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International Telecommunication Union
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Supplement

ITU-T L Suppl. 51 (07/2022)

SERIES L: Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant

Case studies on city science application framework

ITU-T L-SERIES RECOMMENDATIONS

ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

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Supplement 51 to ITU-T L-series Recommendations

Case studies on city science application framework

Summary

This Supplement 51 to ITU-T L-series Recommendation provides successful examples of cities that have already employed the city science approach to solve different challenges. By employing scientific techniques and methods used by the scientific community, city science application framework provides a reliable and consistent way for cities to tackle the rising environmental and sustainability challenges. Recommendation ITU-T L.1610, *City science application framework***,** illustrates the methodology behind the application of city science.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
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* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

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1 Scope

This Supplement 51 to ITU-T L-series Recommendation contains a series of case studies that illustrate the implementation of the city science application framework. They will provide important reference points and examples of how cities around the world can use the methodology described in [ITU-T L.1610] to boost the overall performance and efficiency of different city assets and resources. These case studies include using ICTs for air quality management, measuring happiness among cities, predicting crimes and responses, energy saving in shopping malls and more.

NOTE – The case studies contained in this Supplement are adopted directly from the U4SSC deliverable with the same name.

2 References

[ITU-T L.1610] Recommendation ITU-T L.1610 (2022), *City science application framework.*

3 Definitions

3.1 Terms defined elsewhere

None.

3.2 Terms defined in this Supplement

None.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

4IR	Fourth Industrial Revolution
AB	Assembly Bill
AHU	Air Handling Units
AI	Artificial Intelligence
BAAQMD	Bay Area Air Quality Management District
BEMS	Building and Energy Management System
BMS	Building Management System
CALMET	Computer Aided Learning in Meteorology
CALPUFF	California Puff Model
CARB	California Air Resources Board
D2D	Device-to-Device
DUH	Deutsche Umwelthilfe
FAT/ML	Fairness, Accountability, and Transparency in Machine Learning
FDI	False Data Injection
GDPR	General Data Protection Regulation

HX	Happiness Experience
IADs	Integrated Access Devices
ICT	Information and Communications Technology
IoT	Internet of Things
KPIs	Key Performance Indicators
MAN	Metropolitan Area Network
MQTT	Message Queue Telemetry Transport
NO_2	Nitrogen Dioxide
PoC	Proof of Concept
R&D	Research & Development
RCT	Randomized Controlled Trial
SCAQMD	South Coast Air Quality Management District
UAE	Emirates in United Arab Emirates
UNESCO	United Nations Educational, Scientific and Cultural Organization
WAN	Wide Area Network
WRF	Weather Research and Forecasting

5 Conventions

None.

6 Case studies

This Supplement contains eight case studies that illustrate the city science application framework described in [ITU-T L.1610] being applied in different cities. Each case study begins by introducing the background of the project and the challenges that it seeks to address. It then details the vision, implementation process and results of the smart project.

6.1 Case study 1 – Air quality management in Southern California

Introduction

Background

San Francisco Bay Area population has been intensely growing during the last decades, with a census of around 5 million people in 1980, and an estimation of 7 756 158 inhabitants in 2017.

Figure 1 – Bay Area air quality management district[1]

South Coast air quality management district (SCAQMD) is composed of four counties (Los Angeles, Orange, Riverside and San Bernardino), with an estimated population of around 17 million people.

[1] The designations employed and the presentation of material on this [map / infographic] do not imply the expression of any opinion whatsoever on the part of ITU and of the Secretariat of the ITU concerning the legal status of the country, territory, city or area or its authorities, or concerning the delimitation of its frontiers or boundaries.

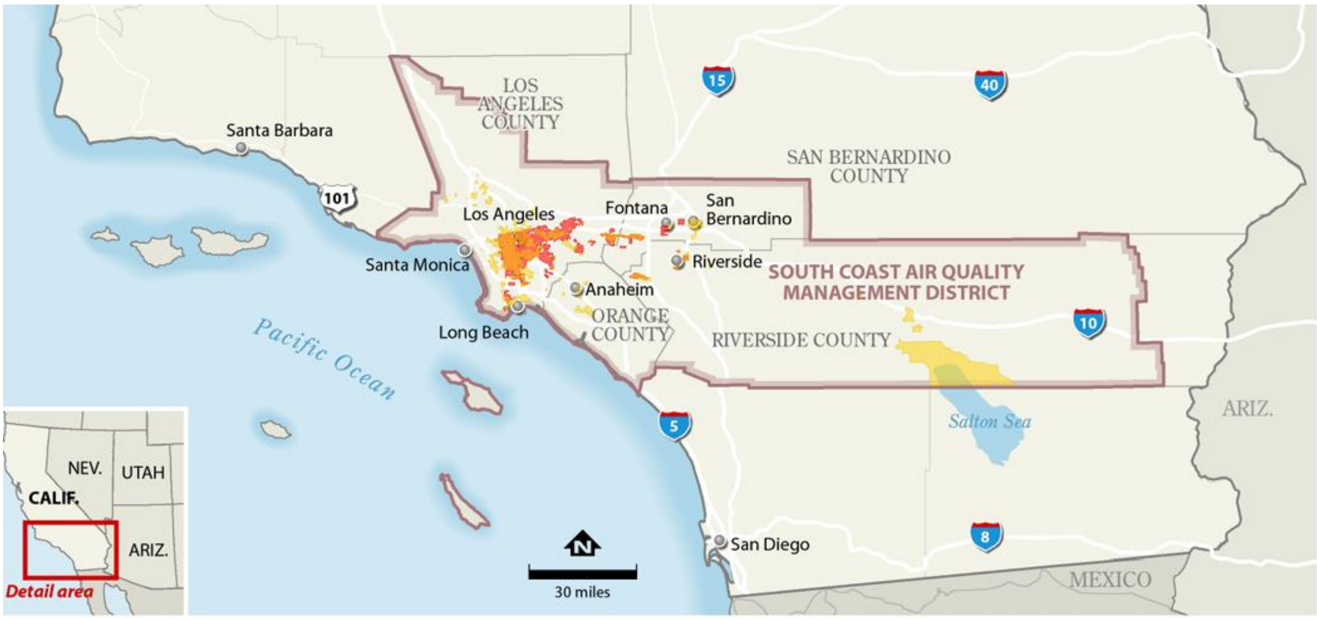

Figure 2 – South Coast air quality management district[2]

The impact on the air quality coming from human and economic activities is very high and public authorities are becoming aware of the seriousness of air pollution and the negative effects it has had on its population's health.

In California air pollution is managed at the regional level across 35 regional pollution districts. Two of these districts are the Bay Area air quality management district (BAAQMD) and the South Coast air quality management district (SCAQMD), which are responsible for regulating and managing the air quality.

Both districts currently use Envirosuite to provide rapid and effective responses to air quality incidents. Presently, sensor data must go through a significant and time-consuming process before it is available to be analysed for managing air quality incidents that have occurred. By the time issues are understood, the opportunity to solve those problems may have already passed. Envirosuite provides insights based on real-time information, this way anyone can quickly understand the issue at hand and employ the unique tools given in the Envirosuite platform for instantly identifying the source of the issue.

There are currently various smart and resilient cities, trends that are promoting these types of Internet of Things projects all around the world, collecting real-time data from sensors and transforming them into valuable information through software, thereby allowing decision makers to act immediately.

For instance, the United States of America (US) department of transportation in 2016 awarded the US city of Columbus with $50 million after being selected for showcasing a holistic and comprehensive vision of "how technology can help all residents move better and access opportunity". The city has grown its initial funding of $50 million to nearly $500 million by the end of 2017.

Challenge and response

Some regions in California experience high air pollution levels every day. This can be attributed to different factors such as the traffic, industry, or wildfires. This high level of pollution is affecting the population's health and life expectancy.

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2 The designations employed and the presentation of material on this [map / infographic] do not imply the expression of any opinion whatsoever on the part of ITU and of the Secretariat of the ITU concerning the legal status of the country, territory, city or area or its authorities, or concerning the delimitation of its frontiers or boundaries.

The Californian legislation has considered using advanced sensing monitoring technologies to reduce air pollution, also stipulating that the districts are to 'identify the contributing sources and provide a catalyst and a platform for community engagement towards eliminating emissions hotspots'.

The solution discussed in this case study visualizes air quality data using an easy-to-understand colour-coding system – this allows regulators to see the issues at hand clearly, identify who is responsible, assess the impacts it has had on the community in real-time and how to fix the problem. Moreover, the system helps to identify the origins of the pollution by drawing back trajectories and pinpointing potential sources within seconds of the incidents occurring, a novel capability previously unavailable.

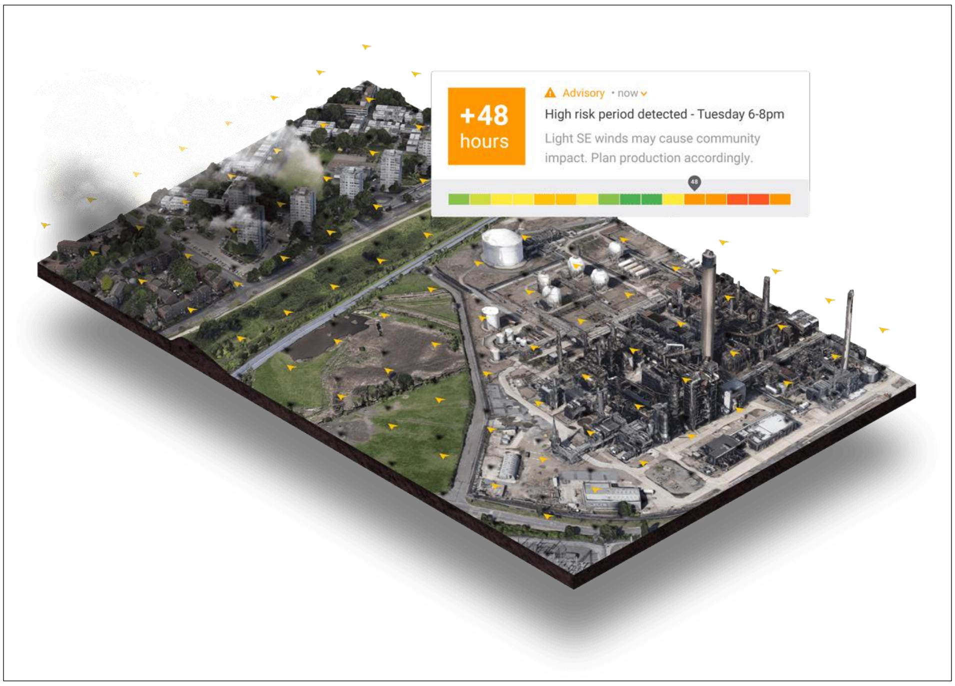

Figure 3 – Illustration of the solution[3]

The smart project(s)

Vision and content

The air quality approach discussed in this case study integrates air quality sensor data with measured and modelled meteorology and presents the information in a way that facilitates rapid understanding and response. Sophisticated analytical methods are used but are re-engineered and presented in a way that non-subject matter experts can use.

The Southern California districts' target is very clear: to clean the air and protect the health of all residents through practical and innovative strategies, adopting policies and regulations, also considering ideas and comments from the public. A governing board comprised of several members discusses the way to improve the air quality and establish effective clean air programs. It has concluded that a digital platform that can analyse a wide range of real-time data is an essential component in improving air quality in the districts.

[3] Source: Envirosuite.com

The key feature is the ability to use proprietary algorithms based on mathematical atmospheric dispersion models such as weather research and forecasting[4] (WRF), computer aided learning in meteorology (CALMET)[5] and the California puff model[6] (CALPUFF).

These models are preferred by the US environmental protection agency for assessing long range transport of pollutants and their impacts on a case-by-case basis for certain near-field applications involving complex meteorological conditions.

Many cities and regions all around the world have implemented online sites, dashboards and platforms that show and graph air quality information, this way citizens can check the air pollution and make decisions accordingly.

Moreover, it is also typical that these smart city platforms allow the checking of other vertical applications data such as water quality, weather data, waste management, car park availability, etc. but it is relatively rare to see that the intelligence behind these platforms correlate different siloed data.

Envirosuite's platform combines multiple data sources data such as air quality data, weather data, emission rates, weather forecasts and altitude to provide a very accurate baseline about air pollution. Significant innovation in design makes complex data sets simple for non-subject matter experts to understand and use in real-time decision making and response to incidents.

This solution has been implemented on a very large scale, covering several counties with the technical challenges this implies.

Information and communications technology (ICT) is crucial for this project as real-time data is needed in order to feed the Envirosuite's proprietary algorithms. Real-time air quality data from these districts' air quality monitoring network is collected and aggregated as a dataset. It is then augmented with real-time actual weather data and sent to Envirosuite's platform for processing (Envirosuite platform runs on Amazon Web Services).

On this platform, cloud computing techniques are applied in order to transform data into usable and actionable information that facilitates pollution mitigation actions.

Implementation

Two unique approaches are used during the implementation phase.

1) Sensor data are integrated with real-time information on wind speed, wind direction and the variability in wind direction to provide a real-time designation of the likely area that a measured value has originated from. With clever design, users of the system can immediately see which industry or other source is the likely cause of the air quality incident.

2) Three-dimensional, non-steady state meteorological modelling techniques (commonly used in advanced dispersion modelling) are re-engineered, reprocessed and displayed in a way to provide an immediate reverse trajectory display of the likely source of the elevated sensor value or complaint in the community.

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[4] WRF is a numerical weather prediction (NWP) system designed to serve both atmospheric research and operational forecasting needs. NWP refers to the simulation and prediction of the atmosphere with a computer model, and WRF is the set of software for this. Source: https://www.mmm.ucar.edu/models/wrf.

[5] CALMET (currently developed by Exponent, Inc.) is a diagnostic meteorological model which reconstructs the 3D wind and temperature fields starting from meteorological measurements, orography, and land use data – Source: https://www.enviroware.com/calmet/.

[6] CALPUFF is an advanced, integrated Lagrangian puff modelling system for the simulation of atmospheric pollution dispersion. Source: http://www.src.com/.

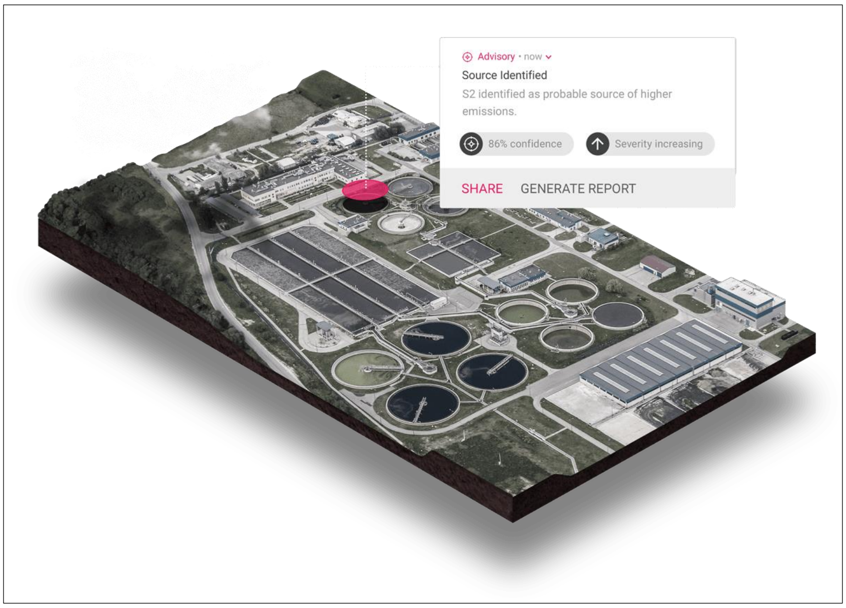

Figure 4 – Illustration of source identification[7]

In response to Assembly Bill (AB) 617[8], the California air resources board (CARB) established the community air protection programme which focuses on reducing exposure in the communities most impacted by air pollution. The BAAQMD was the first district to roll out a community health protection programme under AB 617.

The following entities have been involved during the implementation: California air resources board (CARB), South Coast air quality management district (SCAQMD), Bay Area air quality management district (BAAQMD).

It is innovative and important to provide a tool at the regional level that allows regulators to identify and assess environmental issues in real-time and to determine their impact on the communities.

Since the air quality and weather stations already have wireless connectivity technologies installed in them, the key factor is to connect them to the Envirosuite's platform to allow for data to be sent.

The real-time air quality and actual weather data is then processed in the cloud using machine learning techniques and then converted into an easy-to-understand output.

The Envirosuite platform resides in the Amazon Web Services infrastructure, which is replicated in several parts of the world, thereby providing high availability and reliability due to service guarantees. The key limiting factor in a solution of this type is the reliability of the devices in the field, which are managed carefully by the agencies in this case.

Results

The system allows air quality control agencies in California to respond promptly to incidents and complaints. The outputs of these intelligent systems are used by the authorities to detect pollution sources and adopt immediate actions and elaborate plans in order to reduce air pollution and move towards a more sustainable model. Time and labour related to complaints management are also reduced as manual and expensive analysis of data are no longer required to support investigations.

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[7] Source: Envirosuite.com

[8] Assembly Bill (AB) 617 is a California state bill that encompasses new stipulations on nonvehicular air pollution: criteria on air pollutants and toxic air contaminants.

The project directly contributes to the air quality management at the region level including the cities in it.

The project is still in its implementation phase, and the results will be brought forth in the following years. The projected impacts are indicated below:

- **Social impact**: Better air quality will have positive impacts on citizens' health and wellbeing, increasing life expectancy. Air quality may also play a role in determining housing prices as locations with cleaner and better air quality are often more marketable than areas that have been heavily polluted.
- **Economic impact**: It is expected that the sanitary costs related to illnesses coming from air pollution will decrease as mitigation policies are implemented and improved. Manual analyses of air quality incidents and complaints are significantly reduced resulting in operational efficiencies in the form of cost savings. Companies will also be more involved in formulating corporate social responsibility policies, taking care of their employees and keeping an eye on the environmental conditions they live in. Clean air can also be a determining factor for a company to decide whether it should settle in a more polluted area or move to a cleaner area.
- **Environmental impact**: The positive environmental impact is very clear in terms of having cleaner air, not only for its inhabitants but also for the vegetation in the region. Vegetation is the basis for the functioning of the most terrestrial and aquatic ecosystems. The air pollutants penetrate vegetation through their leaves and cause complex and varied adverse effects on different ecosystems (e.g., eutrophication of ecosystems, mineral deficiencies, reduction of biodiversity). The only negative environmental impact is related to providing energy to the air quality stations – already installed – and to the servers where the platform is hosted. These impacts are considered acceptable.

Conclusions

As demonstrated above, operating the Envirosuite platform at the regional scale has many hurdles to overcome. Noticeably, more processing capabilities are needed when working with huge amounts of data.

Understanding the high degree of interdependence that bordering cities have between each other is quite important. High-accuracy data sources and validated scientific models combined with the proper software processing capability can help fight complex problems such as regional air quality.

The willingness to cooperate among public authorities and the adaptability of the cloud platform to process huge amounts of data coming from different data sources existing on a large area is important.

Moving forward, the project enumerates the following points in order to continue to improve and adapt to the dynamic environments that it is in:

- understanding the feedback from the public authorities;
- assessing the policies implemented;
- being able to compare the initial situation about air quality against the current air situation and;
- measuring the impacts for population health improvement will be challenging and also highly beneficial.

The platform has been designed to be configured very easily and replicable in other cities and regions. The Envirosuite platform is a scalable solution that is flexible in its implementation. It is usually implemented on a local scale, covering facilities such as a port or a refinery, or a small city. The platform has also been adapted at the regional scale such as in the case of the Californian authorities in this case study. In the case of needing a denser network, or the project managers deciding to increase the extension of the project, more air quality and weather stations can be flexibly added to the platform without any problem. Therefore, if necessary the project can be scaled up to having more air quality management districts.

Case study references and further reading

– Bay Area air quality management district. <http://www.baaqmd.gov/>

– South Coast air quality management district. <http://www.aqmd.gov>

Envirosuite. <https://envirosuite.com/>

6.2 Case study 2 – Smart Dubai happiness meter

Introduction

Background

Dubai is one of the seven Emirates in the United Arab Emirates (UAE) and a highly vibrant city with a population of over 3 million people in the Arabian Gulf region. Dubai has set itself on an ambitious course through a rapid and successful transformation in both its economic and social sectors. In the last 40 years, Dubai has witnessed a major transformation by becoming one of the most visited global cities, being home to the world's busiest airport, the 9th largest port in the world, and the world's tallest building.

Dubai has established itself as a robust economy maintaining a significant economic growth over the years. It acts as the leading economic hub in the region with successful economic diversification. Sectors such as trade and logistics, tourism, financial services, retail, and real estate have played critical roles in Dubai's economic achievements, further complemented by a highly modern city infrastructure. Dubai is currently in its third generation of digital transformation with the city already driving public acceptance and the adoption of ICTs in all aspects of life.

