

# SMART PANDEMIC MANAGEMENT THROUGH A SMART, RESILIENT AND FLEXIBLE DECISION-MAKING SYSTEM

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## ABSTRACT:

Over the last few years, the world has seen many social, industrial, and technological revolutions. The latter has enabled a combination of expertise from different fields in order to manage a wide range of multidimensional issues such as integrated societies and industrial ecosystems achievement, urban planning, transport management, sustainable development and environmental protection and currently pandemics management. Super smart society's vision that is driving the 5.0 social revolutions is at the heart of the current situation that requires system resilience, sustainability, proactivity, interoperability and collaborative intelligence between society, economy, and industry. Establishing communication bridges between different entities, of different natures and with different objectives implies solutions that reinforce the development of efficient, dynamic, and communicating business models on a large scale, merging cyber and physical spaces. Through this paper we explored the potential of digital twins for the development of a new vision of world global dynamics under the aegis of a virus whose parameters are still elusive to date.

## 1. INTRODUCTION

Covid-19 also known as severe acute respiratory syndrome associated coronavirus SARS 2 first appeared in China on December 2019 in the province of Wuhan. Covid-19 is a zoonotic pathology belonging to coronavirus family that is potentially highly contagious and attacks the respiratory system at variable levels among affected individuals, causing acute respiratory complications that can lead to more deadly viruses such as SARS and Middle East respiratory syndrome MERS. As of today, the virus has reached all world continents, leading to its declaration by the World Health Organization as a pandemic (CDC 2020).

A wide range of strategies, prevention, response, and protection measures have been undertaken to date. Through their means, resources and intellectual and technological capital, each country has tried to draw up a plan to deal with the pandemic and to reduce its impacts, particularly its emerging economic and social impacts (De Vito and Gómez 2020). Some countries with their strategies have succeeded in controlling the spread of the virus, while others, due to a lack of early preventive measures, have seen the number of victims of the virus rise drastically in recent months (Grasselli, Pesenti, and Cecconi 2020). In the absence of a vaccine against Covid-19, pandemic management remains paramount.

Outbreaks management falls into epidemiological science field that is concerned with investigating the occurrence, causality, effects, and evolution of infectious diseases among populations (Dasaklis, Pappis, and Rachaniotis 2012). Over the history of humankind, there has been a constant convergence in the field

of epidemiology due to the persistent changes in the variables governing the evolution of populations and the frequency and patterns of pathogens that are further influenced by environmental changes (Madhav et al. 2017). The management of pandemics and the current pandemic has raised many issues.

The first issue concerns pandemic risks versatility that is caused by the uncontrollable influences and uncertainties resulting from pandemic evolution throughout populations. This versatility makes the problem of pandemic management more complex and subject to several hazards that notably affect the efficiency of contingency plan management approaches in the event of a pandemic. Given the universal nature of pandemics, international cooperation is highly required which comes to be extremely difficult in the context of the current globalized world and under the various political tensions that arise from it. Globalization, while bringing all regions of the world much closer, has turned out to be an accelerator of pandemic spread and appears to be a major impediment to the development of territorial intelligence.

The second problem is the multidimensionality of the virus, which involves several technical, non-technical and qualitative factors whose evolution over time and space is non-linear and subject to several contextual constraints linked in particular to populations' development characteristics and their reluctance to change, especially those involving changes in habits and behaviour acquired through the socio-cultural environment.

The third issue that it represents a real challenge for science and medicine today is the virus novelty. Many features of the virus are so far unknown, and with the pressure exerted by the spread of the virus and the risks of uncontrollable mutation, scientists are faced with a real dilemma that forces them to use advanced technological means of simulation and modelling that would

make it possible to accelerate the process of vaccine development but also its commercialization, a point that presents a major challenge in the context of pandemic management.

Under the current context, the emerging challenges are prompting scientific and industrial communities, as well as administrations and governmental institutions to reconsider their approaches for emergency management and response. The effort launched by these communities has led to applications of digitalization across all affected sectors and the proposition of innovative strategies for tackling pandemic preparedness and response challenges.

These initiatives have known across their applications a lot of challenges and constraints related to communication, interoperability, and data governance management. Bringing into connection a variety of differently structured systems with heterogeneous concepts, knowledge and data presents a real challenge for its new solutions, especially when it comes to domains that require impotent consideration of security concerns and confidentiality constraints.

The aim of this work is to unveil the potential of smart cities and digital transformation visions and their interactions through multidimensional modelling and smart decision-making for the mitigation of Covid-19 risks and the development of a proactive, flexible and resilient post-pandemic management plan that can deal with the various issues that could hamper countries fight against the virus. The main contributions of the paper are the merging between the concept of digital twins with their dynamic and multi-dimensional modelling capabilities and that of smart cities through the exploitation of feedback from a number of applications that have proven the effectiveness of this vision in the management of Covid-19 impacts and the tailoring of this integration to the requirements of the new global dynamic for the implementation of a resilient system that can meet the needs of different stakeholders in a secure and efficient way.

