

## Conceptual framework of Digital Health Public Emergency System: digital twins and multiparadigm simulation

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### Abstract

**INTRODUCTION:** Two major technological paradigms have been developed in recent years, digital twins and the multi-paradigm simulation. In the Health Sector, the enormous potential of both approaches for the management of public health emergencies is envisioned.

**OBJECTIVES:** This study aims to develop the conceptual framework for the development of a Digital Public Health Emergency System.

**METHODS:** The integration of the digital twins in health with the multi-paradigm simulation for the design of a digital system of public health emergencies is proposed.

**RESULTS:** The proposal establishes the conceptual framework for the integration of a digital public health emergency system, incorporating multi-paradigm simulation in the construction of a digital twin.

**CONCLUSION:** The use of cutting-edge technologies for public health emergencies will allow for a better response to contingencies as well as optimally managing the resources available in a health system.

**Keywords:** digital twin, multiparadigm simulation, hybrid simulation, health public, pervasive health.

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### 1. Introduction

Managing public health resources for the care of a public health emergency has been a challenge for all health systems. It is difficult to predict in advance the occurrence of catastrophic events related to health emergencies, such is the case of the occurrence of natural catastrophes and their

consequent effects on health, the presence of an epidemic or the occurrence of catastrophic events in certain points of territory. However, this does not imply that these phenomena do not occur and, above all, that they do not generate a significant impact on health services. Therefore, the present work aims to develop the conceptual framework for the application of the digital twins approach and the multi-paradigm modelling for planning the management of health services in the presence of public health emergencies.

The concept of digital twins is based on the construction of digital replicas of living or non-living physical entities from the operation of machinery, a logistics network to the operation of the human body. The concept of digital twins is inserted in the fourth industrial revolution (industry 4.0) and goes hand in hand with concepts such artificial intelligence, high connectivity, smart sensors and internet of things. Precisely this connectivity feature at all times allows the digital system to learn from historical data and react to real dynamic scenarios.

In the case of the health sector, the presence of public health problems has shown that there is no health system fully prepared for unexpected contingencies such as public health problems due to natural phenomena, catastrophic events or epidemics. The fact that an epidemic unfolds unexpectedly in a particular region immediately impacts both the health sector and economic activity. Being able to have a digital system that allows operating the system in the best possible way, as well as anticipating abrupt changes in demand for health services in advance, the need to modify inventories of drugs and supplies, and reallocation of financial resources to be able to face the contingency. All these elements required to face a crisis can be obtained by applying the digital twins approach.

Given the particularities in the operation of health systems, it is necessary to add a multi-paradigm modelling approach to the digital model. Considering on the one hand the behavior of possible diseases that arise in the contingency through the use of dynamic models, modelling the operation of the health system in its units according to their level of specialization as required through discrete simulation and finally the interaction between the different agents who participate in the operation of a health system through agent-based modelling.

The present work is a conceptual proposal that integrates the design of a digital model (digital twin) that allows managing the human, financial and material resources of the health system, as well as modelling the particular operation of this sector by applying multi-paradigm simulation. The work is structured in the following way, in the first section the background and most relevant concepts of the proposal are described, the approach of multiparadigm modelling and digital twins. The following section shows the proposal of integration of both approaches for the construction of a digital system, and finally the conclusions and recommendations are presented.

## 2. Digital twins and multiparadigm simulation

This section develops the fundamental concepts for the construction of the conceptual framework. The concept of digital twins is discussed, as well as its main aspects and applications. As a complement to this approach, the multi-paradigm simulation approach is presented, which includes applications from different aspects in simulation techniques, discrete, dynamic and agent-based case.

### 2.1. Digital Twins

The primary motivation for digital twins stems from the attempt to model complex systems, where small variations in key variables can produce catastrophic results. Such complex systems are characterized by a large number of components, various communication channels and sophisticated information processing, which makes predicting their future states very difficult. An important source of this complexity comes from the interaction of these systems with human decisions, as well as emerging behaviors derived from the interaction between the components of the system. These concepts are related to the life cycle of products or systems. During planning process, the desired characteristics of the system are defined as well as its desired and unwanted behavior.