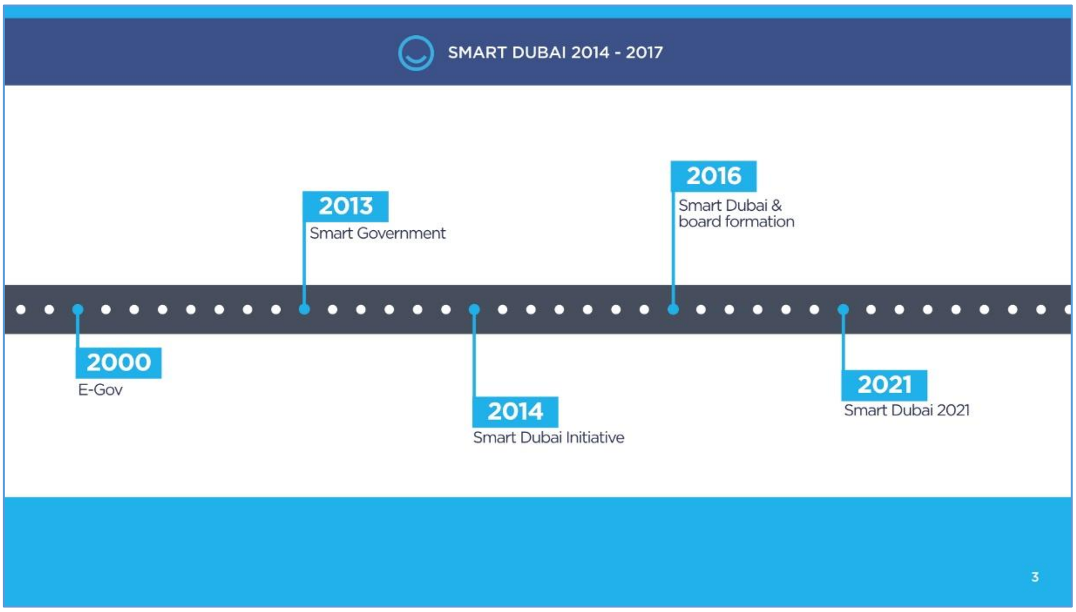

Figure 5 – Digital transformation journey of Dubai

Smart Dubai initiative was born in 2014 out of the visionary approach of His Highness Sheikh Mohammed bin Rashid Al Maktoum, Vice-President and Prime Minister of the UAE and The Ruler of Dubai to **focus the city's unified efforts towards its most valued asset – its people**.

The vision of Smart Dubai is to become the happiest city on earth. In line with its vision, the Smart Dubai initiative has structured its strategic approach to embrace the latest technology innovation that will make the city experiences seamless, safe, personalized and efficient delivering an enhanced quality of life and business experiences to contribute in making Dubai the happiest city on earth. The Smart Dubai initiative plays a key role in guiding and enabling the city's ongoing digital transformation across all sectors.

Challenge and response

The ambitious vision of making Dubai the happiest city on earth has mobilized Dubai entities, both public and private sectors to undertake strategic initiatives under the leadership of the Smart Dubai office. Happiness is not just a slogan in Dubai, but it is at the core of its smart transformation (UAE is the only country in the world with a ministry of state for happiness).

Achieving happiness is neither simple nor a straightforward task. On the contrary, it is quite challenging to translate it into a city-wide policy with concrete goals, action items, incentives and indicators.

Smart Dubai launched the happiness agenda to fuel its city transformation to happiness. Smart Dubai has adopted a globally unique, science-based, and methodical approach to measure, impact and sustain happiness for the whole city.

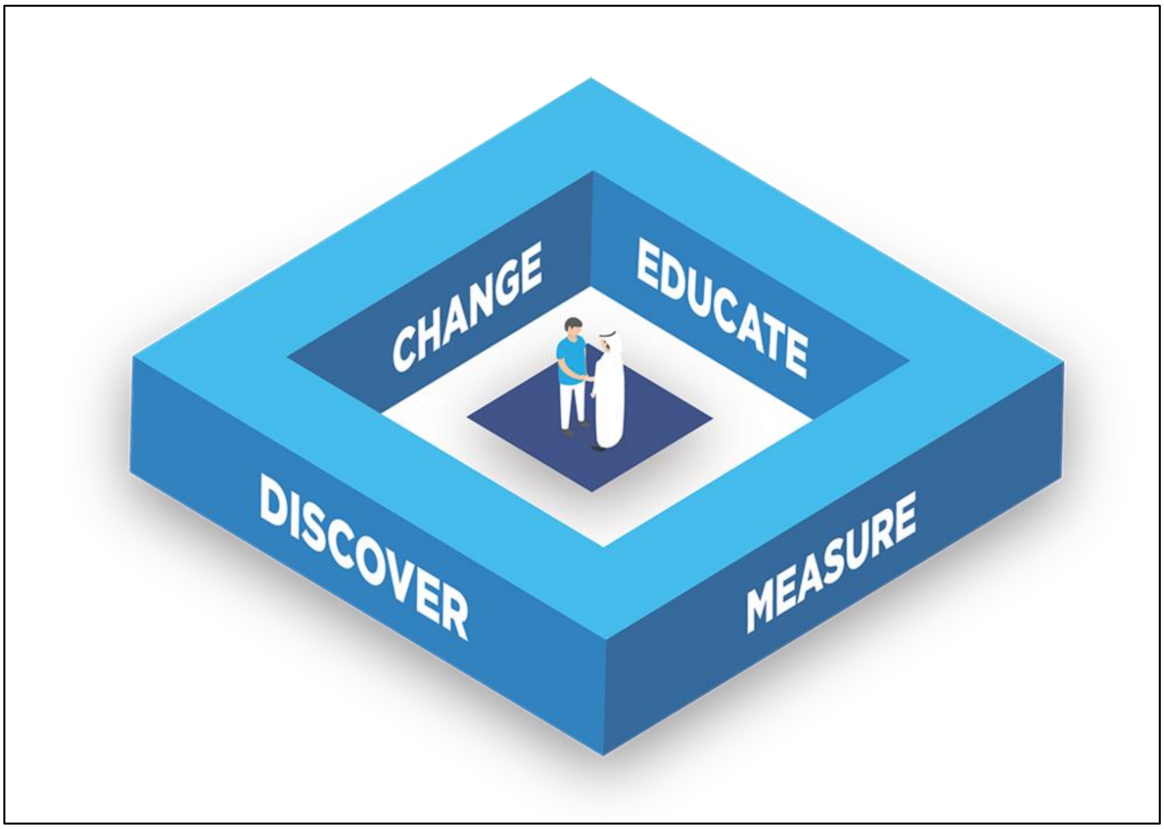

Figure 6 – Smart Dubai happiness agenda

One of the challenges was to collect timely (on the spot) feedback from the users of city services to measure their happiness regarding the city's services' experience. Hence, Smart Dubai launched a simple tool called the happiness meter to measure the city' happiness experience.

The smart project(s)

Vision and content

The happiness agenda measures and impacts people's happiness through an iterative framework to discover, change, educate and measure people's happiness as shown in Figure 6. The happiness agenda benefits from access to innovative technology and a broad partnership network for a unified approach utilising the best tools at Smart Dubai's disposal.

Shared understanding: Today, city leaders and decision makers act from an informal knowledge base with assumptions about what factors influence happiness in a city. Smart Dubai decided to build a unified definition of happiness, beginning with a scientifically aligned cultural baseline and an understanding of the basic and higher needs in Dubai. This formally defined, shared understanding became a guide for strategic activities in Dubai to prioritize happiness.

Without a shared understanding of happiness factors in the city today, neither private nor the public sector are able to fully consider the impact on happiness right from city planning to customer experiences. Building on a culturally relevant scientific model, Smart Dubai aimed to define and promote new policies and approaches to focus happiness on the city and its people.

Needs fulfilment: The happiness agenda aims to address the needs of people that are essential to enhancing happiness for both short and long term. The happiness agenda discovers these needs, creates changes that support them, creates awareness so that others can support them proactively, and innovates towards 'happiness' by satisfying individuals' affective, emotional, basic, cognitive, and deeper eudaemonic needs.

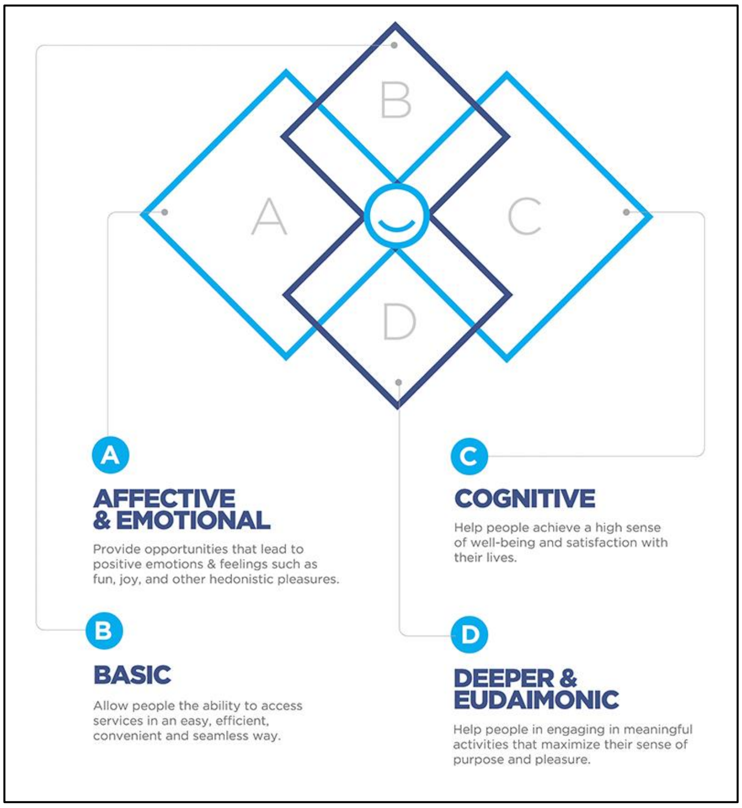

Figure 7 – ABCD of needs

The happiness agenda as indicated in Figure 6 has four strategic portfolios: namely discover, change, educate and measure.

Discover: A primary portfolio in the happiness agenda is the 'Discover' portfolio, which is geared towards ensuring clear and shared understanding amongst stakeholders. The essence of this portfolio is to discover rather than assume facts and concepts that lie at the heart of subsequent activities. This will result in enhancing the efficiency and chances of the success of these activities.

Change: This is the portfolio that is primarily responsible for creating change in Dubai with regard to happiness. This change will be made by having a clear strategy towards happiness experience (HX), as well as producing policies and associated awards that encourage activities and services that enhance happiness. The portfolio also contains programmes aimed at delivering customer interventions as well as city transformations that improve the quality of life in Dubai.

Educate: An important part of increasing happiness in Dubai is to create awareness, train and educate customers and organizations with regards to happiness activities and its culture. This is done by disseminating relevant content and delivering events that promote such understanding. Such activities are undertaken with partners in various sectors, as well as positioning Dubai as an international thought leader in the science and practice of happiness.

Measure: In order to ensure efficient and efficacious delivery of programmes within the happiness agenda, it is important to sustain ongoing measurements of key aspects of happiness and customer needs in private and public sectors. Smart Dubai conducts regular assessments of happiness in Dubai, as well as assessing the effectiveness of the framework within the agenda itself.

This case study particularly focuses on the measure strategic portfolio and more specifically analyses the happiness meter as one of the measurement tools adopted by Smart Dubai at the city level.

Implementation

Happiness and city experiences: Smart Dubai's happiness vision has rallied the entire city administration to fundamentally redesign and enhance its various city experiences while utilizing emerging technologies (and to a limited extent leading edge other technologies as well).

All principal city dimensions are covered in targeted city experiences redesign including mobility, energy, environment, economy, society, education, health and public services. Smart Dubai selected high impact use cases to touch the daily lives of people (e.g., commuting in the city, charging EVs, renting or buying a property, availing prescriptions for health, food safety, enrolling in schools, entrepreneurs acquiring assistance in starting their own businesses from an AI-based agent and applying for commercial licenses through blockchain based registries, etc.). Initially more than 20 blockchain and more than 30 AI use cases, and additionally 100 customer journeys were identified and redesigned in the first stage for implementation pertaining to city experiences in Dubai.

Hence, several initiatives were implemented in the discover, change and educate portfolios of the happiness agenda.

Happiness meter for city experiences: As part of its **Measure** portfolio in the happiness agenda, Smart Dubai has implemented a simple yet very powerful tool, called the **Happiness Meter** to measure city experiences' happiness across thousands of touch points (linking it to its vision of becoming the happiest city on earth).

It is a simple happiness measurement tool which collects data from various points in the city instantly to reflect city residents' and visitors' experiences in Dubai. It is a plain tool with three options to choose from (represented in terms of faces as shown in Figure 8): happy, neutral and unhappy.

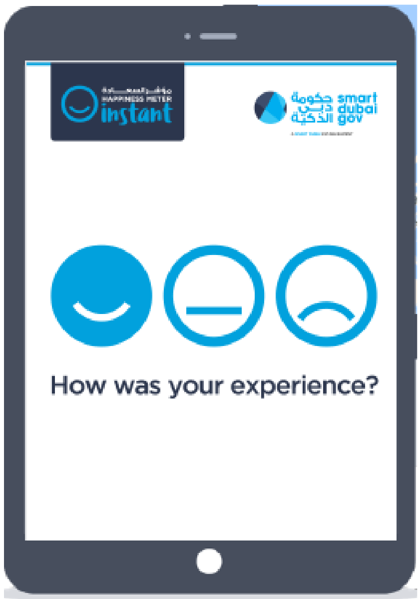

Figure 8 – Illustration of a happiness meter

City-wide implementation of the happiness meter: Smart Dubai has implemented a happiness meter in a phased-manner spanning both public sector and selected private sector entities. It allowed Smart Dubai to unify its city experiences' happiness measurement through a simple tool. The implementation followed the general approach given below:

- It was initiated in a handful of government entities as a pilot and included digital channels only;
- It was gradually rolled out to more than 50 government entities in a year mostly encompassing their digital channels (websites, mobile applications, kiosks, etc.);
- The roll-out was then extended to include physical channels of government entities including their customer service centres (i.e., counter-based face-to-face services);
- The happiness meter design was tested with heavy involvement of users and the tool was intentionally made exceptionally simple and easy to use as confirmed during extensive user experience testing;
- The rapid success and uptake enabled Smart Dubai to extend it to several private sector entities at the city level and their customer service delivery channels in addition to a comprehensive coverage in the public sector entities;
- The initial version of the happiness meter entailed selecting one of the three happiness choices (happy, neutral and unhappy). The subsequent version included asking for a brief feedback as to what made the users of happiness meter provide ratings that they opted for. This allows service providers to gather short, yet insightful feedback from their customers and allows targeted improvements in their service delivery.

Data collected through the happiness meter and its analyses: Smart Dubai collects the following data through the happiness meter:

- Happiness score (one of the three options; happy, neutral and unhappy);
- The entity for which a happiness score is given;
- The channel for which happiness score is collected (e.g., web, mobile application, service centre and counter, etc.);
- The time of the transaction;

- Optionally, customers can provide general comments or feedback from the users about the service (what makes them happy, what aspects can be improved, etc.);
- Optionally, customers can separately rate and provide feedback on the following attributes (relevant ones are presented to the user depending on channel type, e.g., centre appearance only applies to the customer service centres):
  – Ease of use
  – Ease of access
  – Speed of delivery
  – Clarity of presentation
  – Technical performance
  – Customer privacy
  – Staff professionalism
  – Centre appearance
  – Online support
  – Website application design
- The service for which happiness score is given;
- Geolocation (based on the channel);

The collected data enables Smart Dubai to analyse the following, among several others:

- City level happiness score;
- Entity level and entity type consolidated (e.g., public or private sector) happiness score;
- Channel level happiness score;
- Number of votes at city, entity and channel levels;
- Distribution of votes by the time of the day;
- Reasons for happy votes based on the comments from customers (allows dissemination of good practices among the entities);
- Reasons for unhappiness based on the comments from customers (allows service enhancements);
- Various statistical analyses to understand distributional aspects (variations and statistical modelling);
- Various correlation analyses (machine learning) to link happiness to service-related attributes.

Results

Happiness meter actual results: Since its launch in 2015 until the end of 2018, more than 22.5 million votes have been collected from the customers of various city services in Dubai.

- The overall happiness rating reached 90% at the city level in 2018;
- The happiness meter was rolled-out to 172 entities, both public and private, by the end of 2018. Out of these 192 entities, 53 are public sectors and 119 are private sector entities;

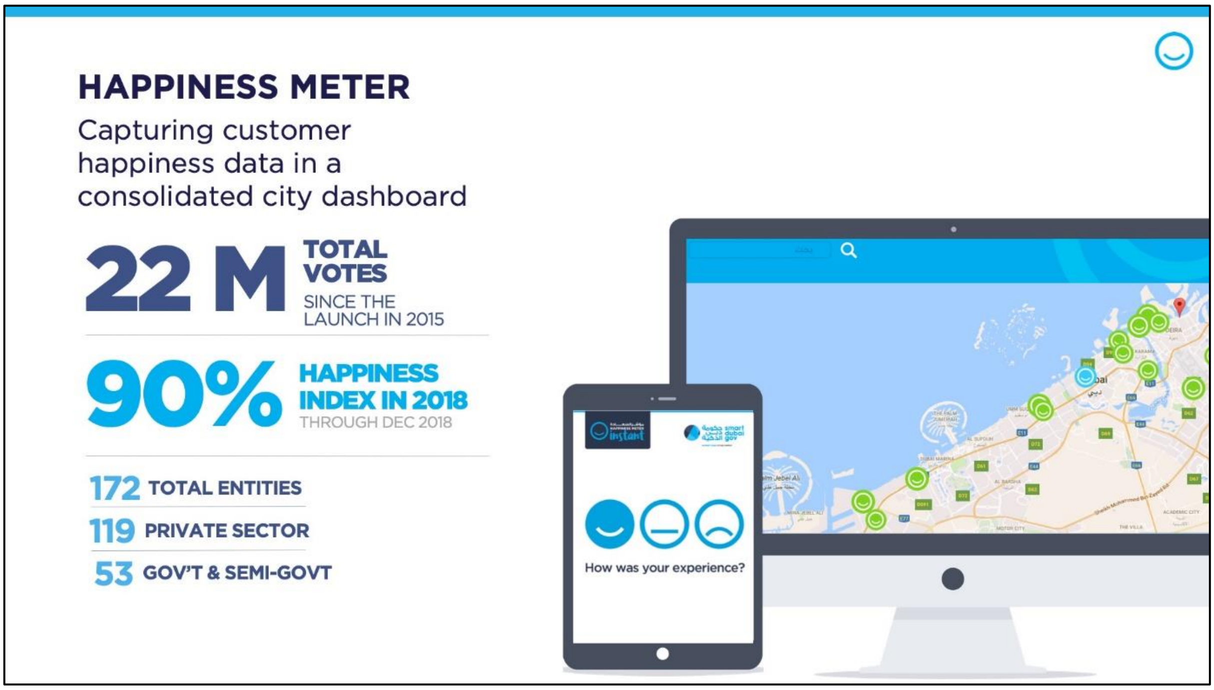

Figure 9 – Consolidated happiness meter results year 2015 – 2018

- The happiness meter has been rolled out to more than 4 400 customer touch points in 192 entities;
- More than 4 400 customer touch points include digital channels of various entities such as mobile applications, websites, kiosks, and physical face-to-face channels such as customer service centres and their individual counters (this allows tracking results all the way cascading down to the individual counters);
- More than 650 000 comments have been received from the users of happiness meter which provides input on what makes the users happy for various services as well as feedback for service enhancements;
- Happiness meter provides the city leadership with real-time access to happiness results as part of its implementation plan creating transparency and an immediate feedback tool to city administrators for enhancing city experiences. The results are accessible to the city leadership through a website as well as a mobile application and gives them to chance to see cumulative and real-time instantaneous results, and also perform analyses such as reporting results by entities, channels, customer touch points, locations, etc.

Happiness meter impacts and benefits: Despite its simplicity, the happiness meter has been a very useful policy tool for collecting happiness data in a timely, and extensive manner with a wide coverage of touch points at the city level.

Social impact:

- Direct linkage to Smart Dubai vision: Happiness meter has played an instrumental role in gauging happiness of city experiences linking directly to Smart Dubai's vision of becoming the happiest city on earth. Smart Dubai uses other complementary measurement tools to assess happiness (e.g., surveys, social media sentiment analyses, etc.), however the happiness meter provides instant feedback as opposed to delayed mechanisms that measure happiness having a certain time lag.
- Engaging public: Happiness meter has been a simple tool to engage people to gauge the satisfaction of their city experiences across several touchpoints. It plays the role of a simple participation tool for people and allows them to provide instant feedback, and if they want, they can also provide detailed feedback for the reasons of their selections.