In the first section of the paper we introduce the role of modelling and predictive analytics for pandemic management while highlighting the different challenges that these two components face for their large-scale deployment through digital technologies. In the second section we introduce smart cities and its surrogates' visions as a promising alternative for intelligent decision-making, we emphasize this significance through real case studies deployed under Covid-19 context and their observed limitations. In the third section, we discuss a set of application cases that constitute the proof of concept of smart pandemic management system we are proposing to build. The last section consolidates all the issues dealt within the paper and paves the way for further opportunities and perspectives.

## 2. SMART PANDEMIC MANAGEMENT OPPORTUNITIES AND CHALLENGES

### 2.1 Modelling and data driven analysis for pandemic management

Epidemiological science has many factors that help to assess the impact of the pandemic, its evolution and spread trends. One of these factors is  $R_0$  referred to as the basic reproductive number, which is an estimate of the average number of people who acquire the virus from a single infected person (Zhang et al.

2020), and which varies from one country to another, and within countries and regions, depending on multiple controllable and objective, but mostly random and multidimensional factors.

Many statistical and stochastic studies and research are currently trying to propose models for the estimation of Covid-19 epidemiological parameters inter alia  $R_0$ . However, the results obtained, and their analysis shows some limitations related to these methods (Delamater et al. 2019).

Therefore, as alternative, scientific research communities to improve the reliability of those estimations proposed a set of indicators that according to their investigations influence this important parameter in the world of infectious and highly transmissible diseases. By trying to identify the fluctuations of these parameters, countries could first monitor the evolution of the pandemic within their respective territories and frame the strategic field of barrier and prevention measures to be taken (Tuite et al. 2020).

In this section, we essentially cite the following three indicators on which we will focus our analysis of the measures put in place to stop the spread of the virus and to respond to it in the event of a spike.

These three factors are firstly the susceptibility of the virus, then the contact rate or the estimation of the probable exchanges between infected person and person suspected of having contracted the virus and finally the last indicator which also interests us the probability of contaminating new person which is strongly linked to the viral charge of the holder.

Currently, literature, organizational and technological levels are trying to propose all possible measures to control its indicators and their different related parameters through advanced simulation tools.

The aspect that interests us the most is related to the attempt to model the evolution of these three indicators its factors, their impact on the evolution of the pandemic and their correlation with other parameters at different social, cultural, economic and regulatory levels that contribute positively or negatively to it.

Multidimensional modelling and advanced simulations enable to mimic complex systems dynamic behaviour and evolution by ingesting real life systems data and information's and as result giving life to complex physical and mathematical models that represents faithfully through ergonomic and dynamic visualization interfaces the real system and its evolution within its real environment. Thus, modelling and data analysis are common concerns for advanced simulation and pandemic management.

### 2.2 Modeling and predictive analysis

The modelling of these three indicators in Covid-19 context and more specifically the predictions taken on their evolution could serve government and society's different institutions to respond proactively to the different changes and hazards related to the virus development life cycle ("The SIR Model for Spread of Disease - Introduction | Mathematical Association of America" n.d.,2020). Predictive analysis involves three categories of predictors that are mathematical predictors of infectious diseases, probabilistic predictors and finally historical and data analysis-dependent predictors. Predictors allow early detection of changes in virus infection parameters by taking advantage of gathered knowledge, data and information acquired to date on

the virus. These three models are currently being used world widely to prevent the spread of the virus and to respond proactively to pandemic spikes, they also enable the selection of appropriate and efficient barrier measures.

Scientific communities currently to manage Covid-19 evolution relies heavily on three types of prediction tools and models that are conceptual models, descriptive models, and interactive maps, and finally surveys and large-scale communities' behavioural analysis.

Conceptual models are used for the identification of interrelationships between government barrier measures, such as containment and stringency measures and the evolution of positive cases and contagion unit (Lin et al. 2020). Descriptive and geospatial mapping models across different levels, including socio-economic level, are used for the estimation of Covid-19 socio-economic impacts and the proposition of immediate response plans ("Tracking Vulnerable Population by Region" n.d.,2020). And finally, are considered surveys that track citizens' attitudes and responses for feedback and management of worldwide knowledge about the virus ("Oxford University Launches World's First Covid-19 Government Response Tracker | University of Oxford" n.d.,2020).

The results of its models are communicated to governments to strengthen effective and adaptive barrier measures according to territorial disparities and to cross-reference them to regions with similar public response characteristics and maintain them for a long period of time.

The main challenge facing the deployment and efficiency of these models in the context of the current pandemic has been the consideration of a broad range of dimensions, incorporating a set of unpredictable and uncertain constraints that relate to social and cultural aspects. Among these aspects are, first and foremost, ensuring that barrier measures are respected individually, and that security and prevention measures are adhered to collectively. The second aspect concerns both individuals' and groups' mobility trends and their effective monitoring without affecting individual freedom. These two aspects, which have been the subject of several studies among different research communities, are of great importance for ascertaining uncertain parameters of virus spread and for the prediction of contagion foci impeding the effectiveness of preventive measures and government response strategies.