The concept of digital twins was discussed for first time in 2002 in University of Michigan presentation to industry for the formation of a Product Lifecycle Management Center. This concept is based on the idea of the possibility of facing the uncertainty inherent in complex systems through the creation of a mirror system of physical systems, a digital system that exists by itself. This twin is linked throughout the life cycle of the physical system that gave rise to it. The fundamental elements of the conceptualization of the digital twin are made up of a real system or space, a system or virtual space, the link between the two through, information flow, as well as the flow of information with virtual subspaces. The physical system that operates in reality and the virtual system that was created based on information from the physical system, but which subsequently interact bidirectionally, forming a mirror relationship between both.

The Product Life Cycle Management (PLM) approach considers a dynamic behaviour between the real and virtual system, through the life cycle of the system in question. Going through four phases: 1) creation, 2) production, 3) operation and 4) disposal. This information mirroring model was called a digital twin [1-4] (Figure 1).

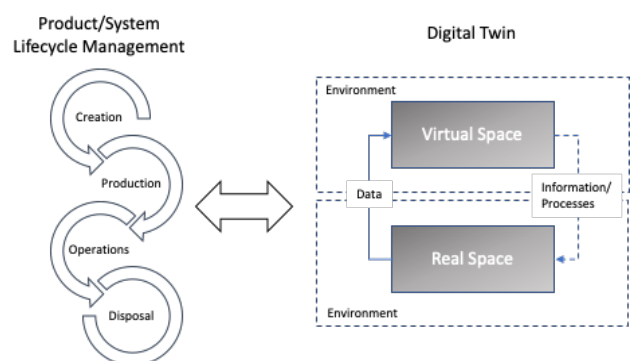


Figure 1. PLM and Digital Twin

The bidirectional interaction stage between the real system and the digital system is the most fruitful in terms of

the aggregation of information on state changes in the real system with probabilities of failure in some of its components and establishing the necessary behaviors to avoid undesirable states of the system.

In accordance with the definitions of digital twins, the aim is to present an adaptation of the concept beyond the manufacture or physical production of products and to reflect this concept in physical and social systems. There are two categories of digital twins, prototypes and instances. The prototype refers to the prototype of a physical system and contains information such as the 3D model, bill of materials, bill of processes, bill of services and bill to disposal. In the case of instance, this describes a specific physical system linked to an individual digital twin throughout the life of that physical system and contains 3D information from the physical system, bill of material that current components and past components, bill of process list of operations performed for the creation of the system as well as the results of its operation. A service record that describes the past services performed and the components replaced, and finally an operational state captured through sensor data, current, past and predicted. Additionally, the digital twin requires a digital twin environment that forms a digital twin application space for various purposes, prediction to predict future system performance behavior, and interrogative to find out why a state current or past and foresee such scenarios in the future [1]. Within the framework of the adoption of the concept of digital twin, five key concepts have been categorized according to the level of development of the digital twin (Table 1).

Table 1. Concepts associated with the Digital Twin

Concept	Description
Digital Twin	Complete virtual description of a physical product.
Digital Twin Prototype	The virtual description of a prototype product, considers all the information required to create the physical twin.
Digital Twin Instance	A specific instance of a physical product that remains linked to an individual product throughout that products life.
Digital Twin Aggregate	The combination of all the Digital Twin Instance.
Digital Twin Environment	A multiple domain physics application space for operating on Digital twins (performance, prediction, and interrogation).

Source: Adapted from [5]

According to [5] in a literature review on the development and application of digital twins in various sectors, a set of characteristics of the digital twin were identified (Table 2).

Table 2. Characteristics of the Digital Twin

Characteristic	Description
Physical Entity/Twin	The physical entity/twin that exists in the physical environment.
Virtual Entity/Twin	The virtual entity/twin that exists in the virtual environment.
Physical Environment	The environment within which the physical entity/twin exists.
Virtual Environment	The environment within which the virtual entity/twin exists.
State	The measured values for all parameters corresponding to the physical/virtual entity/twin and its environment.
Metrology	The act of measuring the state of the physical/virtual entity/twin.
Realization	The act of changing the state of the physical/virtual entity/twin.
Twinning	The act of synchronizing the states of the physical and virtual entity/twin.
Twinning Rate	The rate at which twinning occurs.
Physical-to-Virtual Connection/	The data connections/process of measuring the state of the physical entity/twin/environment and realizing that state in the virtual entity/twin/environment.
Virtual-to-Physical Connection/Twinning	The data connections/process of measuring the state of the virtual entity/twin/environment and realizing that state in the physical entity/twin/environment.
Physical Processes	The processes within which the physical entity/twin is engaged, and/or the processes acting with or upon the physical entity/twin.
Virtual Processes	The processes within which the virtual entity/twin is engaged, and/or the processes acting with or upon the virtual entity/twin.