- Improvement in social services: Happiness meter has been incorporated in several social services (in addition to others in the city) and allows direct feedback on them, which in turn enables targeted enhancements and improvements in social service deliveries.

Economic impact:

- Focus on core business: Since Smart Dubai has taken the responsibility of designing, implementing and operating the happiness meter, Dubai government entities were relieved to implement the same on their own and focus on their core businesses and enhance customer experiences during the delivery of their services. Happiness meter also enabled a uniform way of measuring city experiences' happiness (as opposed to each and every entity formulating its own approach which would complicate the aggregation of the results).
- Cost savings through operational efficiencies: Happiness meter has been implemented as a circular (shared) service capitalizing on the synergies that exist among the city entities that utilize it. This has allowed significant cost savings, since in the absence of such a shared solution, each and every entity would invest on its own to implement it. It would also pose challenges in terms of collecting and aggregating data from several entities. Smart Dubai designed the happiness meter to be flexible and scalable enough to accommodate future expansion in terms of economies of scale (adding new entities) and economies of scope (implementing enhancements).
- Improvement in economic services: Happiness meter has been incorporated in several economic services (in addition to others in the city) and allows direct feedback on them, which in turn enables targeted enhancements and improvements in economic services deliveries. Several public sector entities providing economy related services such as business licensing, trade facilitation, ports management, free zones' services, etc. have all availed it as a customer feedback mechanism.
- High levels of service delivery: Happiness meter provides instant feedback and even in some cases detailed feedback from customers for their happiness ratings. This has allowed government as well as commercial entities to promptly address their service delivery issues perceived by customers. Over time, several entities improved their scores by taking timely action based on customer ratings and feedback.
- Transparency and healthy competition: Happiness meter data stored in the centralized systems and repositories has enabled advanced analytics and business intelligence for various public and private sector entities that are responsible for policy making, services delivery and decision support. It also allowed the advanced fourth industrial revolution (4IR) capabilities to be utilized such as data science, AI, blockchain, etc. due to its flexible design. Hence, entities could benchmark themselves with other entities in the city and understand their relative position with respect to services delivery. This also enables a healthy competition among city entities and provides an incentive mechanism to improve their relative rankings and positions with respect to the happiness meter.
- Leadership engagement: The city leadership has access to the happiness meter results, and they are available across various digital channels including websites and mobile applications. This has allowed monitoring results cumulatively as well as even real-time by the various managers and leaders in city entities, giving them the chance to intervene, if need be, for enhancement and improvement of city services delivery.
- Knowledge sharing for happiness across the public sector: Smart Dubai has provided concrete platforms for sharing and exchanging ideas across the public sector for services enhancements. Entities openly shared their experiences and various techniques that they used to improve their services amongst each other. This way an innovating idea belonging to one entity becomes available to all the other entities when shared openly. Collective knowledge capital in terms of enhancing city experiences was enriched at the public sector level.

Environmental impact:

- Enhanced resilience: The centralized nature of the happiness meter implementation as an ICT service and its corresponding infrastructure enabled disaster recovery and resilience aspects to be implemented as part of its overall shared services approach. Smart Dubai circular ICT services and infrastructure (Happiness meter being one) are resilient by design featuring redundancies, automatic fail-over mechanisms, etc. Hence, it is designed to be resilient to various natural or man-made disasters, etc.
- Reduced environmental impact due to consolidation: Shared implementation approach for the happiness meter undertaken by Smart Dubai has circumvented the need for other city entities to replicate ICT infrastructures in their own premises. Consequently, happiness meter related ICT services and infrastructures have significantly been consolidated due to the economies of scale and scope, resulting in smaller number of overall ICT equipment (IT assets such as network equipment, server equipment, etc.). This in turn has also resulted in reduced carbon dioxide (CO_2) emissions due to consolidated ICT equipment. Hence, it is designed as an environment conscious solution and provides benefits in green computing.

Conclusions

Smart Dubai's vision of "becoming the happiest city on earth" is at the core of its digital transformation. Inherently, this is a vision stated as a goal for the people of Dubai. Hence, measuring people's happiness plays a key role for Smart Dubai to gauge its status with respect to its vision. In this context, Smart Dubai has employed several measurement tools including the happiness meter (among others, such as surveys).

Happiness, well-being, and quality of life are relatively novel goals for policy making in the digital age. Happiness meter acts as a bridging tool to integrate people's impressions of actual city experiences with the overall transformation efforts of Smart Dubai. It is a modest yet formidable tool which unifies happiness measurement for city services on the spot.

Smart Dubai strongly believes that the happiness meter as a concept and as an implemented tool is transferable to other cities. Other cities can take into account their own particular contexts and constraints as well as their stakeholders' specific requirements and expectations; however, the highly horizontal and agile nature of the happiness meter would render it highly applicable in most cases.

The strong positive social, economic and environmental impacts reinforce its compelling case for cities to consider as an easy-to-use engagement tool for its citizens. Its strong uptake in Dubai with more than 22 million votes in a few years, for a city having a population of over 3 million is a testimony to its potential for widespread engagement. Cities can capture its impacts and benefits through a simple implementation coupled with a wide rollout at the city level as discussed in this case.

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6.3 Case study 3 – Crime prediction for more agile policing in cities

Introduction

Background

Rio de Janeiro, or simply Rio, is the second-most populous municipality in the Federative Republic of Brazil and the sixth-most populous in the Americas. The metropolis is anchor to the Rio de Janeiro metropolitan area and is the capital of the state of Rio de Janeiro, Brazil's third-most populous state. Part of the city has been designated as a world heritage site, named "Rio de Janeiro: Carioca Landscapes between the Mountain and the Sea", by United Nations Educational, Scientific and Cultural Organization (UNESCO) on 1 July 2012 as a cultural landscape.

Rio de Janeiro is the headquarters to the Brazilian oil, mining, and telecommunications companies, including two of the country's major corporations – Petrobras and Vale – and Latin America's largest telemedia conglomerate, Grupo Globo. Being the home of many universities and institutes, Rio is the second-largest centre of research and development in Brazil. Rio de Janeiro is also one of the most visited cities in the southern hemisphere and is known for its natural settings, including several beaches.

There are significant disparities between the rich and the poor in Rio de Janeiro, and different socioeconomic groups are largely segregated into different neighbourhoods. Although the city is ranked among one of the world's most populated metropolises, many of its inhabitants live in slums known as favelas. There have been several government initiatives to counter this problem, from the removal of the population from favelas to housing projects such as Cidade de Deus to the more recent approach of improving conditions in the favelas and bringing them up to par with the rest of the city, as well as the development of the "Favela Bairro" programme and the deployment of the pacifying police units[9].

Challenge and response

Crime in Brazil involves an elevated incidence of violent and non-violent crimes. According to a study by the Brazilian forum of public security (a research organization), 63 880 people were murdered in Brazil in 2017, which was up 3 per cent from the year before, resulting in 175 deaths per day[10]. The research indicates that the murder rate in the country was 30.8 per 100 000 people, up from 29.9 in 2016. In comparison to the United States, it had five homicides per 100 000 people in 2015 — down from eight per 100 000 in 1996. Mexico, which is also suffering from a soaring murder rate, had less homicides per capita than Brazil with 25 per 100 000 last year[11].

Despite the high perception of crime in Brazil, Rio de Janeiro, being one of the most populated cities of the country, has a lower crime rate than northeast Brazil. However, it is far more criminalized than the southern region of Brazil, which is considered to be the safest region in the country[12].

Therefore, the challenge for Rio de Janeiro was to predict crime and implement more agile policies to lower the crime rate. The response has been to develop a digital platform to predict crimes based on the available past crime data and also avail it as an application (APP) for residents and visitors of the city.

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[9] Background information is based on data on Rio de Janeiro, http://prefeitura.rio/.

[10] http://www.forumseguranca.org.br/wp-content/uploads/2018/08/FBSP_Anuario_Brasileiro_Seguranca_Publica_Infogr%C3%A1fico_2018.pdf

[11] https://www.nytimes.com/2018/08/10/world/americas/brazil-murder-rate-record.html

[12] http://prefeitura.rio/.

The smart project(s)

Cities are where the future lies. They are hubs of innovation, productivity and experimentation. However, cities are also sites of crime and violence. More than ever, municipal authorities, private firms and civic groups are experimenting with new ways to improve safety in cities. In some cities, new technologies are being deployed to improve situational awareness of public authorities and its citizens. In others, all-encompassing surveillance and monitoring systems are being implemented, raising challenges on the fundamental norms of privacy.

In most developed cities, high-frequency time series information on insecurity is increasingly available. Literally thousands of gigabytes of raw data are available representing the dynamics and characteristics of crime. New high-power computer analysis is giving rise to a next generation of smart, agile, and evidence-informed policing strategies. Predictive platforms in particular can enhance police operations, identifying priority targets for police intervention and enabling more effective allocation of police resources.

Vision and content

Predictive analytics are hardly new. Statistical and mathematical models have long been used to predict where crime may occur. Predictions are based on a series of assumptions. For example, the criminological literature predicts that violent crime and property crime are not only highly concentrated in specific locations but also tend to occur at predictable intervals.

Predictive policing tools are being rolled out by police departments across north America, western Europe and parts of Asia. Police departments typically use thermal maps indicating the locations and times where the probability of crime is highest. Senior law enforcement officers can apply this information to plan their routine operations and send officers and patrol cars to the right locations at the right time.

This so-called "hotspots policing strategy" – merging data analytics with targeted policing – has been around for over two decades. Scientific evaluation studies have shown that it is an effective crime prevention strategy[13]. While concentrating resources on crime hot spots may contribute to a modicum of crime displacement, it happens less than expected. Indeed, departments must regularly update their data systems and operational strategies as crime itself undergoes structural changes over time[14].

Predictive policing is also evolving. They are benefiting from advances in machine learning, coupled with more affordable computational power. When compared to traditional hot spots mapping approaches using retrospective data, and predictive analytics can process more granular data at a more rapid pace thereby generating predictions associated not only to a location, but also to a crime type, and to specific times of the day and days of the week. When applied with fidelity, such tools can help police departments validate their predictions on a daily basis and adapt their responses accordingly to the everchanging crime patterns.

Crime forecasting models are another example of utilizing new technologies for more agile security: promising data-driven and problem-oriented approaches that can speed up decision-making and providing smart solutions that help reduce human biases and inefficiencies[15][16]. In an era marked by the fourth industrial revolution, AI, the Internet of Things and big data are available to help law enforcements and criminal justice authorities to adopt more effective policing strategies.

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13 Braga, Papachristos, Hureau, 2012.

14 Johnson, Guerette, Bowers, 2014.

15 Muggah, 2018.

16 Hussein, Abdulameer, 2021.

In 2016, the Igarapé institute partnered with Via Science – a data analytics firm – to develop the CrimeRadar application, a public-facing crime forecasting platform that evaluates relative crime frequencies in different locations and times in the metropolitan area of Rio de Janeiro.

Implementation

CrimeRadar is a digital platform that forecasts the probability of crime. It runs on smartphones and desktop browsers. The software uses advanced data analytics to show real and relative crime rates and risks for different neighbourhoods at different times in the Rio de Janeiro municipality.

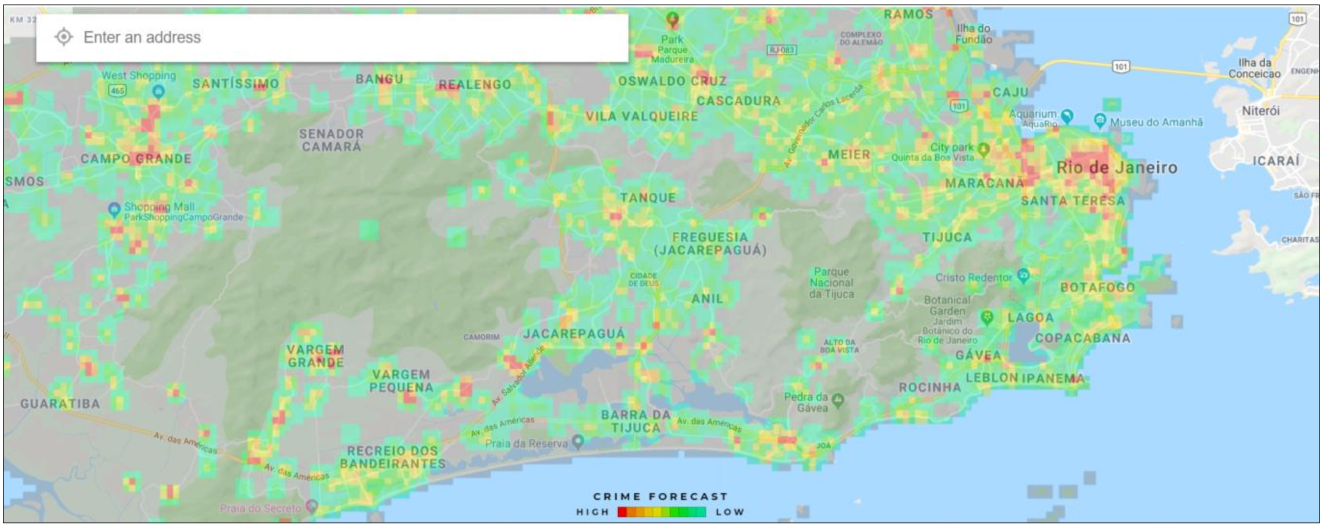

Figure 10 – Illustrative CrimeRadar platform[17]

CrimeRadar visualizes the safety levels in specific locations and times. By making crime data more accessible and transparent, it improves security for citizens.

The underlying crime data was retrieved from the state institute for public safety and official crime records produced by the state civil police. The platform was launched during the Rio Olympics in the August of 2016. Residents and tourists could access the website to view the predictions displayed on an intuitive mobile heatmap.

Solution development: CrimeRadar was conceived by the Igarapé institute and developed with partners Via Science and Mosaico. The Igarapé institute provided expert knowledge about the region and worked with various data providers to gather and verify the accuracy of the historical data.

Meanwhile, Via Science created the mathematical engine behind the application by developing algorithms using their advanced machine learning and proprietary software architecture. The Igarapé institute worked with Via Science to test the results.

Finally, Mosaico, a local software firm, helped design the mobile application interface for the Via Science algorithms and built an immersive user experience. Mosaico and Igarapé institute also designed the historical data platform.

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[17] The designations employed and the presentation of material on this [map / infographic] do not imply the expression of any opinion whatsoever on the part of ITU and of the Secretariat of the ITU concerning the legal status of the country, territory, city or area or its authorities, or concerning the delimitation of its frontiers or boundaries.

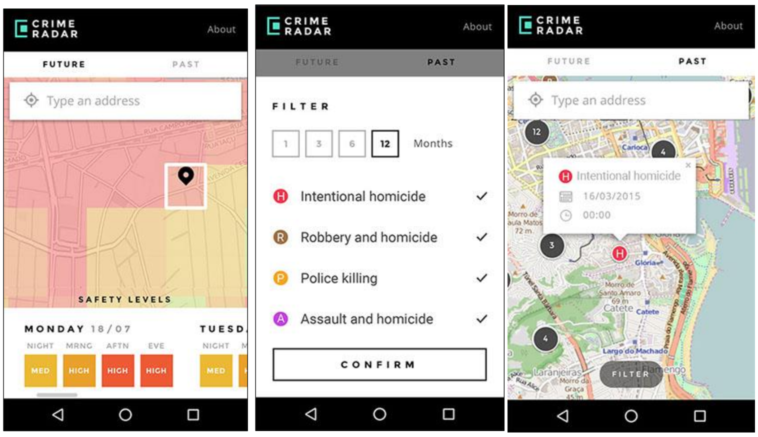

Figure 11 – Illustrations of the CrimeRadar mobile application

Why CrimeRadar? CrimeRadar is an example of a digital platform used for improving personal safety and security. The goal is to improve transparency and access to information for citizens and visitors. CrimeRadar makes crime data accessible, interactive and useful.

Until recently, basic crime data in Rio de Janeiro was inaccessible to the wider public. The data were often poorly collected and registered. However, there has been a major shift in data management. The newly launched ISPGeo, developed in cooperation with ISP, the Igarapé institute and several city partners provided crime data to the wider public in a safer and more accessible manner.

CrimeRadar difference: Other applications that predict crime activity tend to be restricted to police departments and not made available to the public. It is often restricted to a small number of users and the underlying methods are not transparent. By contrast, CrimeRadar is a step towards empowering the wider public to get involved in crime prevention. It is part of a wider movement to make data more open and accessible.

CrimeRadar applies leading edge mathematics, advanced machine learning tools, and an easy-to-use interface to help translate historical crime data into accessible and actionable information for users. CrimeRadar is not intended to prescribe or mandate safety levels in a region. Rather, it is intended to serve as one additional data point that the public can use when making decisions about traveling to specific locations.

CrimeRadar is an example of public private partnership whereby actual city crime data was provided to Igarape institute and its partners to develop a solution which helps both city police as well as citizens and visitors of the city. The institute provided expert knowledge about the region and worked with various data providers to gather and verify accurate historical data. Via Science helped to create and test the formula behind the application using their proprietary machine learning software architecture. Finally, Mosaico, a local software firm, helped design the mobile application interface.

Results

Given its initial success in Rio de Janeiro, starting in 2018, the institute partnered with the state military police of Santa Catarina to develop and pilot a police-facing version of CrimeRadar. Starting in 2020, the initiative will be evaluated using a randomized controlled trial (RCT) to assess the effectiveness of predictive policing on the planning of police patrol itineraries and scheduled operations. The intention is to assess changes in crime levels and crime displacement as well as average police response times and public trust in the police.

More importantly, the entire development process and resulting crime forecasting algorithms are being documented in a "social impact statement". The intention is to describe the challenges associated with (and steps taken to ensure) the monitoring and analysis of crime data. The Igarapé institute is committed to designing and implementing crime forecasting algorithms in a publicly accountable manner.

To start, the software license will require that all police departments deploying the predictive tool will comply with a minimum set of transparency and reporting standards. A list of five minimum requirements is set out below and were prepared by the fairness, accountability, and transparency in machine learning (FAT/ML)[18] work group, a community of researchers and practitioners concerned with fairness, accountability and transparency in machine learning:

- Responsibility and recourse – Make available external visible avenues of redress for adverse individual or societal effects of an algorithmic prediction system and designate an internal role for the person who is responsible for the timely remedy of such issues.
- Explainability – Ensure that algorithmic predictions as well as any data driving those predictions can be explained to end-users and other stakeholders in non-technical terms.
- Accuracy – Identify, log and articulate sources of error and uncertainty throughout the data sources so that expected and worst-case implications can be understood and be well informed of the mitigation procedures.
- Fairness – Ensure that algorithmic predictions do not create discriminatory or unjust impacts when compared across different demographics.
- Auditability – Enable interested third parties to probe, understand and review the behaviour of the algorithm through the disclosure of information that enables monitoring, checking, or criticism, including through provision of detailed documentation, technically suitable APIs, and permissive terms of use.

CrimeRadar was featured in several prominent publications.

CrimeRadar has had the following impacts:

- It has helped Rio de Janeiro residents and visitors by providing a simple visual heatmap tool that displays various city locations and their likelihood for crime.
- It has incorporated new crime data into Rio de Janeiro's public security system as it became available.
- The city residents' quality of life has been enhanced by better safety and security.
- Increased safety has increased economic activities in Rio de Janeiro and will likely to continue to be the case in the long run.
- It has helped in deploying police force more effectively to avoid crime by predicting it before it happens.
- It has created operational efficiencies for the police force by reducing and optimizing various costs such as patrolling, focused deployment of police force, etc.
- Reduced crime rate has improved the image of Rio de Janeiro as a highly visited global city.
- Reduced patrolling by police vehicles has also reduced CO_2 emissions.

Globally, there is still comparatively mixed evidence of the accuracy of crime prediction, its impact on clearance rates, whether it improves response times or even leads to significant reductions in crime. The only way to really gauge the impacts of crime forecasting is to conduct statistical evaluations that isolate the effects of the measure, including randomized control trials (RCTs). The annex provides a summary of the findings from several of the most well-known instances of crime prediction implementation.

[18] FAT/ML (n.d.). Fairness, accountability, and transparency in machine learning. Retrieved February 07, 2019, from http://www.fatml.org/resources/principles-for-accountable-algorithms

Conclusions

CrimeRadar is an innovative AI-based solution that utilizes historical city crime data to predict crime. The solution is adaptive as it is able to incorporate new incoming data and make adjustments accordingly. The prediction algorithm can be applied to other cities as long as the crime data is available for them, hence CrimeRadar is by design transferable to other cities (subject to data consistency and translation where needed).