Key technological initiatives based on digitalization tools have been deployed in order to encounter those challenges, including smart wearables via the Internet of Things, large scale data analysis solutions based on sampling within affected communities, and last but not least digital assistance through Chabot's and e-healthcare applications.

Such initiatives, in turn, face a few constraints for their widespread deployment, particularly in countries that are not sufficiently technologically mature.

### **2.3 Challenges and potential opportunities for predictive analysis**

The first challenge remains on the accuracy and reliability of the developed models for pandemic indicators estimation because the quality of outputs and estimates provided by their use are closely linked to the characteristics of the data that feeds it inter alia data quality, integrity, availability and confidentiality.

Real time data communication, analysis and sharing among various heterogeneous sources can be enabled by IOT technologies that can allow merging effectively different significant information and data from different sources and locations from both physical and virtual spaces (De Arriba-Pérez, Caeiro-Rodríguez, and Santos-Gago 2016).

The main challenge that impedes the deployment of IOT advanced technologies in the current context for smart pandemic management and strategic decision-making, particularly for countries whose legacy communication and information infrastructure is not sufficiently mature, lies in the development of Internet of Things second layer, which is defined as sensing and controlling domain. This layer is constituted through IoT devices that are basically sensors and actuators connected to physical devices and IoT gateways. This layer's main function is to capture field collected data related to physical systems operations and to prepare and pre-process them through IOT gateways for their transmission to processing and analysis layers. The territorial development of this layer primarily involves assessing its maturity in a broader geographical and sectorial context.

Evaluating this layer's maturity within countries mainly concerns three ecosystems. In first place come companies and industrial units that can be considered as significant pandemic foci, in second place public institutions, administrations and public places that are followed finally in the long term by universities and schools. This assessment requires considerable research efforts aimed at identifying all necessary requirements for secure, ethical, and effective use of artificial intelligence tools and IOT technologies.

### **2.4 Challenges and potential opportunities for big data and large-scale data analysis**

Several research communities are currently exploiting big data analysis to deploy interactive map solutions ("GeomatiCovid.com" n.d.,2020), in order to provide multidimensional observations and to identify correlations that reduce uncertainties related to the susceptibility of the virus (Torres and Sacoto 2020).

Real time collected and analysed data from heterogeneous sources represent a reliable portal for artificial intelligence communities that use it for the development of reactive solutions providing early detection and prevention systems of the virus.

Big data technologies implementations in healthcare raise issues related to distributed storage and remote information sharing among various stakeholders through cloud platforms.

Huawei in the context of the pandemic has created a platform based on AI and cloud tools that offer several services including E-learning and E-Healthcare services that combine Internet of Things, big data and cloud computing ("Fighting COVID-19 with Technology\_HUAWEI CLOUD" n.d.,2020).

The advanced open source Application Programming Interface APIs made available by cloud platforms can also be used for early detection of the virus and notification of suspected persons and sharing of relevant data sets around the world. Currently, a huge number of radiology images datasets are made available open source to research community world widely. The purpose of these data is to contribute to the development of deep learning algorithms that allow the detection of similarities with

results from infected cases (LLORET 2020). This type of solution makes it possible to reduce the risks caused by asymptomatic cases. Artificial intelligence combined with relevant input data offer a large range of possibilities, some of which are currently deployed in Asia and Europe for real-time monitoring of patients vital signs in hospitals (Peng et al. 2020) but also for self-quarantine patients (Nundy and Patel 2020) with the use of remote health monitoring and assistance services (Webster 2020).

The challenges that arise from this type of solution in addition to the recurring data governance issues are these time infrastructure issues. As far as infrastructure is concerned, it is mandatory for developing countries to provide solutions that help to improve network coverage of all urban and rural areas and their connectivity (Austin et al. 2020). Citizen engagement is also a decisive factor. Surveys are being carried out to identify disengagement gaps and their causes to address this aspect to take part of the studies established in the framework of data and knowledge management related to the pandemic. Knowledge extraction and capitalization aspects are also important as it could be weaned from the detection of the root causes of evolutionary spikes and the establishment of new barrier measures, cause trees and behavioural mapping are two disciplines presenting significant opportunities and solutions to address these different issues.

### 3. SMART CITIES SUROGATES TOWARDS SMART PANDEMIC MANAGEMENT

#### 3.1 Multidimensional modelling and predictive analysis of Covid 19 through advanced simulation

Digital surrogate as reliable copies of living and non-living physical systems allowing real-time data analysis, multidimensional simulations and dynamic modelling of behaviours, interactions and evolutions of complex systems are among the most promising technologies to achieve the objectives set by smart cities vision (Kaur, Mishra, and Maheshwari 2020). Independently each of the two visions throughout the history of digital twins gave birth to multiple applications and has known the development of several technologies throughout the world and at the level of multiple social and industrial networks. Advanced simulation and smart cities vision have a key role to play within digital ecosystems development (Hajar and Abdelghani 2017).

Currently, several applications have been developed combining advanced simulation and smart cities throughout the world. The first initiative date back several years ago and has its origin in Germany in the context of a project led by a group of researchers for the development of a German city twin that would be used for several purposes and allow the potential of the solution to be exploited on a large scale (Martinez-Velazquez, Gamez, and Saddik 2019). Several smart cities twins have been developed around the world.

