012).

IBM Cognos Business Intelligence (BI) provides the reporting capability to the IOC (Bhowmick et al. 2012). It provides a unified workspace for business intelligence and analytics that is used to query and analyze key business data. With Cognos BI an administrator can view, assemble, and personalize information, analyze facts, and anticipate tactical and strategic implications with predictive or what-if analysis. In addition, an administrator can establish decision networks to share insights, thus, striving towards a collective intelligence. He/she can access information and take action anywhere, taking advantage of mobile devices and real-time analytics and integrate and link analytics in everyday work to business workflow and process (Bhowmick et al. 2012). Furthermore, layer separation of the models allows the update of each layer independently. The IOC incorporates a user-defined report feature allowing users to create a report based on a template without having to enter Cognos. The user-defined reports allow the user to filter and view the report data. The filter options provided are severity, certainty, urgency, event category, event type, and date; and users are able to define custom report pages and link specific reports to particular pages as needed (Bhowmick et al. 2012).

4. Conclusion

The use of new technologies in business models and infrastructure has been fueled in part by the Internet and globalization. The next wave of innovations will be from humans' ability to connect to machines and the data that comes from these connections. The need for smart cities and universities will drive the growth of urban and regional economies, a powerful hub of information and possibilities. The key for future education will be the ability to harness and analyze increasingly large amounts of data. Education systems will transition from analyzing individuals to the overall efficiency of an entire system (Carey, 2015; Kaplan et al.

2014). In an urbanizing world, cities are gaining greater control over their development; those that become the most successful are those that have instrumented and interconnected core systems.

The opportunity presented by smarter cities is the opportunity of sustainable prosperity. Pervasive new technologies provide a much greater scope for instrumentation, interconnection and intelligence of a city's core systems. Workers of the future will function in a web of collaboration surrounded by limitless information pathways requiring greater capacity for computational resources (Galata et al. 2014). Educational institutions must adapt and become more efficient and student-centered, developing each citizen with the skills required in order to prosper and thrive in the cities of tomorrow (Galata et al. 2014). Around the world, leading cities are putting in place smarter systems, such as Galway's SmartBay advanced water management system, Songdo's Wired City initiative or Singapore's eSymphony transport system. Becoming a 'smart city' is a journey, though, not an overnight transformation (Bhowmick et al. 2012). Cities must prepare for change that will be revolutionary, rather than evolutionary, as they put in place next-generation systems that work in entirely new ways (Bhowmick et al. 2012).

As IBM noted, becoming 'smart' requires a shift in thinking; and in becoming successful, cities must have city administrations that work to organize and collaborate with multiple levels of government. These cities must rise to the challenges and threats to sustainability to be efficient, while building relationships among various systems to solve long-term problems (2010). The 19th century was the era of empires, and the 20th century was the era of nation states. But, the 21st century will be the era of cities (Bhowmick et al. 2012).

After conducting this overview of smart cities we plan to conduct a pilot study on our University's campus, recognizing that a college campus can often mimic a city in terms of the interactions and connections of its students/citizens. The study will include an assessment of tools through an analysis of the current level of our University Smartness, and the development of a set of recommendations based on the results.

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