Limitations of crime prediction: For all their promise, predictive crime analytics are not a panacea. For one, certain types of crime – including domestic and interpersonal violence – is not easily amenable to predictive models since they are seldom concentrated in specific locations and cannot be readily attributed to specific profiles of victims. While predictive algorithms may reduce certain forms of human bias by reducing subjectivities, they ultimately rely on often flawed crime data with systematic reporting biases.

Furthermore, predictive policing experiences, when subjected to closer scrutiny, have registered a host of challenges[19]. They are often expensive owing to the data storage lacking transparency in relation to the underlying algorithm and having on occasion led to the violation of basic rights and civil liberties[20]. Without high quality data and due care in the way they are built, predictive algorithms can unintentionally reproduce and exacerbate societal prejudices[21]. Identifying biases in data sets is complex, requiring deep knowledge in statistics, mathematics, and programming. As with most policing technologies, successful application requires a comprehensive approach. It depends not just on institutional leadership and the technical capacity of law enforcement agencies to incorporate predictive tools into routine operations, but also the development of minimum standards for responsible development, auditing, and evaluation.

Designing and deploying predictive tools: Crime forecasting is a mixed method, involving a host of integrated tasks. These include time-series modelling, intensive data mining, hot-spots analysis, and socio-temporal assessment applied to historical crime data. It is important to stress that predictive policing goes beyond basic online mapping tools that track crime.

Statistical methodologies include the *near-repeat theory* and *crime hot spot analysis*. These approaches assume that once a particular violent or property crime occurs in a particular location, it is likely to occur again in that same area. Meanwhile, the *risk terrain model* is more focused on geographical analysis, seeking to identify risk factors and features of crime-affected locations such as insufficient public lighting and potential escape routes.

Predictive policing is grounded on several established theories of crime behaviour and crime opportunity explaining crime concentration and repetition, and why crime occurs in some places and not in others. These include:

- Routine activity theory that states that crime depends on multiple factors including the motivation of offenders, suitable targets and an absence of capable guardians[22];
- Rational choice theory underlines that criminals make rational decisions based on the opportunity and estimated costs such as the possibility of being imprisoned and punished[23]; and

[19] Knight, 2017.

[20] Lum, Isaac, 2016.

[21] Oram, 2016.

[22] Cohen, Felson, 1979.

[23] Cornish, Clarke, 1987.

- Crime pattern theory explains why, when and where crime happens, focusing on the intersections and commonalities between victims and perpetrators[24].

By applying different combinations of these methods and theories, a growing number of universities and commercial vendors have developed predictive policing software, serving some of the world's largest police departments. Existing commercial solutions can be broadly categorized into two categories:

i) methods that predict the location of crime; and

ii) methods that predict likely crime offenders and victims.

The first method involves processing historical police reports, emergency hotline calls, weather forecasts and even the locations and dates of large public events to calculate the probability of crime happening in space and time. The second – and perhaps more controversial – method often processes arrest data[25] including criminal records and social media profiles as well as location, race, age, gender and ethnic data. The method generates a shortlist of high-risk individuals who are determined to be potentially involved in future crimes.

Controversies associated with crime prediction: There are widespread concerns that predictive policing tools could unintentionally exacerbate over-policing of marginal areas and undermine privacy. It is widely known that algorithms can reproduce existing patterns of discrimination, reinforcing previous errors and biases of programmers and become embedded in databases. There are very real ethical questions about the extent to which such tools can influence police to disproportionately surveil marginalized neighbourhoods and communities. Relatively, there are fears that such tools may augment race and age profiling and undermine privacy rights and civil liberties.

Recent studies funded by the US national science foundation demonstrates how predictive policing models are susceptible to 'runaway feedback loops'[26]. In these cases, police are repeatedly sent to the same identified hot spots, irrespective of the true crime rates. The researchers demonstrated how historical crime incidents that have been "discovered" by on-duty officers can aggravate the degree of runaway feedback, while in turn, historical incidents that were "reported" by citizens can attenuate but cannot entirely remove such feedback.

The accelerated pace and the spread of crime and violence prediction tools means that these concerns will only grow in the coming years. Indeed, new platforms are already being tested that aim to automatically classify gang-related crime[27], combine social media with criminal history to predict crime[28], and use artificial intelligence to identify individuals[29] with higher risk profiles of committing terrorist acts. The rapid roll-out of these tools invariably raise complex ethical questions in relation to police action and civil rights.

Establishing standards and regulations: There are several considerations that law enforcement agencies would do well to consider before implementing predictive policing systems. First and foremost, departments must evaluate the quality of their crime data and the capabilities of officers and officials to perform such an evaluation. Specifically, it is imperative that crime underreporting, and blind-spots are dealt with, and that departments can ensure that citizens from all neighbourhoods and social groups have confidence – and make use of – the police emergency hotline to report crimes when in need. Likewise, police reports must indicate precise addresses including their geographic

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24 Cullen, Wilcox, (n.d.).

25 Lum, Isaac, 2016.

26 Ensign, Friedler, Neville, Scheidegger, Venkatasubramanian, 2017.

27 Winston, Burrington, 2018.

28 Winston, 2018.

29 Mortimer, 2017.

coordinates. Also, to help mitigate the risk of runaway feedback loops, incidents must be [25] labelled to indicate if they were reported by citizens, or if they were initiated by an on-duty officer while on routine patrol.

Capital and operational expenditures associated with crime prediction tools must also be carefully assessed. The most sophisticated forecasting packages are expensive and may not be suitable for all police departments, especially smaller and mid-sized units in low- and medium-income settings. Instead of purchasing expensive software, some police departments may benefit more from hiring and training analysts[30] to use standard (and often open source) software to plot crime events on a map and run simple (yet useful) time series analysis.

Policing innovations for agile security should also make use of the interconnection of urban infrastructures[31] including sensors and unstructured data. Even so, privacy concerns should be paramount in the decision to process such information. Where possible, predictive tools should allow citizens to understand what is inside the "black box". While private vendors understandably seek to protect their source code, this lack of transparency (coupled with their underlying mathematical complexity) makes it difficult for law enforcement agencies and civil societies to understand how the predictions are generated. This can undermine confidence in the tool. Complicating matters, the secrecy associated with predictive tools may subject departments to increasing legal liabilities as cybersecurity and privacy regulations continue to evolve.

Above all, people must remain the most important element in the crime forecasting process, even when the most advanced software packages are used. Predictive tools must not replace the intuition and experience of law enforcement officers, but rather complement them in a transparent and auditable manner. When responsibly implemented, predictive policing tools can improve law enforcement's capabilities to solve problems, make decisions and effectively plan their operations.

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Annex to Case study 3

Selected applications of predictive policing and evaluation results

City, date of the evaluation, software name	Findings
Shreveport, Louisiana (United States of America), 2012, Predictive intelligence led operational targeting (PILOT)	Formal evaluation (blocked randomized controlled field experiment). No statistical evidence that crime was reduced to a greater extent in the experimental districts than in the control districts.
Los Angeles (USA), 2013, PredPol	Formal evaluation (randomized control trial). Average 7.4% reduction in crime volume as a function of patrol time. Reduction of property crimes by 12% compared with the previous year in the treated area (Foothill); in neighbouring districts, property crime rose by / to 0.5%. NOTE – Non-independent evaluation, done by founders of PredPol.
Chicago (USA), 2013, Strategic Subjects Litc- SSL	Quasi experimental evaluation. No impact on the list of people most likely to be involved in a shooting.
Greater London Area (United Kingdom), 2013, Metropolitan police service (MPS) algorithm ('MBR')	Evaluation of crime forecasting accuracy. Burglary – 'very low' to 'low' predictive accuracy (hit rates of 0-5%). Theft from motor vehicles – 'low' predictive accuracy (hit rates of 1-10%). Robbery – 'low' to 'medium' predictive accuracy (hit rates of 0-20%). Theft from person – 'medium' to 'good' predictive accuracy (hit rates of 13-54%).
Kent (UK), 2014, PredPol	Operational review. PredPol is 10 times more likely to predict the location of crime rather than random patrolling and twice as likely to predict crime as boxes produced using intelligence led techniques. During the north Kent pilot 25% of boxes were visited on average and a 4% reduction in crime was observed.
Milan (Italy), 2008-17, KeyCrime	Quasi random evaluation. Increase in clearance rates. Reduction of robberies in 18%. Saving in prevention of violence up to USD $ 2.5 million.
Richmond, Virginia (USA), 2006-17, WebFOCUS-IBM SPSS's clementine and predictive enterprise services	Report of results (no evaluation). Since implementation, reduction of incident rates of murder (32%), rape (20%), robbery (3%), aggravated assault (18%), burglary (18%) and auto theft (13%).
Aguire et al., 2019	Report of results (no evaluation) 89% of effectiveness in the tests carried out by the police.
La Plata (Argentina), 2018	Report of results (no evaluation). Reduction of crime in 40% in identified hot spots.
Durham (UK), 2013, Harm assessment risk tool (HART)	Royal united services institute study. HART was found to predict low-risk individuals with 98 per cent accuracy and high-risk with 88 per cent accuracy.
The Netherlands, 2017, Crime anticipation system (CAS)	Trial pilot. Over 30% of thefts were committed in the zones predicted by the algorithm.

City, date of the evaluation, software name	Findings
Baden-Württemberg (Germany), 2016, PRECOBS	Max Planck institute evaluation. Moderate effects in the reduction of burglary.

6.4 Case study 4 – Data driven energy saving in Hyperdome Shopping Center, Queensland, Australia

Background

Logan City is located in Queensland, Australia, and is home to 320 583 residents with 217 different nationalities among its population. The number of residents increases approximately by 1.5% each year and the city's median age is 34 years old with 22.6% of the population aged under 15 years, and around 50% of residents are under 30. Being such a young city has contributed to its strong desire to limit the impacts of climate change, which is a primary focus for the Logan City council.

Figure 12 – Logan City in Queensland, Australia

Challenge and response

Logan City acknowledges climate change as a growing crisis and encourages its residents to do their part in slowing down the global warming process. Buildings contribute 40% of the global energy usage and carbon dioxide emissions, providing a massive opportunity to increase the overall sustainability in the city.

The Logan Hyperdome shopping centre located in Shailer Park, Queensland, is the largest shopping centre in Logan City and one of the largest single-storey shopping centres in Australia[32].

[32] Source: https://hyperdomeshopping.qicre.com/

Figure 13 – Hyperdome shopping centre

Hyperdome as a major shopping centre uses significant amount of energy which results in the release of a substantial amount of carbon dioxide emissions. Optimizing the Hyperdome's building operations could significantly reduce energy use and move the needle in the right direction in the fight against climate change.

To optimize energy usage and limit the Hyperdome's emission, a switch platform has been installed, a digital platform that is connected to the building management systems of the Hyperdome. It provides operational insight to the facility team at the Hyperdome that aims to save electricity consumption and fine tune all the building management system equipments to run as designed. At the same time, the conditions within the building remained comfortable for occupants as the air conditioning equipments were optimized to save a substantial amount of energy.

It is a practical case study that demonstrates the use of actual building data to reduce and optimize energy consumption, making it highly pertinent for the U4SSC city science application framework deliverable.

The smart project(s)

Vision and content

The vision behind the switch platform project is to optimize the Hyperdome shopping centre's building operations to significantly lower energy usage and cost while maintaining a comfortable environment for tenants and shoppers.

Logan City focuses on sustainable living and combatting climate change and the city places a huge emphasis on reducing energy usage for residents. To realise this vision, the city:

- Offers rebates for energy efficient equipment installed;
- Implemented a lighting upgrade project funded by the Australian Government; and
- Set a plan for achieving carbon neutrality for the Logan City council's operations by 2022.

As a marquee institution in Logan City, the Hyperdome attracts thousands of visitors and is highly visible to its residents. The Hyperdome building management company has invested the necessary resources into optimizing the shopping centre's energy consumption, leading the charge for other organisations to follow suit.

Using the building's network infrastructure including the Internet of Things (IoT) sensors and the existing building management system (BMS), the switch platform (the platform which integrates the building data, systems and equipment to provide insights into the site performance) connects into the BMS via the cloud to add deeper visibility into the energy consumption pattern of the Hyperdome. By using this single digital platform, the building management company is able to fine-tune the BMS operation of the chiller plants and its associated air handling units (AHU) in order to maximise the efficiencies of all the equipment, while maintaining conditions within the building to ensure occupant comfort.

Due to the centre's large single-storey floorplan, the air-conditioning utilises cooling from seven separate chilled water plants that are spread across the centre. Because of this unique layout, the Hyperdome proved to be cumbersome for managing energy in comparison to a site with a central cooling plant. The multiple chilled-water plants and nine separate power supply transformers for the site (spread across four switch rooms) have also added another layer of challenges to maximize the Hyperdome's energy efficiency.

Peak demand utility usage accounted for almost half of the total electricity costs for the site. Therefore, it was necessary to implement a strategy to reduce peak demand. To ensure that conditions were maintained at all times within the centre, the demand-limiting strategies utilised variable control to automatically adjust load shed field devices and to ensure no loads are switched off. This allowed the building management company to successfully reduce peak demand without losing conditions and avoiding any complaints from the tenants or customers.

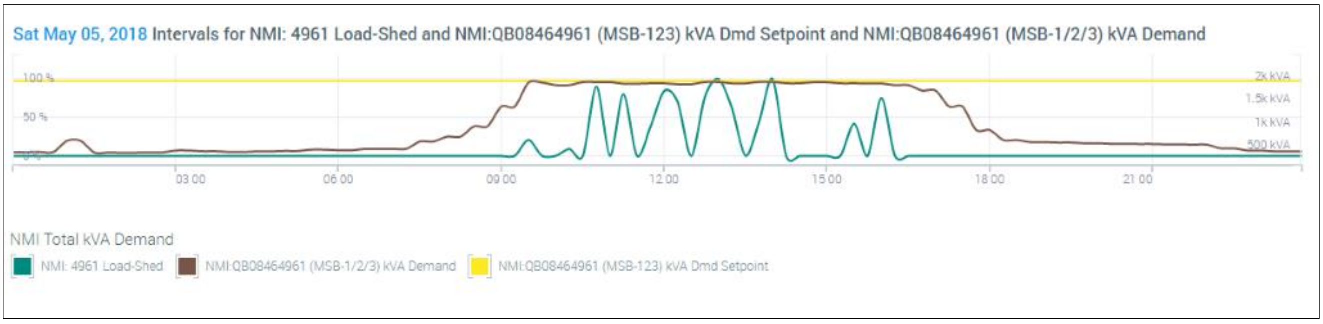

Figure 14 – Site-analysis chart showing the kVA demand did not exceed the setpoint. If it was to approach, the BMS load-shed signal (0...100%) would begin to increase, ensuring the peak demand was maintained below setpoint

Switch automation, the developer of the switch platform, connects to the building management company's existing BMS using the existing network infrastructure and IoT sensors. The switch platform then uses an IoT gateway to post sensor data to the cloud and aggregates the sensor data to perform advanced building analytics for optimizing the operations, energy usage and cost. Optimization techniques utilised in this case included big data analytics and machine learning capabilities coupled with systems integration and user-configurable fault detection.

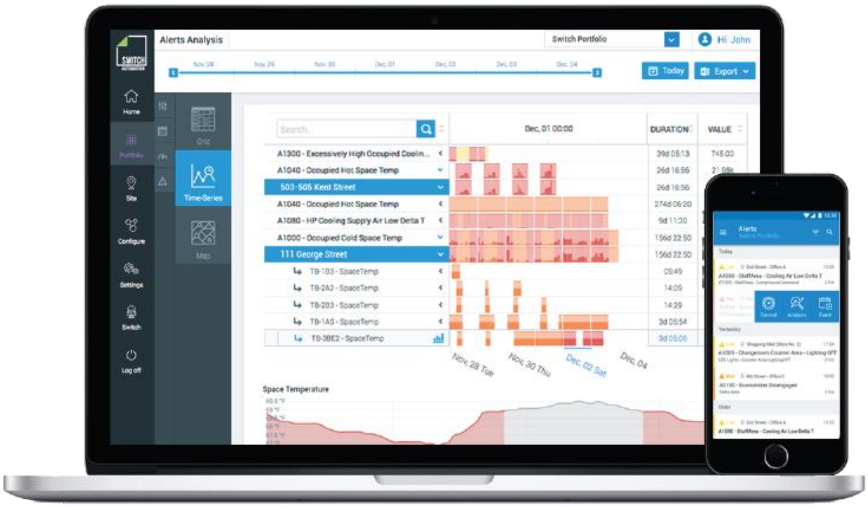

Figure 15 – Performance optimization through analytics[33]

Implementation

The Hyperdome's building management company worked closely with switch automation to connect the existing BMS to the switch platform, delivering a comprehensive building optimization solution. The switch platform connected virtually to the company's existing system to reveal deeper insights into the Hyperdome's energy consumption.

Prior to the project implementation the BMS was doing exactly what it was designed to do: control all equipment to setpoint, with the least number of possible errors. However, temperature and pressure setpoints needed to be optimized and the control of all plants needed to be in conjunction with the energy use. By implementing the switch platform, the BMS was successfully converted to a building and energy management system (BEMS), where energy consumption is monitored and optimized without compromising the occupants' comfort.

The team at the Hyperdome's building management company and at the switch automation were the key drivers of this project. The collaboration between the building manager at the Hyperdome's management company and a building engineer at the switch automation played a key role in realising the project's full potential. Together they identified:

- Opportunities for savings;
- Key building systems to connect; and
- Appropriate adjustments to make in order to maximise operations.

Additionally, the following enablers were crucial in its success:

- **Leadership**: The owners understood the opportunity to make the Hyperdome more performant through the use of real-time data from the BMS. This data enabled the facilities team to tune the BMS to perform at its optimum without compromising the comfort of the shoppers in the mall. Additionally, once the fault detection rules were deployed, a continuous commissioning programme could be realised, this way the BMS would continue to operate at its peak.
- **Financial**: The team at the Hyperdome's building management company saw the value of investing in a platform to add deep energy consumption insights to their existing BMS. The return in energy cost savings ultimately offsetted the initial investment in the switch platform.
- **Organization**: The team at the Hyperdome's building management company and the team at the switch automation partnered to implement this project.

[33] Source: https://www.switchautomation.com

Some other critical success factors included:

– Standardised fault rules deployed at scale;
– Consistent naming convention that could be deployed across multiple buildings, allowing all site teams to benefit across the portfolio;
– Connecting into the Hyperdome's IoT sensors and the existing building management system;
– The switch platform interface with the BMS via the cloud to add deeper visibility into the energy consumption.

Replacing the previous way of manually managing buildings, owners can now digitally monitor and adjust building systems from a single platform.

As conditions change due to external weather events and occupancy levels, the solution keeps the Hyperdome's energy use optimized.

It required significant amounts of data to be collected in order to be successfully implemented to the project. The collected data included, among others:

– Energy consumption for the building for each piece of equipment;
– IoT sensor data collected in 15-minute intervals;
– Occupancy sensor data collected in 15-minute intervals;
– Utility bill data.

The switch automation solution used the following mathematical models for optimizing energy usage:

– Statistical models of energy consumption;
– Machine learning for pattern recognition using historical data to calculate performance benchmarks;
– Weather normalisation modelling to account for outside conditions.

Results

During the first year of integrating the switch automation platform, the Hyperdome building management company identified cost energy savings of $337 516. This figure represents 12.6% of the total energy costs for the Hyperdome shopping centre site. More specifically:

• 1 220 884 kWh of energy saved at the Hyperdome site alone;
• $337 516 in annual energy cost savings achieved;
• 7.7% peak demand reduction attained; and
• Occupant comfort maintained despite lowering the energy usage.

With this solution in place, the building will continue to save on costs and energy consumption while maintaining occupant comfort. The project requires buy-in and efforts from the building management company to maintain and monitor, and to continue to invest the capital needed for continued success of this project.

Furthermore, the project significantly reduced energy consumption in a large, marquee building in Logan City, advancing the city's vision for implementing sustainable practices and fighting climate change.

The impacts from this project are briefly indicated below.

• **Social impact**
  – By implementing this strategic solution at such a high-profile institution, the Hyperdome paved the way for other businesses in the city to follow suit.
  – The Hyperdome occupants' comfort was maintained without adverse impact on them.

- **Economic impact**
  – The Hyperdome building company and its various outlets saved on the energy costs, resulting in direct economic impact.
  – Lowered building operational costs are passed on to the consumer, giving them more cash (disposable income) to spend to stimulate the economy.
  – Projects like this provide ample opportunity and demand for private sector companies and start-ups to invest in energy saving solutions by developing and deploying them.
- **Environmental impact**
  – The Hyperdome's energy usage lowered by 12.6% as a result of the project implementation. Owing to the large footprint of the building in the Logan City, this has a massive impact on the overall sustainability and energy consumption for the city.
  – The reduced energy consumption concomitantly reduced the carbon dioxide emissions for Logan City, having a positive impact for the environment and climate change.