Digital surrogate concept in recent years is undergoing an important evolution, due to the development of real-time communication and computational capacities through the exploitation of cloud technologies and Internet of Things in multiple domains. This evolution has allowed to extend their field of application to several domains more particularly for the urban modelling and cities management, smart healthcare, smart buildings and geospatial intelligence domains that enable

multidimensional analysis to be performed in a real time manner virtually, effectively and safely (Dembski et al. 2020).

Different architectures were proposed through the literature for digital twins' development under the context of smart cities. Those architectures tried to take smart cities context constraints and requirements to establish effective, secure, and flexible solutions. Figure 1 represents the functional view of smart city twin architecture.

The first layer of the architecture is perception layer. This layer acts as an interrogation mechanism for the real systems that constitute the smart city. Its main missions are sense, act and operate. The real system interacts with its environment through sensors and actuators. Sensors record fluctuations in system parameters, states and events that characterize their interactions with their environment. Actuators allow the systems to act on the real environment and to perform the various functions for which the system was designed in a scheduled and programmed sequence. The concept conveyed by smart cities vision is to create connected networks, through which components could exchange a wide range of data in a flexible, reliable, and proactive way. Through the Internet of Things and Edge Computing within smart cities framework today, these two drivers can come to life and interact intelligently with their environment through communication interfaces and embedded intelligence mechanisms. These drivers produce a significant amount of data of different types and nature, structured, unstructured, and semi-structured data. Depending on their type, these data require special processing that varies according to their consumers and producers but also according to the smart city real time simulator modules that are responsible for data and information short- and long-term processing. These data can be quality data, production data, operational data or Master Data linked to systems Meta structure and views.

Outputs from this layer are transferred to the second layer of the architecture through communication protocols and schemes. Protocol selection depends on data criticality and various concerns related to system behaviour, services provided and data sources structures. According to these parameters we can distinguish two types of medium components Field Gateway and middleware platforms and intermediate storage units.

The second layer of the architecture is composed of two blocks of the first block has as its main mission explaining the acquired data and their interpretation, while the second block is responsible for ensuring system prognostication and learning features. On this level, the system receives collected data from the different perception agents. The first block is dedicated to data contextualization, pre-processing according to clearly defined logics by the system architects and its stakeholders, and finally data storage using intermediate storage mechanisms that connect the system to the second block. Three levels characterize the first block in charge of data interpretation. The first level is inspired by the standard architecture of IOT systems proposed reference architecture (Bauer et al. 2013).

Three agents interact at this level. The first agent is operations and policies manager whose mission is to maintain the system in optimal condition and therefore it is tasked with managing system internal tasks according to regulations and optimized planning. The second agent is Model Rules and logic provider, this agent is responsible for handling the end to end management of all services governed by the system and intended for internal and external digital and physical users of smart city shadows. Through this module the architect establishes operating logic for the various services and can thus

ensure their assignment based on responsibilities through its various internal and external entities. The third agent is Transactions and Resources Manager, who is in charge of managing transactions flow by providing a Road Map to the appropriate resources and adapting their usage while at the same time controlling their access and ensuring the efficiency of incoming and out coming data and information transactions from the two other modules. This agent holds metadata related to data producers and consumers, as well as semantics that describe the functional logic of smart city shadows. Regulated outputs generated by the interactions between its three agents are communicated to smart city agents' shadows, which constitute a dynamic simulation of physical agents and their associated logic within smart city. These agents can be equipment, systems or a set of systems driving a process. A shadow's role is to faithfully imitate, in real time, the functioning of the real entity to which it is connected. This imitation is done by feeding models of real systems with data collected from the system and its environment through the three agents that constitute the first level of the block. This first simulation is an instance simulation, in the sense that the developed models are specific to the real system they represent and serve to dynamically visualize parameters and indicators proper to the connected instance. The results of these simulations are communicated to the second block of the system. The mission of the second block is to extract, through the results of the simulations and the multidimensional modelling induced by applying Virtual shadows concept to cities agents modelling, structured and relevant information on a set of instances of the same type. This information is input for the first level modules of the second block which are threefold. The first two functions geo spatial business intelligence and smart performance tracking aim at developing a learning mechanism that, based on the multidimensional analysis of the outputs of a number of instances belonging to different contexts, will allow the development of a solid knowledge base for intelligent decision making at both strategic and operational levels.

The third module Artificial intelligence and activities optimization acts as a prognostication unit for the prediction of future scenarios and the definition of optimization parameters for smart city agent shadows type models. The simulation of these scenarios is done at smart city twin level, which represents a mature shadows agent able to react proactively to uncertainties and unpredictable events and to provide a set of interactive modules responding to several critical issues facing decision-making processes.

The last layer of the architecture is the back-end interface for communication with system stakeholders. It consists of dynamic user-centred interfaces, interactive knowledge repositories resulting from learning workflows, and finally a collaborative platform allowing experience sharing between different parties with disparate expertise and priorities.