Conclusions

Buildings provide a huge opportunity for lowering energy consumption in a city and positively impacting the environment. Investing in an advanced platform that aggregates building data and translates it into actionable insights can dramatically reduce energy use and operational costs. Reduced building operating costs results in lower costs for tenants, and ultimately these savings trickle down to consumers. Shoppers have more cash to spend at the Hyperdome stores which helps stimulate the economy of the entire city.

The partnership between the Hyperdome's building management company and the switch automation was the most critical factor in this programme's success. By working closely with the switch's engineering services team to integrate their systems, the building management company of the Hyperdome gained new insights and data on the patterns of energy consumption of the building. The switch platform is then able to analyse and visualise the collected data to optimize the energy usage of the Hyperdome.

Optimizing building equipment while maintaining comfortable conditions for occupants continues to be a challenge. While it's crucial to lower the overall energy usage, if the building temperature is out of an acceptable range, shoppers are less likely to spend their time and money at the Hyperdome. Maintaining open lines of communication and collaboration between the Hyperdome's building management company and the switch automation is crucial to the continued success of the project.

There is room for optimization of buildings in every city. With proper building network infrastructures and facilities management teams in place, enterprises can connect building systems and realise huge savings in energy consumption and costs.

Buildings with existing network infrastructure can connect sensors to a comprehensive building management platform like the switchs to optimize energy consumption and equipment performance. Building owners and operators can also optimize entire portfolios from a single platform to lower costs and drive down energy usage.

6.5 Case study 5 – Fine dust filtration

Introduction

Background

In recent years, there is a growing awareness of the high levels of air pollution in cities. Despite the air quality in the Federal Republic of (Germany) improving over the years, 18 cities are still not in compliance with the government-regulated limits for certain air-borne pollutants, with most lapses due to excessively high nitrogen dioxide (NO_2) levels. NO_2 is emitted from the road traffic and can be dangerous during events of prolonged exposure. In addition, particulate matter from road traffic is especially harmful to human health. Small particulates (PM2.5) are able to penetrate deep into the human lungs and may cause chronic lung and heart diseases. According to figures estimated by the World Health Organization, particulates are responsible for the death of around 47 000 people every year in Germany alone, and globally, more than 3.7 million deaths are attributed to outdoor air pollution.

In public debates, road traffic is blamed for a substantial part of both the NO_2 and the particulate matter in a city. Measures such as driving bans are repeatedly discussed and are met with resistance from the population. The non-governmental organization "Deutsche Umwelthilfe" (DUH) (The German environmental aid, which champions environmental and consumer protection) filed a lawsuit against several federal states in 2015, seeking to mandate NO_2 levels and a ban on diesel vehicles. This affected not only Stuttgart, but also other major German cities including Cologne, Düsseldorf, Frankfurt and Berlin. In addition, the European Union Commission has also decided to take legal action against Germany for non-compliance, hence there is a critical need for action.

Stuttgart, the state capital of Baden-Württemberg, adopted its first air pollution control plan in 2005. While it contained more than 30 measures leading to significant improvements in air pollution in Stuttgart, it was not complied evenly at city-wide level. Subsequent updates of the air pollution control plan were made in 2010 and 2014. Despite additional measures, short-term exposure to particulate matter (see Figure 16) and short and long-term exposure to NO_2 often exceeded their limit values in Stuttgart. A road section at Neckartor has been particularly affected by rising levels of pollutants in recent years.

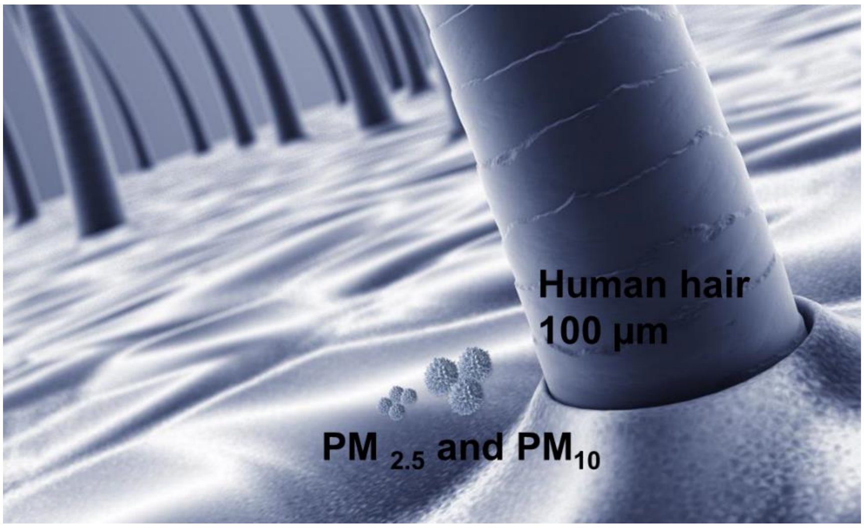

Figure 16 – Size of particulate matter (PM) compared to the thickness of human hair. PM2.5 can be lodged in the lungs, while PM10 can enter one's bloodstream, and is considered the most dangerous

Challenge and response

The Stuttgart "fine dust alarm", that is unique to Germany, has significantly raised public awareness on the issue of air pollution. An alarm is triggered as soon as the German weather service forecasts that the atmosphere will have a severely limited ability to disperse particulate matter and NO_2 on at least two consecutive days, indicating a risk that the limit might be exceeded. Car travel should be avoided, and the use of fireplaces, prohibited.

The local pollution is mainly due to low wind conditions, pollution from the power generation, agriculture around the region; as well as urban pollution caused by building sites, households and small consumers. Furthermore, concentrated road traffic in Neckartor combined with poor air circulation added to the problem.

Despite various regulatory and behavioural measures taken by the city and its populace, long term, lasting change was still elusive. The key challenge was to clean up the air in Neckartor, for good.

Response, through innovative technologies

The work started off by asking, "What if we could improve the air quality along the road?".

At MANN+HUMMEL, a filtration technology for particulate matter reduction was being developed. The impact of the technology was simulated based on the current pollution levels and subsequently, with the support of the city of Stuttgart and the ministry of transport for Baden-Württemberg, the technology was piloted at a critical street junction at Neckartor. The technology was designed into modular cubes, code-named "filter cubes". A further development of this filtration technology was to use the filter cubes to reduce the NO_2 on site as well, solving the two major issues raised above.

The smart project

Vision and content

Relation to city-wide vision and strategy

The city of Stuttgart is taking various measures to improve the air quality in polluted areas and in the city as a whole in order to achieve their green vision. The pilot project from MANN+HUMMEL, sponsored by the ministry of transport in Baden-Württemberg and supported by Stuttgart, was implemented at the Neckartor road junction in Stuttgart at the end of 2018.

Key features and design

The pilot project is designed to investigate whether the technology can be used to reduce the local fine dust pollution and included the 17 × 3 filter cubes measuring 3.6 metre in height, and these filter cubes were equipped with fine dust particle filters and energy-efficient fans.

It is assumed that the combination filter elements will have to be replaced approximately every 30 days during the pilot project. The exact replacement intervals will be determined within the project and defined based on the requirements for proof of effectiveness.

During polluted days, a running time of 12 hours is planned. With a consumption of approximately 1.5 kW and an assumed electricity price of 20 cents per kWh, this results in energy costs of only €3.60 per day and column.

Filtration technology:

- Filter columns consist of a number of filter cubes stacked on top of each other (e.g., Figure 17 includes two columns each consisting of 3 cubes).
- A filter column with 3 filter cubes is able to clean 14 500 m^3 of air every hour.

  The technology was developed and integrated to a newly developed combifilter medium which has a filter layer that retains fine dust particles. This also includes additional activated carbon layers having a large surface area to effectively adsorb the NO_2.
- For the particle filtration layer, an electrically charged filter medium, known as an electret medium, was used for the particle filtration. The deposition of NO_2 on the activated carbon is carried out via the following parallel adsorption mechanisms at the surface of the activated carbon:
  - Physisorption: physical adsorption of NO_2
  - Chemisorption: chemical binding of NO_2 in the form of HNO_3
  - Catalytic reduction of NO_2 to NO and CO as well as to N_2 and CO_2.

Both NO_2 and the particle filtration technologies are characterized by a particularly low drop in pressure and therefore are able to efficiently clean the air while using a low amount of energy.

Smart technology:

- The filter column contains several sensors for monitoring ambient conditions such as the temperature, humidity and air quality. These measurement data are currently used to control how the system is used, but with more data and insights, there will be more applications that can emerge from data usage.
- The fans are controlled according to the demand (i.e., concentration of pollutants in the air) in order to consume less energy.
- The data of all the filter columns are transmitted via a cloud connection where it is processed and evaluated. Each user (i.e., designated city officials and the MANN+HUMMEL project team) will be able to upload their data and can access a combined database via web applications that provide accurate real-time data on pollution levels.
- In general, the intelligent systems will be able to provide a self-regulating swarm intelligence that can control the operation of the systems based on factors such as the time of day, noise acceptance, weather or actual levels of pollution. The prediction of maintenance and service requirements is also simplified by the use of intelligent technology, as it makes it easier to estimate when the filter element needs to be replaced.

Figure 17 – Filter cubes along a street in Neckartor

Data collection and analyses

<u>Sensor data</u>

The sensors on the filter cubes collect the following data:

- Presence of rain
- Temperature
- Relative humidity
- Particulate matter size PM2.5, PM10
- Pressure loss
- Particle count

Simulations conducted and estimated PM10 reduction

Simulations were conducted by a certified simulation laboratory to predict the PM10 reduction for different wind directions and velocities, showing a strong influence of the wind direction. The design was optimized to provide the most effective filtration results for typical local conditions:

- Wind from 222° (South-west)
- Low wind speeds of 1 m/s (10 m above ground)
- High traffic emission modelling representing the peak hour.

Predicted PM10 reduction, when 50 μg/m³ PM10 are measured at public measurement stations, i.e.,:

- ~5 μg/m³ at a public measurement station
- 5-15 μg/m³ in the western area (walkways)
- 10-15 μg/m³ in the eastern area (walkways)
- >15 μg/m³ in the proximity of the columns.

Evaluation filter columns' effectiveness at Neckartor

Concentration comparison was made between the On and Off state, based on the following parameters:

- Baseline data: 30-minute average values by LUBW (note that this is a preliminary, unpublished data)
- Concentration change achieved by the columns in operation
- Public measurement data shows that the predicted 10% decrease of the PM10 concentration is achieved.

Implementation

The following parties are involved in the project:

- The state capital of Baden-Württemberg, Stuttgart
- Ministry of transport Baden-Württemberg
- MANN+HUMMEL.

MANN+HUMMEL approached the authorities of the state of Baden-Württemberg and presented its newly developed technology, the filter cubes, for the filtration of fine dust at the end of 2017. As a result, an independent engineering office carried out a simulation for the road section at Neckartor, which included the performance of the filtration systems, traffic conditions and the environmental conditions. The cubes promised a reduction in fine dust pollution on site. The state transport ministry then initiated the pilot project with MANN+HUMMEL and the city of Stuttgart in order to implement these cubes.

The city of Stuttgart is a central partner for MANN+HUMMEL. The municipal civil engineering office (part of the city of Stuttgart) was responsible for the planning and preparation of the infrastructure as well as the installation of the systems, which included:

- Consultation regarding the necessity of a building permit
- Coordination and definition of the locations of the systems
- Provision of the electrical cabling and supply
- Design and construction
- Road closure.

The municipal office for environmental protection (part of the city of Stuttgart) and MANN+HUMMEL coordinated the activities for the proof of concept. This includes:

- Planning and implementation of the measurement campaigns

- Selection and provision of the measuring equipment.

The costs of the project are shared by all three project partners. The project itself was scheduled to run for two years until the end of 2020. The first evaluation results have proven the effectiveness of the filtration technologies, and a final evaluation of the project will take place after the end of the two years.

Following the installation of the filter columns at the Neckartor in Stuttgart, MANN+HUMMEL has proved that the filter cubes can reduce both particulate matter and the NO_2 concentrations at polluted locations. The laboratory results from MANN+HUMMEL and the simulations carried out by an independent engineering office have proven that the effectiveness of the fine dust filters can be transferred to NO_2 technology. It was agreed between the project partners that the filter systems already installed would be converted to this technology by the summer of 2019.

Results

Results of the initial on-site measurement campaigns

The initial assessments of the project indicate that the filter cubes make a considerable contribution towards the reduction of the local particle concentration by 10% to 30%, which corresponds to 40% of all the fine dust particles caused by heavy traffic at the road junction. The positive initial results regarding the fine dust filtration are similar for the effectiveness of the technology in reducing the NO_2 concentrations. This has been verified by the results of simulations carried out by an independent engineering office.

The filter removes 80% of the fine dust from the surrounding air drawn in, with very low energy requirements. All the 17 filter cubes together has reduced the local particle concentration by 10% to 30%, according to the results so far.

The filter cubes at the Neckartor junction will be adapted to include the new technology by the summer of 2019. In future, they will be equipped with the newly developed combifilter medium which will enable the filters to retain particulate matter and also adsorb NO_2 from the ambient air. With the updated combifilter mediums, it is expected that the local concentration of NO_2 will be reduced by 10% to 30%. This in turn corresponds to 40% of all NO_2 and fine dust emissions caused by road traffic.

Results of the additional on-site measurement campaigns

Procedure:

- 7 days of measurements under the scientific supervision of Prof. Dittler, KIT, Karlsruhe.
- Utilization of high quality scattered light measurement devices.

Main findings:

- Fine dust reduction was observed across the whole investigated area.
- The reduction potential declined with increasing distance from the columns.
  - At the public measurement station, lower reduction values were measured than the values along the walkways. This is a consequence of the comparatively large gap in the net of the columns stipulated by the contracting authority.
  - In the proximity of the filter columns, reductions of > 30% were found.

Conclusions

In the city of Stuttgart and elsewhere in Germany, the advocation for effective measures to improve air quality, including driving bans and other extreme measures, has been greatly discussed by the civil community. There have been repeated demonstrations from both sides on this issue. The use of the filter cubes could improve air pollution in the short term, contributing to human health protection, alleviating the social tension created by the debate, and creating respite while a long-term solution is sought.

The critical success factor of the project was the transition from a technical prototype with a limited range of effect to a large-scale project with an active filtration network of 17 columns along a 250 m street in an open atmospheric environment. An independent engineering office had previously simulated the effect of the technology under local conditions such as the traffic volume and the weather.

The main lesson learned is the the proof of concept through large scale installation and measurement campaigns, enables validation of internal development tests and simulations and provides a basis for further development. In the next step, the extension from particulate matter filtration to a combined filtration of particulate matter and NO_2 will require an increase of the filter size and a 50% increase in air flow.

Scaling up after prototype phase

MANN+HUMMEL is rolling out this technology in various countries around the world. The technology has already been transferred to several countries in Asia such as Japan, People's Republic of China (PRC), Republic of (Korea) and the Republic of (India) for market investigation and prototype testing with local partners. The European market is mostly driven by maintaining legal limits and avoiding regulatory risks, while Asia and other emerging markets have a much more intense challenge since these agile markets and their populations are growing at an astonishing speed. Due to the associated increase in the manufacturing production, traffic, and resource consumption, air pollution and the negative effects on human health are also increasing.

The current state of development of the filter cube technology has been made available in Germany, China, and India for medium scale volume in single batch productions until demand necessitates large scale production. Furthermore, MANN+HUMMEL is extending the product portfolio for alternative applications by altering the system in shape and size, e.g., transfer to storage areas and subways.

In the short run, the Neckartor project will evolve over time by analysing and comparing the external signals and the archived cleaning efficiency. The target is to optimize power consumption and filter efficiency together with the maximum usability of the filter, thereby reducing maintenance costs and downtime. The model needs to balance between optimal filtration efficiency over time for human protection, and lowest usage of resources in terms of energy, human resources, financial investment, and material costs.

In the long run, MANN+HUMMEL is planning to install stationery and mobile solutions equipped with filtration and sensor units, working in an intelligent swarm to collect real-time data. This enables the team to draw an urban heat map of air quality and air pollution with potential applications such as:

- Identification of changing emission sources e.g., where are the pollutants coming from and whether there are new emission sources.
- Use of data to predict and redirect traffic flows depending on the pollution levels.
- Creating services that provide advice to sensitive or vulnerable groups to avoid unhealthy areas e.g., parents with young children, elderly or infirmed, joggers and cyclists.

Case study references and further reading

Press releases

– <https://insightaas.com/mannhummel-presents-technology-to-reduce-no2-pollution-on-roads-with-heavy-traffic/>

– <https://www.mann-hummel.com/en/the-company/current-topics/press-releases/pilot-project-to-reduce-fine-dust-pollution-along-the-stuttgart-neckartor-begins-with-installation-of-first-filter-columns/>

– <https://www.mann-hummel.com/en/the-company/current-topics/press-releases/together-against-fine-dust/>

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– <https://www.businessghana.com/site/news/general/181674/MANN-HUMMEL-presents-technology-to-reduce-NO2-pollution-on-roads-with-heavy-traffic>

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6.6 Case study 6 – Smart Dubai – Rashid – City concierge

Introduction

Background

Dubai is one of the seven Emirates in the United Arab Emirates (UAE) and a highly vibrant city with a population of over 3 million people in the Arabian Gulf region. Dubai has set itself on an ambitious course through a rapid and successful transformation in both economic and social sectors. Over the span of the last 40 years, Dubai has witnessed a major transformation in becoming one of the most visited global cities and is home to the world's busiest airport; the 9th largest port in the world; and the world's tallest building.

Dubai has established itself as a robust economy maintaining significant economic growth over the years. It acts as the leading economic hub in the region with successful economic diversification. Sectors such as trade and logistics, tourism, financial services, retail, and real estate have played critical roles in Dubai's economic achievements, and they are complemented by a highly modern city infrastructure. Dubai is currently in its third generation of digital transformation and the city has already driven public acceptance and adoption of the ICTs in all aspects of life.

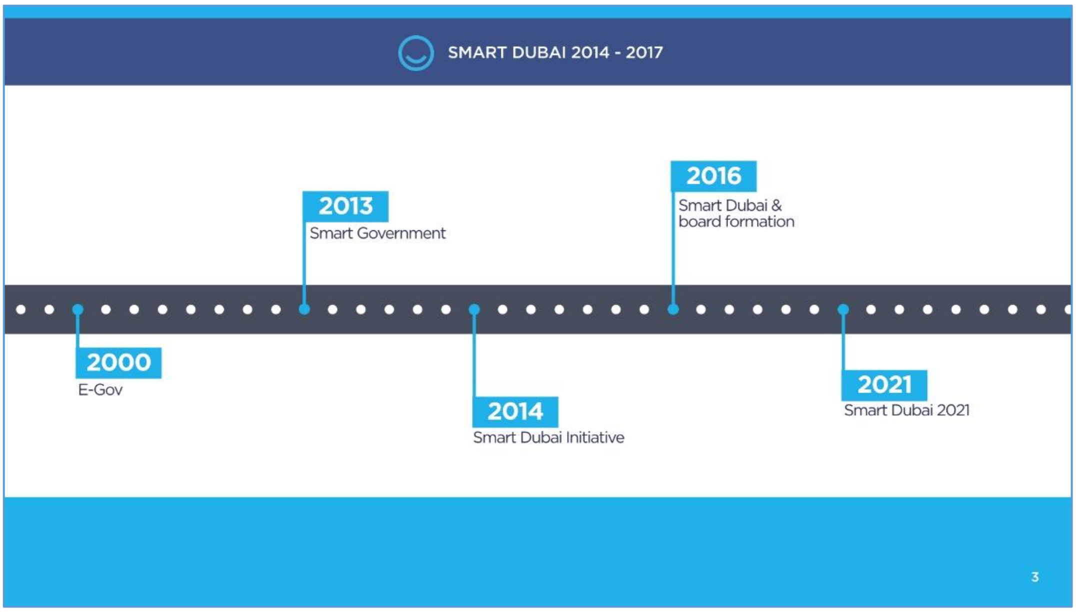

Figure 18 – Digital transformation journey of Dubai

In this context, Smart Dubai initiative was born in 2014 out of the visionary approach of His Highness Sheikh Mohammed bin Rashid Al Maktoum, Vice-President and Prime Minister of the UAE and The Ruler of Dubai to **focus on the city's unified efforts towards its most valued asset – its people.**

The vision of Smart Dubai is to become the happiest city on earth. In line with its vision, the Smart Dubai initiative has structured its strategic approach to embrace the latest technology innovation that will make the city experiences seamless, safe, personalized, and efficient, delivering an enhanced quality of life and business experiences to contribute in making Dubai the happiest city on earth. The Smart Dubai initiative plays a key role in guiding and enabling the city's ongoing digital transformation across all sectors.

Challenge and response

The ambitious vision of making Dubai the happiest city on earth has mobilized Dubai entities, both public and private sectors, to undertake strategic initiatives under the leadership of the Smart Dubai office. Happiness is not just a slogan in Dubai, but it is at the core of its smart transformation (UAE is the only country in the world with a ministry of state for happiness).

Smart Dubai has strategically embraced the fourth industrial revolution (4IR) and launched three emerging technology related comprehensive strategies to enable and complement its smart city transformation: namely artificial intelligence (AI), blockchain and the Internet of Things (IoT) strategies.

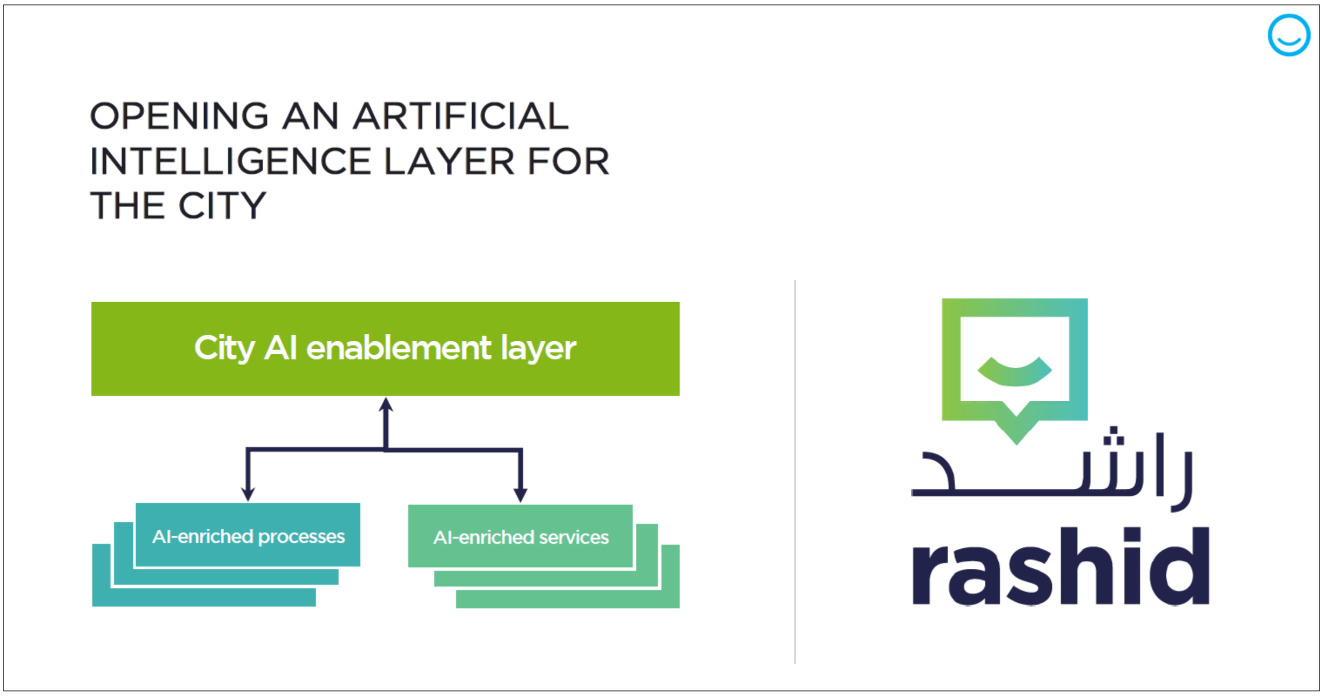

Figure 19 – Smart Dubai AI approach

Smart Dubai created a city AI enablement layer to utilize AI for city happiness. Hence, Smart Dubai has capitalized on various aspects of the AI including cognitive computing, machine learning, deep learning, natural language processing, etc. Smart Dubai AI strategy encompasses an implementation roadmap developed by the Smart Dubai AI Lab which consists of more than 30 use cases identified for implementation (the number was growing during the time this case was being written).

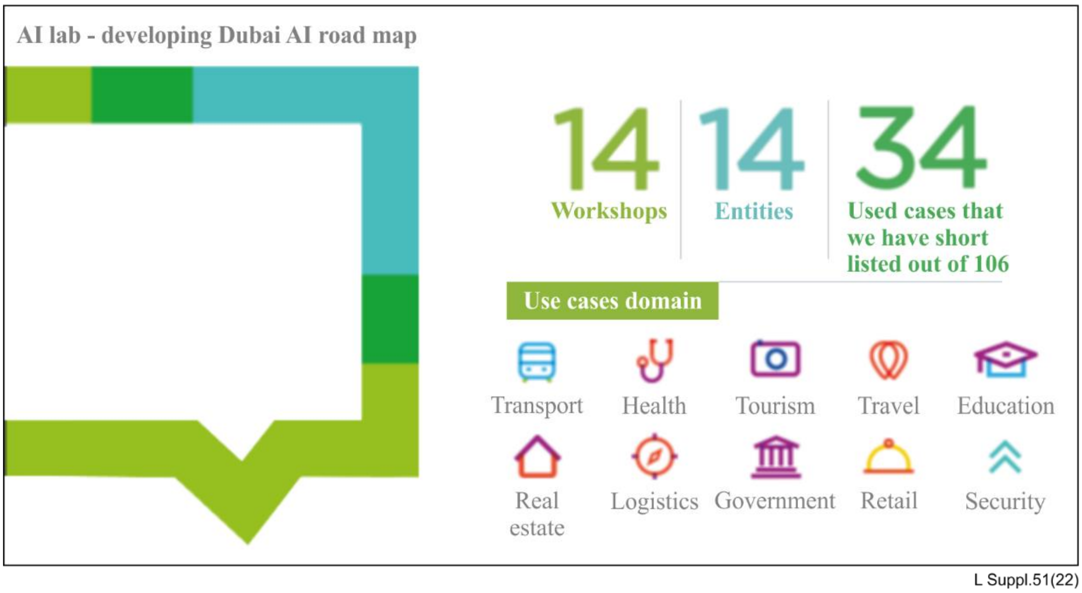

Figure 20 – Smart Dubai AI lab overview

One of the major initiatives undertaken by Dubai as part of its AI strategy is called Rashid (Arabic: *guide*) which combines cognitive computing and natural language processing to help residents, visitors and businessmen in Dubai to answer their queries about doing business in Dubai, living in Dubai and also visiting Dubai. Hence, Rashid acts as a city concierge and guides and helps its users for any inquiries they might have about Dubai. In other words, it acts as a virtual assistant and intends to make living and visiting Dubai easier which in turn promotes the happiness of Dubai residents and visitors.

This case study specifically discusses Rashid and its implementation, highlighting data aspects and problem-solving techniques that are utilized.

The smart project(s)

Vision and content

Rashid is designed as a digital city concierge to address various issues and needs for living in Dubai, visiting Dubai, and doing business in Dubai. Initially, it was designed to answer queries about Dubai and help people. However, the long-term vision is to also conduct transactions and hence obtain various city services in addition to helping people for their inquiries.

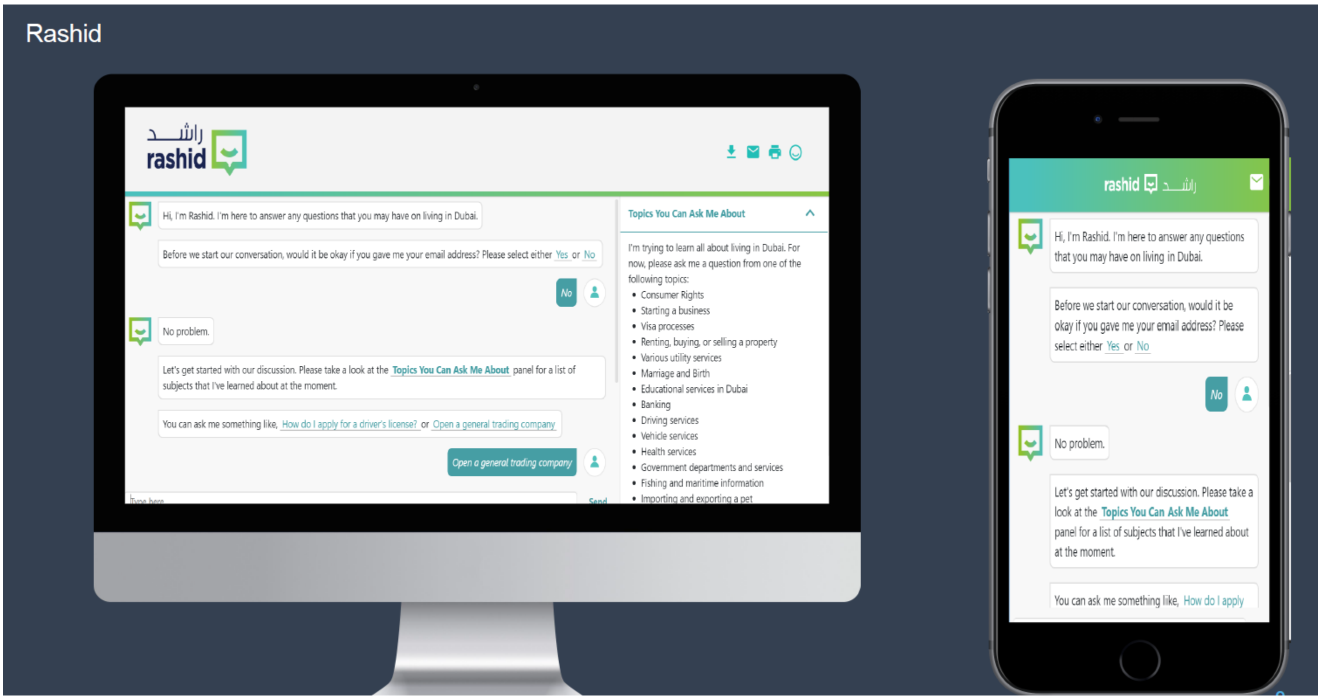

Figure 21 – Rashid as a city concierge

It is designed as an intelligent chatbot to perform the city concierge function. Figure 23 includes some of the initial topics included in Rashid in early 2019. The long-term scope of Rashid is to incorporate an extensive list of topics covering various aspects of city living. It will be developed gradually by incorporating new domains and topics along with a long list of potential inquiries (questions).

It is designed in an adaptive and decentralized manner to incorporate flexibility in expansion. That is, new domains and topics can be added over time, this way Rashid will be enhanced and equipped to handle the new needs of Dubai residents and visitors. Also, it is designed in such a way that new domains and topics can be added by different entities in Dubai (both public sector and eventually private sector) to enhance and enrich it.

Rashid is intended to contribute to Smart Dubai's vision of becoming the happiest city on earth by making people's city experiences seamless, personalized, and efficient as well as enabling them to meet their demands on the spot. Hence, it constitutes an important building block.

Implementation

Smart Dubai established a long-term partnership with IBM Watson to implement Rashid by using the latest cognitive computing technologies available. Rashid is one of many worldwide novel concepts which can be implemented as it encompasses a large number of topics spanning various city experiences. Smart Dubai designed and implemented Rashid in various phases as explained below briefly.

Rashid initial proof of concept and pilot phase: Rashid in its early pilot phase in the fourth quarter of 2016 (Q4 2016) included information about only starting a business. Smart Dubai partnered with Dubai's economic development department to implement the initial pilot phase. Hence, the target audience were entrepreneurs who wanted to start their own business. Entrepreneurs were able to ask questions to Rashid to determine various legal and procedural requirements for starting a business in Dubai. Rashid, by asking questions: the business type, number of partners, etc., advised entrepreneurs the business type(s) they can choose from (e.g., sole establishment, limited liability company, corporation, etc.). Subsequently, Rashid also guided entrepreneurs for the required documents as well as requisite steps for opening their business (most of these services are digitally enabled in Dubai).

Figure 22 – Rashid simplifying business licensing for entrepreneurs

This simple initial pilot phase was highly successful, and the uptake was quite significant. It provided on the spot information for aspiring entrepreneurs, and encouraged them to start their own business with ease.

City-wide implementation of Rashid: Upon its initial success, Smart Dubai has enlarged Rashid implementation to several other topics and entities in the city.

- Several additional government entities were added to enrich the list of topics they were responsible for,
- Rashid is implemented through digital channels including website and mobile application,
- Rashid has gone through several extensive user tests with the heavy involvement of city residents and visitors,
- The rapid success and uptake enabled Smart Dubai to extend it to pilot private sector entities at the city level in addition to a wide coverage in the public sector entities,
- Rashid is still under intensive development for new releases capitalizing on its success over a short period of time.

Design of Rashid and data collected: As indicated in Figure 23, Rashid includes several topics.

- Consumer Rights
- Starting a business
- Visa processes
- Renting, buying, or selling a property
- Various utility services
- Marriage and Birth
- Educational services in Dubai
- Banking
- Driving services
- Vehicle services
- Health services
- Government departments and services
- Fishing and maritime information
- Importing and exporting a pet
- Public Transport Information
- Dubai Taxi Information
- Shopping Festivals and Malls
- Cycling Tracks
- DTCM E-Permits

Figure 23 – Early Rashid topics in 2019

These topics are collected from several public and private sector entities and are organized further around sub-topics and various potential questions along with their answers.

Hence, a significant amount of data was collected for each topic from various entities. The collected data also included questions which can potentially be asked by the users of Rashid and their answers as well. The list of questions and answers are continually updated with additional ones as new inquiries by users of Rashid are captured, analysed, and incorporated periodically to enrich it.

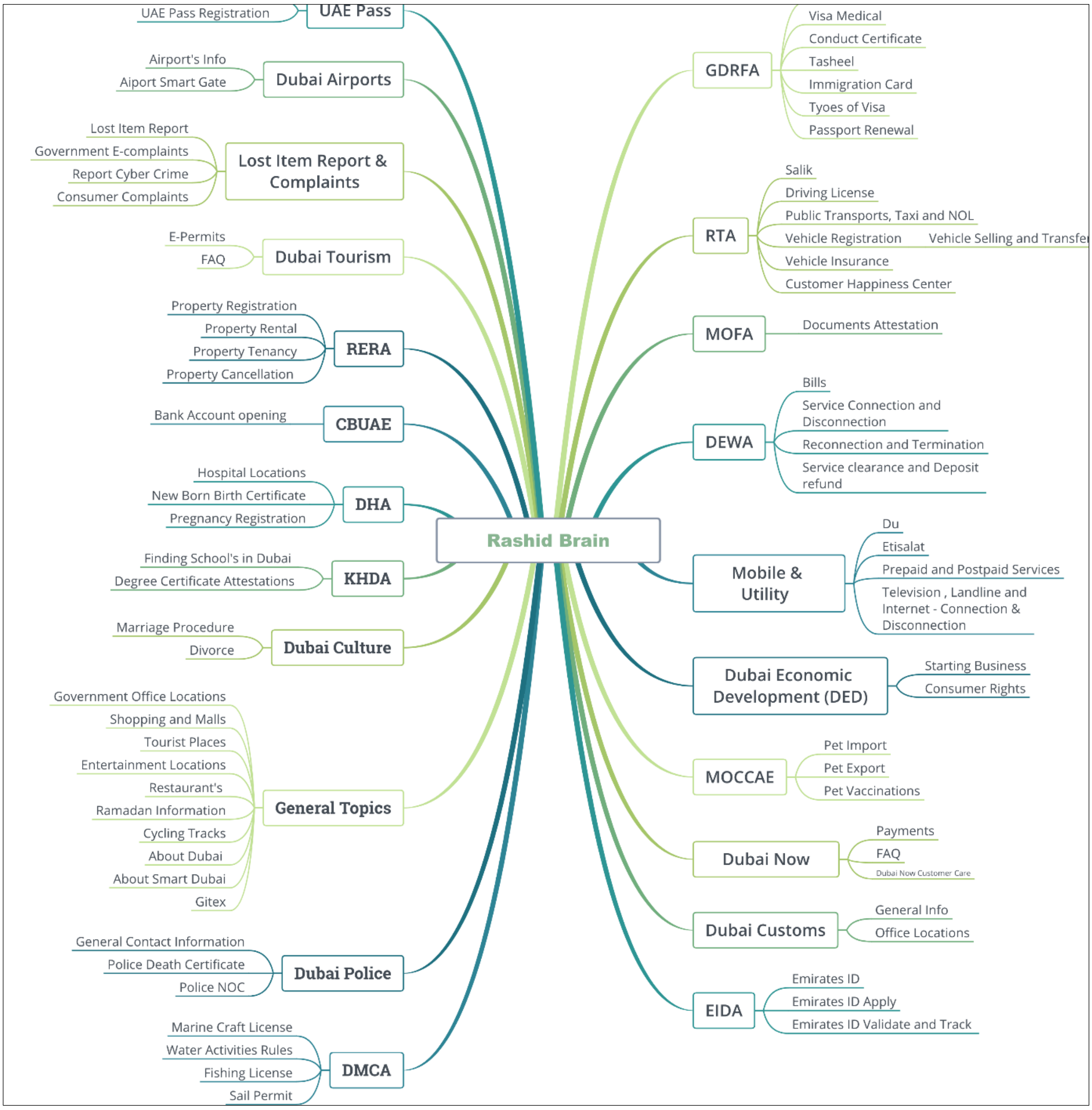

Figure 24 – Overall Rashid design and topics

Results

Rashid uptake and implementation results: Since its launch in Q4 2016 until the end of 2018, the uptake of Rashid has been significant regarding various city services in Dubai. Some adoption related figures reflecting actual results from Rashid are listed below.

- Total number of customers' conversations with Rashid from the initial launch till the end of 2018 – (59 241).
- Total number of questions that were asked from the initial launch till the end of 2018 – (275 105).
- Number of main topics Rashid can answer questions on – (122).
- Average number of questions Rashid is asked daily – (464 per day).
- Average length of each conversation by Rashid – (3.9 minutes).
- Rashid also provides a feature rich backend system as part of its implementation which allows Smart Dubai and entities to analyse its results, statistics, and more importantly answered and

unanswered questions. Unanswered questions are further analysed and systematically incorporated as continuous enhancements to Rashid.

Rashid impacts and benefits: Rashid has been a very successful tool for Smart Dubai at the city level. The impacts are briefly indicated below.

Social impact:

- **Direct linkage to Smart Dubai vision**: Rashid is designed to meet Dubai residents' and visitors' needs to have happy city experiences linking directly to Smart Dubai's vision of becoming the happiest city on earth.
- **Engaging public**: Rashid is a simple tool that uses natural language processing to engage people to meet their city needs across digital channels. In certain instances, people feel more comfortable asking their inquiries openly to Rashid rather than talking to a government official through the telephone.
- **Augmenting social services**: Rashid has been incorporated in several social services (in addition to others in the city) and enhances social services delivery.

Economic impact:

- **Focus on core business**: Since Smart Dubai has taken the responsibility of designing, implementing and operating Rashid using cognitive computing and natural language processing, Dubai government entities were relieved to implement the same on their own and focus on their core businesses and enhance customer experiences during their services delivery. Scarce AI skills were utilized effectively and efficiently by Smart Dubai to deliver a city-wide service.
- **Cost savings through operational efficiencies**: Rashid has been implemented as a circular (shared) service capitalizing on the synergies that exist among the city entities that utilize it. This has allowed significant cost savings; since in the absence of such a shared solution, each and every entity would invest on cognitive computing and natural language processing skills and systems on their own to implement it. It also eliminated various call centre telephone calls diverting them to Rashid as a freely provided digital service. Smart Dubai designed Rashid to be adaptive and decentralized to accommodate future expansion in terms of the economies of scale (adding new entities) and also in terms of the economies of scope (implementing new topics and sub-topics).
- **Encouraging entrepreneurship**: Rashid has been incorporated in several economic services (in addition to others in the city) including starting a business which actively promotes and encourages entrepreneurship. Rashid has played a complementary role in enabling start-ups and new businesses to be established in Dubai.
- **Knowledge sharing across the public sector**: Rashid collects detailed information about various city services and related topics in Dubai. This allows Rashid to compile a powerful list of topics, questions and its corresponding answers resulting in a rich knowledge base at the city level. It centralizes human knowledge and experiences by mimicking experts' knowledge into the brain of the system. It will also be enhanced with private sector information eventually.

Environmental impact:

- **Enhanced resilience**: The centralized nature of Rashid's implementation through a private sector partner enabled the disaster recovery and resilience aspects to be implemented as part of the overall partnership approach. Rashid and its infrastructure are resilient by design featuring redundancies, automatic fail-over mechanisms, etc. Hence, it is designed to be resilient to various environmental stresses and disruptions.
- **Reduced environmental impact**: Shared implementation approach for Rashid undertaken by Smart Dubai has circumvented the need for other city entities to replicate ICT

infrastructures in their own premises. This in turn has also resulted in reduced CO_2 emissions. Hence, it is designed as an environment conscious solution and provides benefits in green computing.