Security, interoperability, and persistence management apply across the complete smart city twin architecture. Security deals with confidentiality, integrity, and availability issues. Resilience deals with systems abilities to recover from unexpected events in this framework it concerns architecture flexibility and resiliency mechanisms developed to management layers agents' changes and evolutions across their lifecycle.

Finally, interoperability with technical interoperability through communication and policies management and end points connectivity, semantic interoperability for content and context

awareness between systems internal and external agents, syntactic interoperability for data exchange structures and models management.

### **3.2 Smart cities surrogates experience feedback in smart decision making for cities management**

In the context of pandemics management geospatial intelligence plays a key role particularly for the management of various areas with different social and economic parameters and indicators.

Cities management system provided with multiple viewpoints enabled by digital surrogates' models can enable each stakeholder according to its needs to deals with Covid-19 impacts that are threatening its activities.

Social distancing that is necessary to reduce contagion unit of the virus require the reformulation of criteria for the management of public transport and transportation in general. Urban mobility management has been the concerns of cities decision makers for years. A lot of research communities have been trying with the use of developed algorithms and heuristics to mitigate this problem. Currently, around the world developed cities digital twins proved the potential of cities digital surrogates to reinforce results achieved by these works. Digital twins are an ideal solution for tailoring this new vision for the advantages they offer of real-time tracking, simulation of optimization scenarios and interoperability between different data sources and decision-making dimensions (Madurai Elavarasan and Pugazhendhi 2020).

Digital surrogates in combination with Building Information Modelling BIM approach provide spatial and temporal representations of data in 3D and 4D formats of structures such as buildings, strata plans, terrain, property lines and utilities such as electrical, water and sewer lines (Sofia, Anas, and Faïz 2020). These representations combined with advanced analysis can be used by policy makers as a support for proactive decision making but also as a basis for communication between public and private institutions, administrations, and companies for the management of operations and activities vital to their business continuity under the current pandemic.

Complex systems operational status such as cities depends closely upon their geospatial context of evolution. The understanding of this context and its integration in the analysis of system performance changes through interactive mapping allocated by Geographic Information Systems Technologies combining geospatial analysis and business intelligence will be of great added value in the context of Covid-19 for both industries and cities. The contribution of digital twins on cities management can help evaluate unemployment rates and the communication of industries inherent needs due to the pandemic that causes a lot of companies to migrate their production systems and can help connect employees with employers more easily. This can reduce pandemic social and economic impacts and in long term revolutionize human resources management within cities; it can also reinforce territorial intelligence within developed and developing countries.

### **3.3 Smart cities surrogates to tackle pandemics management system challenges**

As we have seen through the previous sections, countries are currently facing several challenges in managing the pandemic

efficiently and reducing its impacts, particularly socio-economic impacts. Through the previous parts we have been able to apprehend the different opportunities offered by advanced simulation and the vision of smart cities to counter these different challenges.

The first challenge concerns addressing pandemic risks and uncertainties arising from limited systems resiliency for the management of pandemic aspects evolution. The architecture proposed through the paper provides an independent learning mechanism that, through feedback and knowledge capitalization, offers an interactive virtual reference platform for the simulation of risk scenarios and the proposal of corrective actions and preventive plans to be followed while taking into account all the geo-spatial, temporal, environmental, technical and non-technical parameters related to the real system and its environment.

The second aspect concerns the multi-dimensionality of the pandemic. The development of smart city surrogate enables real-time interrogation of multiple agents and ensures the integration of heterogeneous and relevant data from different stakeholders with different expertise and in different fields so as to explore the connections resulting from the combination of these expertise. According to the priorities defined by the users and the responsibilities assigned to each service, the surrogate allows to mimic in real time the functioning of real-world systems and to communicate the performance gap identified with respect to references and tolerances defined by system key stakeholders.

The third challenge relates to virus novelty, which requires increased proactivity from all systems involved in managing its spread, including healthcare systems, medical industries, and social and governmental ecosystems. The functionalities of the two simulation blocks allow the prediction of system outputs relative to disparate and different inputs and thus to identify new relationships and correlations around the pandemic and its consequences. Optimization, prognostication, and artificial intelligence modules combined with collective intelligence platform resulting from their interaction reinforce the attempts to explore virus epidemiological parameters.

#### 4. PROOF OF CONCEPT AND LIMITATIONS

Our analysis of different solutions and digital technologies developed and deployed against the Covid-19 and its impacts, as well as detailed research on the potential of simulation, modelling and smart cities vision, have enabled us to propose a set of solutions that will serve different purposes but share a common objective of countering the spread of the virus and limiting its impact on the industrial, economic and social networks of countries.

Through this section we will describe three proofs of concept of the architecture that we proposed in the previous sections, with each solution aimed at covering one or several aspects of the pandemic.

Our first solution consists of the development of a modular digital platform that manages pandemics, from prevention to return to normal life, by exploiting advanced information and communication technologies and intelligent decision support tools. It will consist of four modules that operate interactively and dynamically with each other to response to pandemic impacts and challenges. This solution has different scientific, technological, and socio-economic implications.