Conclusions

Happiness is at the core of Dubai's digital transformation. In this context, Smart Dubai is utilizing various emerging technologies, including AI, to strategically enhance its city experiences.

This case study illustrates the use of cognitive computing in addressing various inquiries of city residents and visitors through the use of natural language processing. The case study demonstrates that cities have a wide range of technologies at their disposal to enhance happiness as well as the quality of life. The topics given in Rashid, the AI-based city concierge in Dubai, have been selected on purpose to include its most popular and sought after topics that ensured its uptake and success.

An initial proof of concept (PoC) has been quite beneficial in understanding the technology and its application in the context of a use case. The PoC has then been extended to additional use cases and enabled adoption at a much larger scale.

Recently, Smart Dubai published its AI ethics principles and guidelines together with an ethical AI toolkit and an AI ethics self-assessment tool. Hence, Rashid as well as other AI use cases are designed to abide by these principles and guidelines. Dr. Aisha Bint Butti Bin Bishr, Director General of Smart Dubai, states that Smart Dubai's vision is to excel in the development and use of AI in ways that both boost innovation and deliver human benefit and happiness. Therefore, cities can consider formulating and abiding by a set of AI ethics, principles, and guidelines as they implement their own AI-based solutions and services.

The achieved results as well as the positive social, economic, and environmental impacts strengthen the case for smart use of AI in city services. Smart Dubai embraced AI as a key emerging technology and strategically invests in it to achieve happiness at the city level.

Case study references and further reading

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– Smart Dubai Rashid usage and adoption statistics.
– Smart Dubai AI ethics, principles & guidelines.
– Rashid.ae. <https://rashid.ae>
– Digital Dubai, *Artificial intelligence principles & ethics*. <https://www.smartdubai.ae/initiatives/ai-principles-ethics>

6.7 Case study 7 – Identifying cascading effects on vital objects during flooding

Background

Towards adaptive circular cities, concepts for a sustainable urban environment:

The research project "Adaptive circular cities" in which the institutes LEI Wageningen UR, Alterra, Deltares, the Energy Research Centre of the Netherlands (ECN) and Netherlands Organisation for Applied Scientific Research (TNO) worked together in collaboration with the Dutch ministry of economic affairs to bring knowledge aiming to make cities more adaptive, circular and more sustainable. Several stakeholders from the Amsterdam Living Lab Buiksloterham acted as a discussion partner or "launching customer", and in addition, the district is used as a test case for the solutions offered.

– The project addressed major challenges for urban areas[34]

[34] Source: http://www.adaptivecircularcities.com/towards-adaptive-circular-cities/

– Implementing climate change mitigation
– Adaptation to climate changes and sea level rise
– Sustainable use of natural resources and ecosystems
– Finding alternatives for valuable resources
– Transition to circular economies.

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Figure 25 – Towards adaptive circular cities[35]

Identifying cascading effects on vital objects during flooding is a case study under the **Adaptive circular cities** project. Increasingly we see flood-related events, and these will intensify in the future due to climate change and social-eco development, especially in coastal cities (high-tides, storms, hurricanes, tsunamis) as well as pluvial flooding (heavy rain or long rainy periods) and fluvial flooding (in river deltas).

Challenge and response

Identifying cascading effects on vital objects during flooding.

Flood related events can cause enormous damage to cities if not controlled. The first stage is the flood itself and the second stage is the cascading effect on the city infrastructure that can potentially paralyze the entire city.

It is essential to understand the short-term and long-term effects of flooding in order to be able to improve the resilience of the impacted cities and control the cascading effect.

Different challenges and measures for urban areas are to be considered, which include implementing climate change mitigation and adaptation actions, rising sea level, sustainable use of natural resources and ecosystems, finding alternatives for valuable resources, and transition to circular economies.

In response, a tool has been developed to build a model (3Di) that allows a detailed analysis of the cascading effect, called the circle knowledge. It is performed on critical infrastructures where information can be gathered from different stakeholders in an area. In combination with the high-resolution hydraulic model, 3Di is capable of stimulating a flooding scenario by making use of a variable-size computational grid combined with high-resolution underlying input data. The results are based on a combination of information from the stakeholders and the high spatial and temporal resolution of the model.

3Di is a state-of-the-art computational model to simulate flooding, both fluvial and pluvial (*see references 2 and 6 for this case study for details*). The 3Di instrument is based on detailed hydraulic computations. The computations are extremely fast and therefore allow for interactive modelling with multiple stakeholders on a touch-table.

3Di is a process-based, hydrodynamic model for flooding, drainage, and other water management studies. It can be used for the computation of water flow in 1D and 2D. The software is developed by

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[35] http://www.adaptivecircularcities.com/

a consortium of Stelling Hydraulics, Deltares, TU Delft and Nelen & Schuurmans. With 3Di it is possible to make fast simulations while using a high level of detail. 3Di allows the user to interact with the model during a simulation. One can interactively influence the simulation by changing the rainfall, wind force and model components like cross-sections, breaches and pump capacities. Deltares has also developed a fully open source model to complement 3Di, called Delft3D Flexible Mesh. More information about that model can be found here[36].

The first analysis has been conducted in north Rotterdam followed by several cities around the world.

The smart project(s)

Vision and content

"**Identifying cascading effects on vital objects during flooding**" is conducted using cases within the Dutch cities (Utrecht, Amsterdam, Almere, Duiven and Rotterdam) in collaboration with the Dutch ministry of economic affairs. The leading Dutch institutes for applied research Deltares, Netherlands Organisation for Applied Scientific Research (TNO), Wageningen University & Research and the Energy Research Centre of the Netherlands (ECN) combined forces in the 2015 project adaptive circular cities.

The project investigated and experimented with methods for interdisciplinary research and development to tackle multifactorial challenges.

Looking into the content of this case study, "Identifying cascading effects on vital objects during flooding" addresses what happens if a dike breaches in Rotterdam.

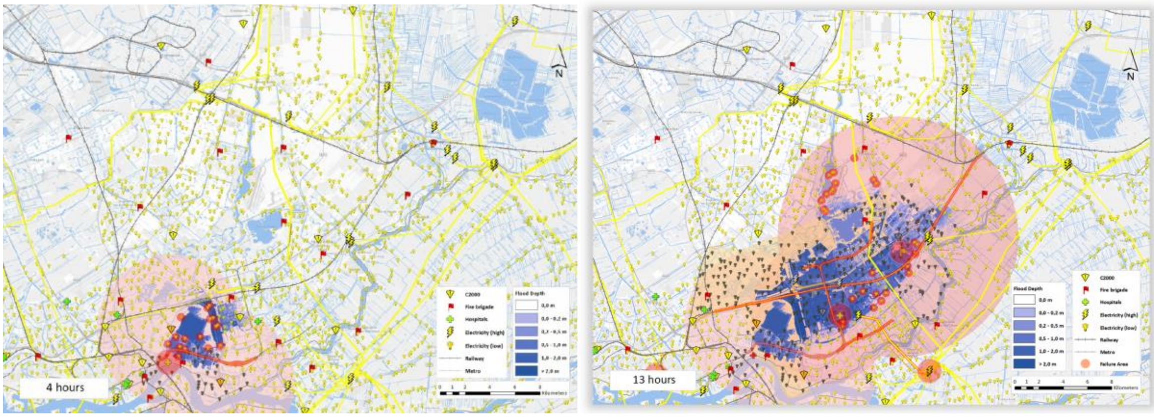

Figure 26 (a) – Visualization of impact in Rotterdam in the first 4 and 13 hours[37]

As seen in Figure 26 (a), it models and identifies the direct and indirect impact of flooding in the city. The aforementioned 3Di tool allows the visualization of these impacts over time, i.e., it displays how the flooding progresses over time in the city and how different city infrastructures will be affected if they are within the range of impacts. The image on the left side of Figure 26 (a) shows the impacts in the first 4 hours, whereas the image on the right side shows the impact in 13 hours. As expected, the impact range (shown by the shaded orange area) has significantly increased in 9 hours. We can see an indirect and cascading impact of the flood effects, as the metro network and the railway network that cannot be used due to embankment instability. The C2000 emergency communications network is also affected. Additionally, power outage (largely outside the flooded areas) is expected to take place and will have direct impacts on hospitals and other public establishments (needs to be evacuated).

36 https://oss.deltares.nl/web/delft3dfm

37 http://www.adaptivecircularcities.com/wp-content/uploads/2016/03/Description-of-CIrcle-method-and-combination-with-flood-modelling.pdf

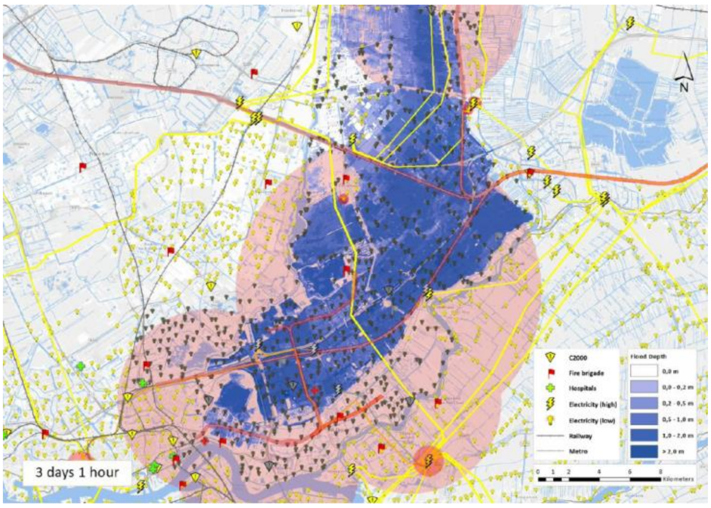

Figure 26 (b) – Visualization of impact in Rotterdam after 3 days

Few days following the incident, the flood and the outages moves north as shown in Figure 26 (b), making the evacuation process significantly more challenging. Without electricity, water pumps around the city will stop working, directly affecting the availability of drinking water. The lack of drinking water will potentially damage the health of the entire population, which is particularly devastating in a highly populated area like Rotterdam. The cascading effect of flooding will continue to spread until the city has sufficiently responded to the situation.

Implementation

As mentioned earlier, it is important to understand the short-term and long-term impacts of such events in order to improve the resilience of cities and to better understand the impacts of flooding. To that end, we need to be able to distinguish between direct and indirect impact.

The first step to identify indirect impacts is to understand the cascading effect that is often larger than the initial direct damage. That is, flooding can set in motion a cascade of effects influencing many other features. For example, flooding can trigger outages in the electricity infrastructure. This in turn may cause water and sewage pumps to fail leading to water and sewage system outages.

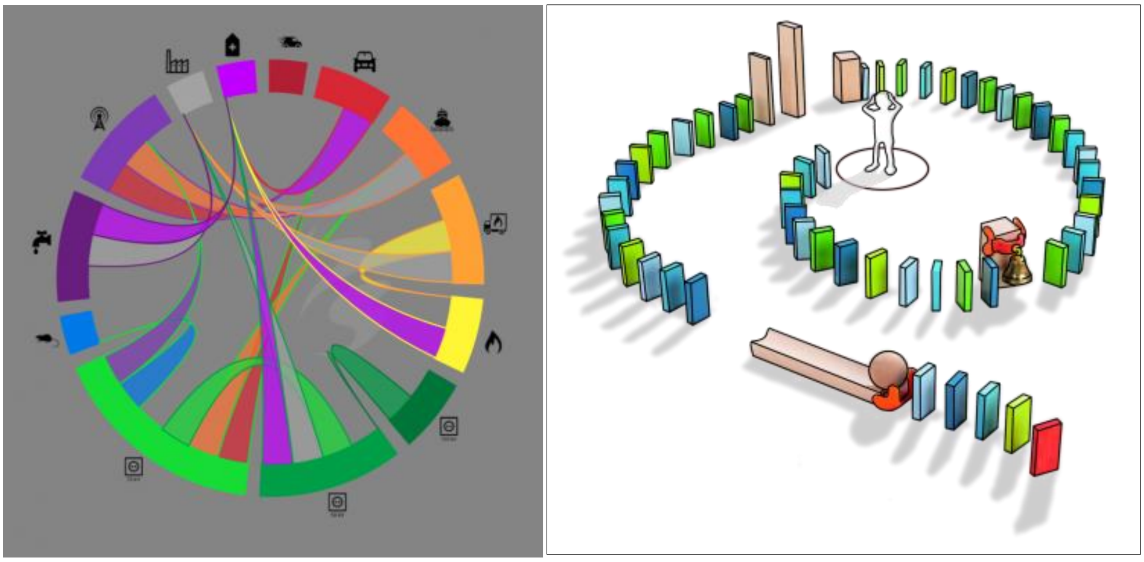

Figure 27 – Impact and cascading effects

The flood scenario for Rotterdam was used to calculate direct damages to critical infrastructure networks caused by the flood as this damage can expand to other dependent networks.

Stakeholder workshops were conducted to assess direct and indirect impacts including the cascading effects. The matters discussed includes and is not limited to the relationship between electricity and emergency communications (can last from 4 to 8 hours), the railway transport and how to communicate with the operators, hospitals, etc. Analysis can be found here[38] which simulates the cascading effects for Rotterdam in a short movie with respect to the time frame.

Another example of the cascading effect can be found in Cork, Ireland. The video is available here[39].

Figure 28 – An excerpt from the video simulating the impact on city critical infrastructures – City of Cork, Ireland

Other tools are developed to control the city and prevent it from flooding, such tools application examples can be found here[40].

38 https://www.youtube.com/watch?v=7N3SXMXAszw&feature=youtu.be

39 https://www.youtube.com/watch?v=9tISZo8cmMY

40 https://www.youtube.com/watch?v=GAuQ5ft8vr4

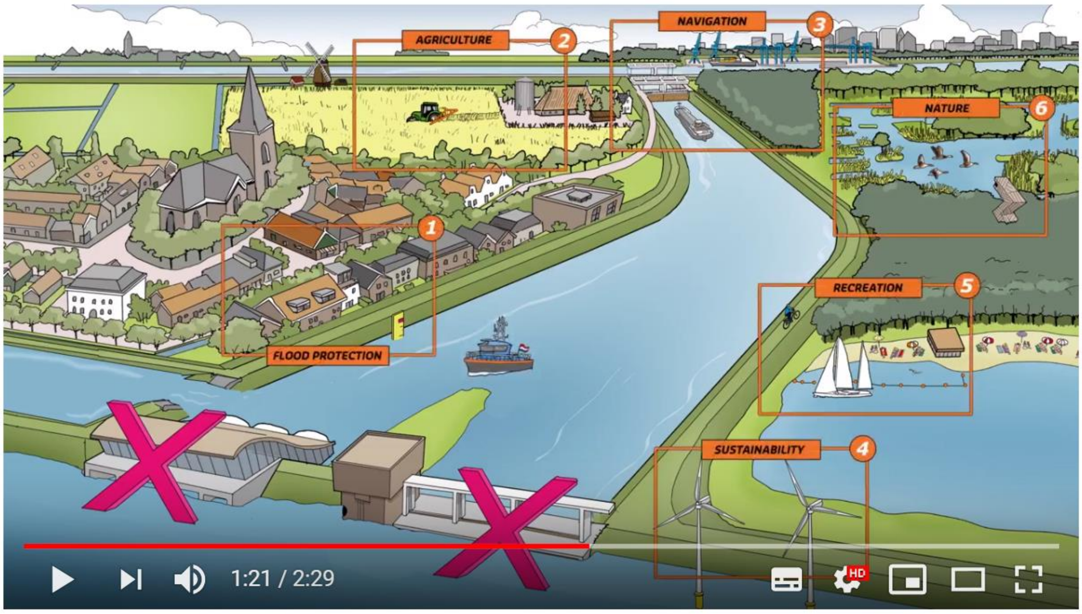

Figure 29 – An excerpt from the video simulating city impact – Deltares animation RTC tools for smart water management

Results

Rotterdam flood scenario has been calculated with the hydrodynamic 3Di model. The tool can be considered as a new versatile water management instrument that supports operational water management, calamity management and spatial planning design.

The potential benefits of such a predictive tool for cities and communities are multi-fold. Simulations allow increasing the preparedness and the resilience of cities for various unexpected yet disastrous events. Precautions and safeguards that can be taken as a result of understanding the potential impact of such events could save human lives. They can also help in preparing communities and informing the community in advance, what to do in such circumstances. Additionally, rescue efforts can be better organized and more efficient. Requisite resources such as equipment, personnel, etc. can also be better distributed and utilized by predicting their needed quantities and locations. The project now has an analogue version of circle, called CLrcle-Bao. This was made for use in areas where there is no available digital information. This method focusses on bringing together stakeholders and identifies what are the possible impacts of flooding. A description of the workshop format can be found here[41] and a video can be found here[42] for cascading effects on critical infrastructure in the United Republic of (Tanzania).

Further planned development is to look at how these tools can be integrated in the 'digital twins' of cities. These are virtual reality copies of cities that are used for urban planning.

It is useful to know that the circle method is not limited to use for assessing the effects of flood events. It can also be used for other natural hazards or man-made events that lead to the failure of the critical infrastructure.

Conclusions

Citizens are more and more dependent on technologies and information systems that are run by the cities. This socio-technical system interdependency has had significant impacts on the way in which cities response to disaster situations. However, in the case of technological failure (such as that caused by flooding), it is important to understand the cascading effects on the critical infrastructures of a

41 https://www.deltares.nl/app/uploads/2015/04/Particpatory-CIrcle-Bao-Workshop_Guideline_Final.pdf

42 https://www.youtube.com/watch?v=uNccvrk3MuA

city. Therefore, conducting studies and developing methodologies to better understand risk propagation and the cascading effects of natural disasters are fundamental building blocks in improving disaster responses and creating a more resilient urban infrastructure.

The key factors to be considered here include the probability of failure of a given critical infrastructure and the time required for repairing a damaged critical infrastructure before it spreads to another critical infrastructure, through the cascading effect. There are methods, tools and models being developed to achieve simulation of flooding effect using the information provided by the stakeholders. Workshops are arranged to allow the stakeholders to share their knowledge and devise a coordinated plan when disaster strikes.

It is expected that new tools and models that incorporate other frontier technologies will be further developed over time. This may include virtual reality, IoT devices to collect information, automation, etc. to facilitate automated control on such incidents.

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6.8 Case study 8 – Unlocking the potential of trust-based AI for city science and smarter cities

Introduction

Background

With the rising economy and social opportunities that urban areas have to offer, people have been moving from the countryside to cities, resulting in the largest wave of urbanization throughout the world in our history. By 2030, the urban population is estimated to reach 5 billion (about 60 per cent of the world population), which produces massive opportunities for the economic and social development of cities [6]. Due to the ever-growing demands of local residents, the development of fundamental infrastructures and policies are lacking behind. Moreover, this unplanned and overly fast urban growth is amplifying some of the greatest urban challenges that cities are already facing, including climate change, growing energy demands and consumption, environment degradation, and human health.

To mitigate the challenges of rapid urbanization, it is imperative to improve governance and service delivery, offer swift and seamless mobility, facilitate easy assessable urban public facilities, access to affordable housing, quality healthcare, education, etc. [2]. A special spotlight is needed, covering urbanization trends in innovative management of urban operations, and delivering a variety of "smart" services to local residents, visitors, and the government to satisfy the ever increasing and diverse demands [3].

As an emerging paradigm, the smart city leverages a variety of promising technologies such as the Internet of Things (IoT), cyber-physical systems, big data analysis, and real-time control, to enable intelligent services and provide a comfortable life for local residents [7]. It integrates ubiquitous sensing components, heterogeneous network infrastructures and powerful computing systems to sense the physical changes from cities and the feedback to the physical world. Specifically, RFID devices, sensors, and versatile wearable devices are promoted to offer real-time monitoring and ubiquitous sensing, from energy to environments, from road traffic to healthcare, from home area to public venues, and so on. This sensing information is then transmitted to a control centre via heterogeneous networks. This control centre takes a comparative advantage of the powerful computing systems such as the cloud servers to process and analyse the collected data.

Fuelled by human intelligence, the control centre makes optimal decisions and manipulates the urban operations via feedback components, such as actuators [3]. Having the advanced information, communication, and control technologies as the backbone, a smart city can offer various applications including intelligent transportation, smart energy, intelligent healthcare and smart homes. Not only can this up-and-coming connected city quickly identify the demands of the people and a city, it can also manipulate urban operations to improve urban living quality in an intelligent and sustainable way. It is expected that the global smart city market will exceed US $1200 billion by 2020, which is almost triple than the numbers in 2014 [6].