Indeed, in terms of scientific impact, this solution can help achieving autonomy and scientific recognition for the management of large-scale contingencies such as pandemics and sanitary crises. For the Technological Impacts, it will enable to emerge with Home-Made technological solutions that are efficient, intelligent, and open to several scientific, industrial, economic, institutional, and primarily social communities.

For Socio-Economic Impacts, the proposed platform will allow the detection of different socio-economic problems and risks throughout cities and ensure an intelligent and efficient management of its risks.

Digital technologies and tools in recent months have been distinguished as an efficient weapon in the fight against the proliferation of the virus and its impact on public

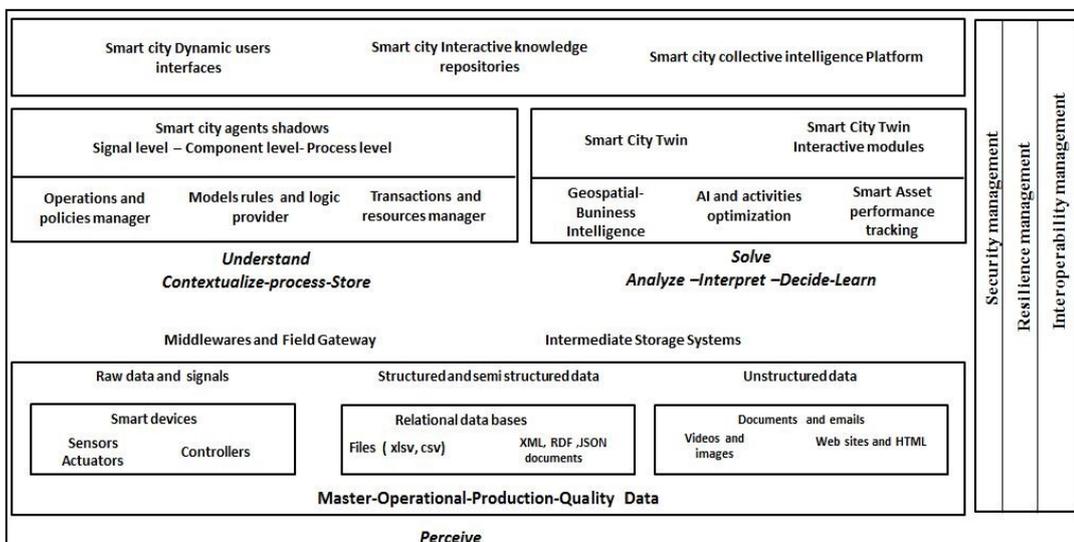


Figure 1. Smart city surrogate architecture

health systems. This second solution is addressed to isolated patients with home-based care and mild to moderate symptoms, its aim is to reduce the pressure on health system, by reinforcing the management of this community. The solution is inspired by the medical protocol for the treatment of chronic obstructive pulmonary diseases, and it is made up of two modules, a first real-time smart monitoring module and a second closed-loop Oxygen Therapy module. The main purposes of the solution are firstly to predict home quarantined patients' complications and reduce the pressure on healthcare systems and hospitals, secondly to use advanced technologies to manage the pandemic in cases of home isolation, and finally to develop individual and collective autonomy and proactivity to face the impact of the pandemic and daily management of the new standard of living resulting from Covid-19. Figure 2 and 3 represent solutions overall architectures.

#### 4.1 Smart city surrogate for smart pandemic management

The first solution as described in the previous section is a modular platform for smart pandemic management covering all the ecosystems directly and indirectly affected by the health crisis. The five services of the Platform are Interactive mapping for the management of cities most affected areas by Covid-19 impacts, Intelligent online testing service, on-line mental Health service, Post-Covid Intelligent action plan after the crisis and finally Covid-Innov service to support the implementation of innovative ideas concerning pandemic risks mitigation.

Interactive mapping aims to help cities act more quickly to combat the Coronavirus pandemic. Indeed, it is intended for citizens and stakeholders to fulfill a set of significant functionalities. It will enable governmental institutions and healthcare specialists to follow daily infection foci parameter, including information and trends on infected individuals, their number, symptoms, age, gender, nationality, and location. This service combined with cities 3D models will allow a global visualization covering all countries regions. With the help of defined indicators, the selected area (neighborhood, city, or country) can be evaluated compared to other areas, thus allowing real time visualization of overall risks and eventually risk rates in a specific geographical area.

Intelligent online testing service will assist healthcare professionals in performing their tasks and will help them minimize pressure on their testing services by offering online solutions. Indeed, this module is composed of two sub-module that are testing pre-testing and intelligent testing.

Pre-testing is based on a basic survey in accordance with common symptoms presented by global health organizations; and an analysis of individual health indicators over a predefined period depending on Covid-19 incubation period. This sub-module allows users to take the necessary measures more quickly, by carefully monitoring their own health for signs of possible infection.

Intelligent testing is a smarter version adopting the latest technologies including intelligent sensors and IoT devices within perception layer and Deep learning and case-based reasoning within smart city twin block to detect suspected asymptomatic cases. This solution will be available to limited stakeholders on a subscription basis.

Intelligent Action Plan service is based on artificial intelligence and multi-criteria decision-making, simply enter the indicators of the current situation to derive the appropriate

recommendations. This module includes guidelines for team building, a planning framework, and risks to be anticipated, useful tools and funding information for corrective and preventive plans deployment.

Covid-Inov is dedicated to project leaders, industrialists and people wishing to contribute to the financing of projects to face Covid-19.

For project leaders, this module will offer an intelligent knowledge capitalization service. In this sense, the project leader will be able, by inserting the theme of his idea, to be redirected towards a system that will present to him ; a set of national and international standards and regulations related to his idea and a set of procedures to be followed in case the project leader wants to patent his idea. And finally, a communication bridge with other project managers and investors through a discussion forum.

For industrialists, this module has two functions, an interface with the standardization bodies and the laws established under Covid-19, the new updates concerning health and safety at work under pandemic auspices.

Each service has a set of rules that govern its functioning and exploits a given set of input data coming from its data processing mechanism. The first level of abstraction of the smart city twin that includes the shadows concerns field inquiry services such as interactive mapping and online assistance.

The results extracted from these two services are communicated to the smart decision making and mental health monitoring services which are based on more cognitive processes requiring the use of prediction and learning tools and approaches mainly inspired by domain ontologies and semantic web models.

#### 4.2 In-house Oxy-Shield

The functional architecture of the solution is essentially based on two modules, which constitute the smart city agents' shadows and smart city twin.

The first module of the platform will consist of two parts, a hardware part and a software part based on an application for real-time monitoring of patient health indicators. This module governs the interfaces dedicated to health care professionals and home isolated patients and constitutes the overall structure of the smart city agents' shadows. The hardware part is based on smart IOT devices and wearables with various integrated sensors, and a system for analysing and adjusting the biases of smart measurements, which are used to measure patient health indicators. Indeed, for the prevention of respiratory complications, the SpO2 oxygen saturation rate must be measured, as well as other indicators such as heart rate or sleep apnoea. These data, as well as the results of questionnaires filled in by users allowing the establishment of specific electronic health record, and the approximation of his oxygen needs through the analysis of the daily activities of the patient, will serve as input to the system of prediction of differential pressure of oxygen PaO2 among affected patients. The main objective of this first module is to predict the treatment of respiratory complications in the targeted patients, and to improve the immune system response through preventive actions according to the results of each user.

The final role that this module will play is to create an intelligent value chain for the supply of equipment needed for