When cities become smarter, people may suffer from a series of security and privacy threats due to the vulnerabilities of smart city applications [5]. For example, malicious attackers may generate false data to manipulate sensing results such that services, decisions, and control in a smart city are influenced and not "intelligent" enough. Moreover, these malicious attackers could also launch denial-of-service attacks, disrupting the sensing, transmission, and control to degrade the quality of the intelligent services in a smart city. In addition, the pervasive video surveillance in a smart city captures a tremendous number of images and video clips which may be utilized to infer local residents' trajectories and inherently endanger their privacy.

The home area information collected and managed by smart home applications may pave the way to disclosing residences' highly private sensitive lifestyle and can even cause economic loss. Although some off-the-shelf techniques (encryption, authentication, anonymity, etc.) and policies might be directly applied to avert these problems [5], the emerging "smart" attackers could still infer and violate privacy in many other ways, such as side channel attack and cold boot attack [4]. Without sufficient security and privacy protections users may refrain from accepting the smart city which would remain as a far-off futuristic idea.

Figure 30 – Smart city applications [8]

Challenge and response

Smart cities provide services that benefit from the city-scale deployment of sensors, actuators, and smart objects. Such services are mainly driven by data and can be broadly classified as producers of data, consumers of data, or a combination of both. For example, a parking service that deploys a message queue telemetry transport (MQTT) broker to publish parking lots' availability data is considered a producer, while cars which subscribe to that broker are considered as consumers. Cars can produce other data for use by other smart city components. For example, cars use device-to-device (D2D) communications to alert nearby vehicles and pedestrians of their presence and potential traffic hazards. In a city scale deployment of smart services, data is generated at high rates which presents new challenges for smart city designers and developers.

Unfortunately, most of the generated data is wasted without extracting potential useful information and knowledge because of the lack of established mechanisms and standards that benefit from the availability of such data. The main culprit is the lack of a large amount of labelled data. Moreover, the highly dynamic nature of smart cities calls for a new generation of approaches that are flexible and adaptable to cope with the dynamicity of data to perform analytics and learn from real-time data. Development of smart city applications supported by big data analytics is subject to several challenges that need to be addressed to achieve a reliable and accurate system. Some of the major challenges include the following.

Integrating big and fast streaming data analytics

In a smart city context, there are many time-sensitive applications (e.g., smart and connected vehicles) that need real-time or near-real-time analytics of the stream of data. Such applications call for new analytic frameworks that support big data analytics in conjunction with fast streaming data analytics.

Preserving trust, security and privacy

Data-driven approaches (e.g., deep learning) can be attacked by false data injection (FDI), which compromises the validity and trustworthiness of the system. Resilience against such attacks is a must for such inference algorithms. In general, entities must be capable of building up an opinion about every other device / service they interact with, and eventually more authoritative and reliable communication can be built up with the same pair of hosts. Privacy preservation is another important factor since a large part of smart city data comes from individuals who may not prefer their data to be publicly available. Data modelling algorithms should address these concerns to enable the wide acceptance of smart city systems by organizations and citizens.

On-device intelligence

Smart city applications also call for lightweight AI algorithms deployable on resource constrained devices for hard real-time intelligence. This is also in line with the trust, security and privacy preservation requirement since data is not transferred to the fog or cloud.

Big dataset shortage

Development and evaluation of smart city applications need real-world datasets, which are not readily available for many application domains. It is necessary to confirm results based on the simulated big data.

Context awareness

Integrating contextual information with raw data is crucial to get more value from the data and to perform faster and get a more accurate reasoning and actuation. For example, detecting a sleepy face in a human pose detection system could lead to totally different actions in the contexts of driving a car and relaxing at home.

In addition, there are other challenges that affect the design of a smart city ecosystem such as integration of different analytic frameworks, distribution of analytic operations and lack of comprehensive testbeds.

The ever-growing volume of data and devices in a smart city poses open problems for intelligent services, trust and privacy. Inside-attackers exploit human intelligence and have access to big data such that the privacy of data owners may be inferred and violated, even if the traditional cryptographic schemes have been applied to big data.

An alternative to detect these inside attackers is to enhance the traceability and allow a trusted third party to monitor and audit these attackers. Meanwhile, collaborative efforts among municipalities, regulation departments, industries, academia, and business companies are necessary to set up privacy policies and regulations.

In addition, to improving data privacy, availability, and management of the city network, a distributed computing architecture which delegates AI based processing of data towards the edge of the network must be considered. Further a smart city is vulnerable to false data injection in both sensing and control phases. Digital signature techniques cannot prevent the data from being tampered from its origination. An insight into detecting false data injection is to leverage machine learning and data mining along with trust-based concepts to come up with a boundary of reasonable sensing data.

The proposed approach intends to instil a trusted environment for various city science applications in the smart city context. It proposes a distributed computing architecture which is conducive to enhancing trust while enabling innovation for city science applications.

Important note: This case study is an example of a research & development (R&D) project related to city science, rather than an actual city example. City science is a relatively novel field and will require substantial R&D for developing future urban solutions. The proposed approach is an actual research project currently being conducted by the author.

Trust-based AI data management solution

Vision and content

The proliferation of computing, networked systems and end-node processing power have made Internet a highly dynamic system. Maintaining trust across a large-scale heterogenous distributed system is a formidable task. It requires the preservation of data processing security policies in a distributed system which can be substantially challenging. Existing security mechanisms (e.g., authentication, authorization) are not sufficiently scalable for today's large-scale networks. Hence, the trust-based approach to distributed systems is developed to address the inadequacy of traditional mechanisms.

In a smart city, user-related information works like an oil to fuel the state-of-the-art applications and services. Consumers, who use these services, provide personal information to service providers, intentionally or unintentionally and often without considering their trustworthiness. However, this personal information often reveals one's identity and may lead users to face unexpected outcomes, ranging from uninvited advertisements to identity theft. To regulate such issues, this approach investigates the state-of-the-art data governance techniques that are built on trust, blockchain and the distributed AI concepts.

As the aim of a smart city is to make decisions about its data in a more trustworthy manner and meeting the essential key performance indicators (KPIs), the proposed trust-based data management solutions have enormous potential to securely process and handle data of any service providers or customer.

Further combination of blockchain and IoT will facilitate the sharing of AI services and resources leading to the creation of a marketplace of services between devices.

For cross-border applications, it can serve as an intermediate broker to handle the negotiations for particular interactions without any ambiguity or human intervention which outsmart current techniques based on the third party regularity bodies.

With great interest in artificial intelligence around the world today, the approach has the potential to open a new chapter in human-machine interaction by giving interoperability to existing AI technology and combining it with the trust-based data governance concepts.

The proposed trust-based AI cross-domain microservices across ROOF, Fog and the cloud continuum will not only support the development of real-time applications that address latency and bandwidth related problems of the current systems but also privacy leakages and security attacks. It will also support plug and play AI reusable and dynamically composable components that are deployed as microservices for the development of value-added cross-border use case applications.

Implementation

Figure 31 illustrates a conceptual system model for data collection, processing and sharing in smart cities from various data sources, including personal data. In a smart city big data architecture, collected data are processed and stored in a structured format that can be queried using analytical tools in an analytical data-store for supporting querying from smart city agencies. Also, data is shared with third-party service providers through an open data-store after conducting publishing control mechanisms.

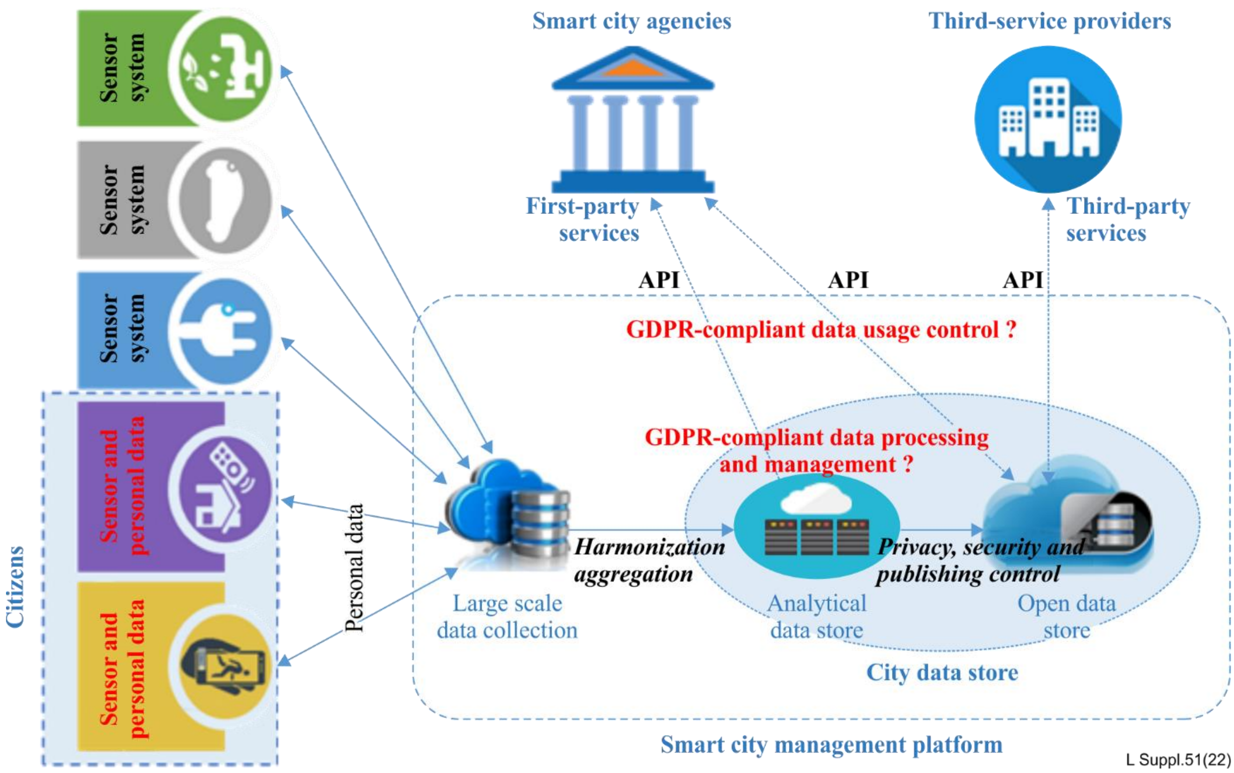

Figure 31 – Data management and sharing in smart cities

According to the General Data Protection Regulation (GDPR) [1] legislation in smart city contexts, citizens (i.e., data subjects) authorize smart city operators (i.e., data controllers) to control their personal data. Data controllers determine the purposes for which, and the method in which, personal data is processed by data processors (i.e., smart city agencies and third-party service providers) – who will be responsible for processing the data on behalf of the controllers. Therefore, data controllers are subject to comply with requirements and obligations imposed by the GDPR when determining personal data usage policies for data processors.

GDPR also specifies the rights of data subjects including the right of access and right of granting citizens the rights to monitor their personal data and information about how the personal data is being processed; and the right to control the related personal information. Therefore, a smart city management platform which takes on the role of a data controller should take appropriate measures not only to provide citizens information related to how their personal data is being processed and managed but also the ability to control their data usage ensuring security and privacy.

Moreover, in the absence of proper safety mechanisms, data can be compromised at various points or even via the interfaces of different smart city devices. Nevertheless, objects in large-scale networks in a smart city possibly lack the knowledge to evaluate services' reliably, since both untrustworthy and trustworthy objects can interact with each other in the absence of a trusted intermediary that governs each transaction.

To fill this gap, the suggested approach proposes an intermediary authority named the trust manager to evaluate each interaction in a trustworthy manner as shown in Figure 32.

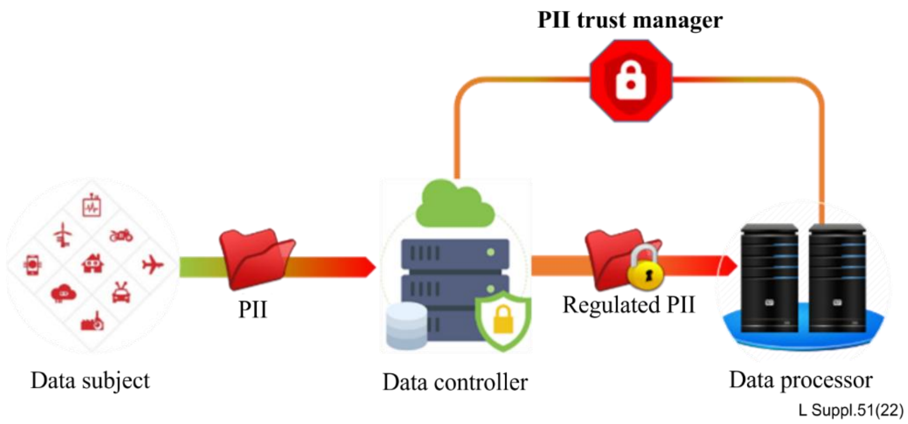

Figure 32 – High level architecture of the trust based data governance

In a large heterogeneous distributed system (e.g., smart city), there is a large number of requests to access and process data. In Figure 32, data subject refers to any individual that can be identified, directly or indirectly, through an identifier and whose personal data is being collected (referred to as PII – personally identifiable information). The data controller determines the purposes for which and the means by which personal data is processed. On the other hand, the data processor processes the personal data on behalf of the controller.

The interactions related to several distributed data subjects, data controllers and data processors in a smart city context can be handled by a trust manager from a security perspective. Different systems in a smart city may have different local policies for security. In general, there is a staggering number of resources and services to be accessed in a smart city. Trust manager receives these access requests together with a set of credentials and determines if the provided credentials for access request comply with the local security policy to access the intended resource or service (in this case it can be data that entails personally identifiable information). Hence, it uses a general-purpose application-independent algorithm and supports features like delegation, policy specification and refinement at different layers of a policy hierarchy. This way, the trust manager solves the consistency and scalability problems present in traditional mechanisms.

Recent technological innovations of smart edge devices and services which rely heavily on real-time data processing and localized intelligent decision-making, have created a vacuum for a novel approach that extends the traditional means of research in cloud computing towards edge computing. The idea of edge computing refers to fluid data management and decision-making towards physical things, working as a middle layer between cloud and the users.

Major advantages include but not are limited to (a) minimizing response delay by addressing the bottom level request at the network edge instead of servicing it at far located cloud data centres, (b) minimize downward and upward traffic volumes in the network core and (c) maximizing the support for cross-border applications due to effective resource and security management at the cloud. Complying with edge computing requirements, the proposed approach further breaks down the so-called middle layer by introducing two layers, ROOF computing and Fog computing which is placed just below the cloud as shown in Figure 33 in order to make the system architecture more feasible and deployable in real-time environment, with an ambitious vision for seamless fluid control and decision-making through harmonize resource management among different layers.

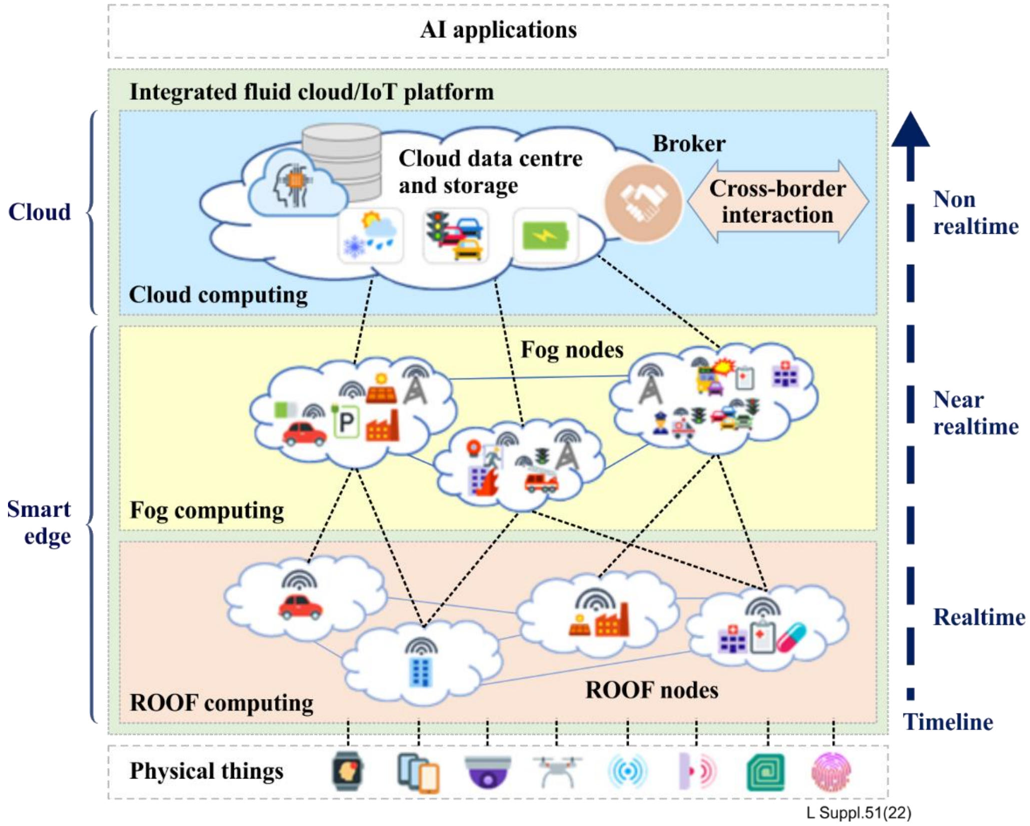

Figure 33 – Vision towards an integrated fluid cloud / IoT platform

Fog computing layer is implemented with the idea of achieving the second objective of the edge computing scenario which is improving the application performance and resource efficiency by removing the need for processing all the information in the cloud, thus also reducing the bandwidth consumption in the network. A Fog node can be defined in several ways. It can be regarded as an entry point into the enterprise or the service provider core networks. Examples include routers, switches, integrated access devices (IADs), multiplexers and a variety of metropolitan area network (MAN), and wide area network (WAN) access devices.

Unlike the Fog and the cloud, the primary goal of the ROOF computing layer is to provide real-time computing needs for building the contexts and required actions together with efficient and flexible connectivity to the Fog and Cloud providers. As the ROOF will be the first contact points for heterogeneous physical things, it must be equipped with technologies that can handle interoperability, mobility and important smart decision-making abilities to fulfil the goals of the three-layer architecture presented here.

The distributed AI based architecture will not only improve the fluidness of the traffic flow and the promptness of the decision-making but will also save ample number of resources at the cloud layer, which can then be used by future applications like cross-border interactions. This will open a new paradigm for new business models, like inter-regional collaboration for law and order, international travelling and global research activities. However, ensuring business uptake and regulatory compliance in such an environment is critical and manual intervention is almost impossible without an autonomous and more secure intermediate agent called, the trust manager. The trust manager essentially ensures trust across different domains. It allows free flow of data or services while maintaining trust as it passes across different domains (each domain might have different governance, regulations, administration, etc.). In this context, the main responsibilities of the trust manager will be to regulate the federated AI platform and ensure reliable and trustworthy data aggregation and decision-making.

Results

Approximately 70% of the world's population will live in urban areas by 2050 according to a recent United Nations report. This will exacerbate the existing pressures on resources and infrastructures in cities and communities. If appropriate steps are not taken this will significantly and adversely affect the quality of life of all citizens.

From a technical perspective, the trust paradigm, coupled with the power of AI to unlock insights from big data, offers significant opportunities to make our cities and communities "smarter", "more responsive", and "trustworthy". Potential benefits include efficient transportation, optimization of the use of natural resources and enhanced safety for citizens.

On the other hand, association of trust and AI microservices will foster and enhance the capability of SMEs and other small-scale technology companies to exploit proposed federated cloud-edge platforms to deliver cutting edge AI-based applications in a more trustworthy manner.

SMEs can take advantage of the new technologies provided to break the current barrier regarding transmitting of huge volume of IoT data to the cloud for analytics to provide real-time intelligence at the edge. SMEs providing smart living services, smart city applications, smart cars, smart transportation such as emergency support, crowd congestion control, etc. will benefit from the provided technologies.

Conclusions

The processing and analysing big data by leveraging cloud computing technologies are becoming an important resource that can lead to new knowledge, drive value creation, and foster new products, processes, and markets.

However, large-scale collection and analysis of data can pose difficult privacy, security and trust issues ranging from the risks of unanticipated uses of consumer data to the potential discrimination enabled by data analytics and the insights offered into the movements, interests, and activities of an individual. Therefore, it is important to process and handle data in compliance with user needs and rights in various application domains without human intervention.

To cope with the development of many complex and intelligent applications and services such as in smart cities, it is a must to create a trusted environment for ICT infrastructures in order to share information and create knowledge. Consequently, there is a critical need to develop a trusted infrastructure as one of the most important parts in the future ICT environment.

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