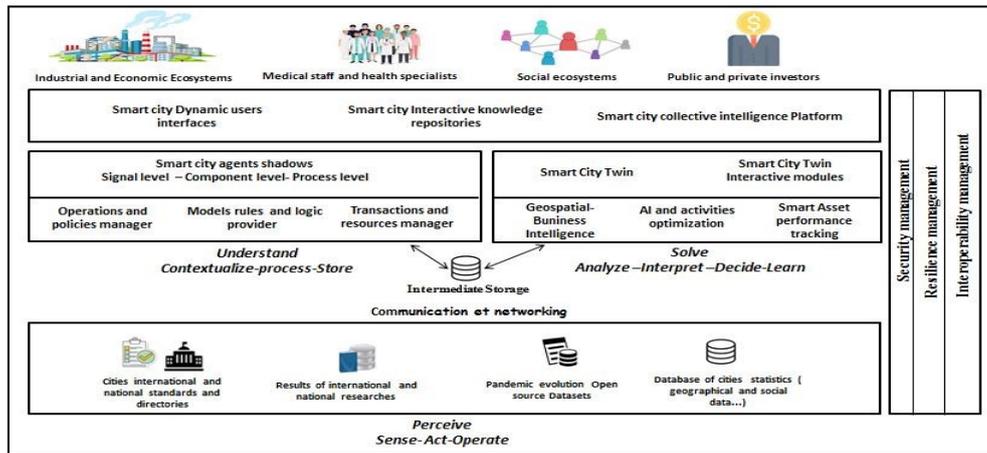


Figure 2. Smart city surrogate architecture for pandemic management

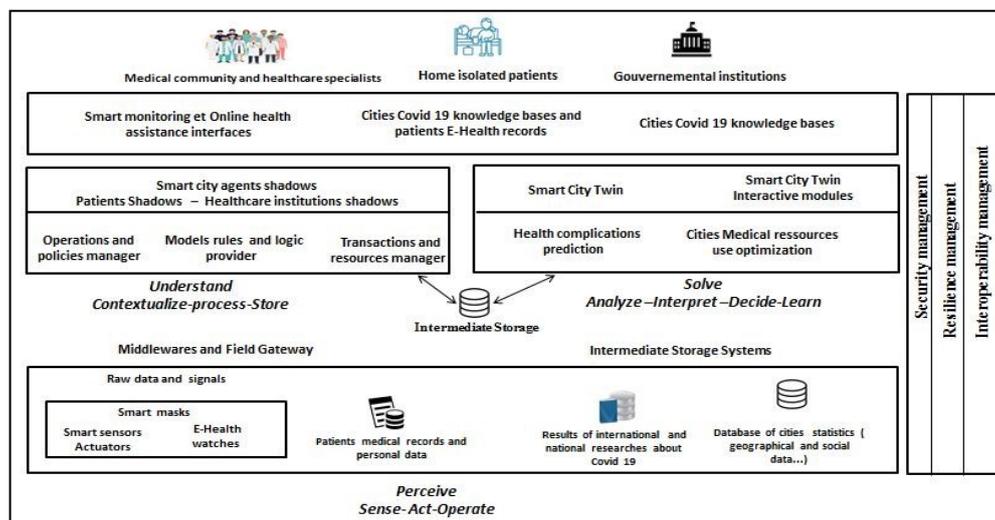


Figure 3. In-house Oxy shield

home care. Securely and continuously connected to the suppliers and stakeholders involved, this module will serve as an interface for communicating forecast needs, avoiding stock shortages, and responding to fluctuations due to the hazards caused by the pandemic.

In addition to providing a proactive model for respiratory complication prediction, the system will provide a secure data exchange mechanism based on block chain technology, creating a transparent communication and collaboration between patients, health professionals, governmental institutions, and healthcare industrial.

The second module that governs smart city twin's operation is also made up of two parts, a hardware part based on an oxygen therapy device and an advanced control software part connected to the previous module. The oxygen therapy device will first be constituted according to the availability of nasal cannulas or face masks, without recycler used in normal cases for oxygen therapy. This first element will be connected to an oxygen tank which can be a concentrator, a liquid oxygen tank or an oxygen bomb.

In our case, we have chosen to use the oxygen bombs, and to connect them to an intelligent regulation system. This control system will be designed with an automatic inhalation and expulsion device. The purpose of the latter is to regulate the oxygen flow, taking into account the operational data collected in real time through the first module, and the predicted targets defined through the simulation scenarios carried out by the system for predicting malfunctions and PaO2 fluctuations at the user's premises. This system will thus offer its users several functionalities.

A complete support according to their activity during the day and during their sleep, thanks to the knowledge base developed through the simulations and the adjustment system. An efficient means of communication and remote assistance that can be cross-transversal improved through algorithms and prediction models and maintained for respiratory complications as a promising alternative to technologies based on the use of concentrators.

The results collected will enable cities to develop a proprietary knowledge base for the remote monitoring of Covid-19 patients, which is of significant benefit for pandemic management and

the deployment of smart healthcare under the framework of smart cities.

## 5. SOLUTIONS IMPACTS IN THE FIGHT AGAINST THE VIRUS AND MAIN IMPLEMENTATION CHALLENGES

Our proposed solutions are based on generic and adaptive platforms characterized by a data driven and services-based architectures relying on layers interoperability and security. The interoperability system of the architecture consisting of a data governance unit and a specific security mechanism that will be integrated during the development phase of the hardware and software components aims to improve the scalability of the platform. Its first role is to ensure adaptability of the platform to a variety of contextual and functional constraints of its deployment environment, and its second role is to establish standard communication and data exchange models based on an analysis of flows between the layers of the architecture governing the platform, thus creating a set of metadata and conceptual reference models for each type of system involved in the realization of services. For this component we will be mainly inspired by domain ontologies and semantic web models.

The implementation of its solutions requires a common consensus between a set of stakeholders with different expertise and responsibilities. This consensus cannot be reached without improving system trustworthiness and interoperability. Improving the interoperability of the system requires considerable investment in the further refinement of cities' network architecture and regulatory systems related to data sharing, the use of artificial intelligence and the exploitation of personal data. Ethics related to artificial intelligence use is currently evolving; however, the standards and reference systems available to date remain limited, particularly regarding a specific territorial context.

## 6. CONCLUSION AND FUTURE WORKS

The current health crisis is to date one of the most critical crises in the history of humanity. To date, digital technologies have proven to be one of the most effective weapons against the crisis which can reduce its socio-economic, industrial, and sanitary impacts. The use of artificial intelligence and simulation in health care for modelling, prediction and decision making is not new, and in recent years, driven by the development of IOT and cloud computing technologies, the concept of smart cities has gradually expanded worldwide. As we have seen, several cities around the world are trying to integrate this vision. Simulation has proven that it can accelerate this deployment. The merging of digitization tools and the feedback acquired from their use with the new vision of intelligent cities and advanced simulation tools are improving pandemic management by establishing a large-scale smart decision-making system.

Through this paper we have tried to outline a portfolio of applications that demonstrate the potential of this fusion through two applications, each addressing one aspect of pandemic management and addressed to a group of stakeholders. The work on these solutions as well as the analysis of the previously tested solutions have both allowed us to detect a set of problems inherent to the deployment of digital

solutions and tools in a global context such as the management of smart cities.

To overcome these issues in the current pandemic context, a considerable effort is needed regarding territorial intelligence improvement, cities' current infrastructure development, especially in developing countries, and finally regulatory framework establishment for digital and artificial intelligence tools. Our forthcoming studies will focus on the development of these three axes and the deployment of the proposed solutions across several contexts.

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