Source: Adapted from [5].

The digital twin requires as a fundamental input a large amount of information and computing capacity, hence its natural link to big data and the feasibility of its implementation. This in turn allows to decrease implementation costs by not using physical resources, as well as optimizing its use when implementing in a real model after validating the virtual model. Or in its case the improvement of an existing system through bi-directional feedback with the virtual model.

With the development of massive connectivity, the Internet of Things, cloud computing, artificial intelligence, wearables, 5G and tactile internet, augmented virtual and mixed reality, sensors and actuators, the development of this type of digital models is possible [1],[5]. The fact of having a large amount of information on the operation of the physical system, through intelligent sensors that collect key information, requires the use of data science tools that allow analysing the information as well as using it for modelling

and do prospecting of the digital twin. The information age has been defined by the ability to have large volumes of data but also by the ability to process and use it for strategic, operational and prospective decision-making [6,7].

The great added value of the vision of digital twins lies in their interconnection between digital objects and physical objects, which allows a response in real time. The process of build the digital twin allows taking into account the historical operation of an object or a physical system, but once the link between the physical and the digital is made, it is possible to track and interact with the digital twin based on the information collected in real time. In the operation phase of both physical and digital systems, simulation becomes a fundamental tool that allows reducing the complexity of the system by being fed in real time with the behavior of the system. Allowing to build a range of future desired and unwanted states and define action strategies to achieve the desired results [1].

The planning and design process of the digital twin requires the participation of experts involved in the operation of the physical system. This will allow designing the digital model as close as possible to the real object. In addition, according to the operators of the physical system, it is necessary to define key variables in its operation, which will be an essential input for decision-making. In the implementation and operation of the digital model, it is necessary to continuously monitor and evaluate the operation of the physical system, through the generation of control panels on key variables, which must be operated by the experts of the system. They will support decision making in the operation. The fact of having real-time information allows multiple probable scenarios and the relevant lines of action to be projected in advance. This stage will be supported by artificial intelligence tools that allow maximum use of the available information. The operation of the digital twin in practice requires a new vision within organizations, as well as the necessary capabilities in their human capital [5].

The digital twins approach has been applied in various sectors and technologies, and the initial definition has been enriched over time. The main reasons for its great acceptance lie in the reduction of costs, innovation, improvement of productivity and quality of products and processes, as well as risk management. By allowing to monitor, understand, and optimize the functions of living or non-living physical systems. There are multiple applications of digital twins in the industry, including product design, production, forecast, and health devices management [8, 9].

In the particular case of the health sector, there are multiple peculiarities in its operation. Whether health services are provided by public or private entities, in the face of a public health emergency, the health system must operate in a coordinated manner to optimize resources and maximize results. There are multiple facets where the digital twin can provide added value in the operation of health services, from the operation of health units, the management of supplies and drugs, as well as human resources. Further to strategies aimed at patients, regulator and healthcare provider. Applications for medical devices have been

developed, through the collection of real data from the human body, it is possible to design devices to monitor the person's health status. Even through wearables it is possible to detect unhealthy lifestyles and predict possible health problems [9].

Concepts such as personalized medicine and digitally supported engineering have been developed. Through compiling gained information on individual, the development of digital twins has enabled analysis of emerging information in preventive and curative healthcare practice. It is an emerging area in medicine with enormous potential for the future [10]. In medical research, allocation of resources and prediction of medical activity, the digital twin and health approach has been combined, seeking to provide health services in an efficient and timely manner. The development of smart healthcare is a reality trough using wearable medical devices to monitor, diagnose and predict health aspects, especially of the elderly that require greater care either because they suffer from a chronic disease or because they are more prone. From this, the concept of digital twin healthcare arises, which is based on three parts: the physical object, the virtual object and healthcare data [11].

Other authors have focused on the development of devices for health monitoring, such is the case of the adoption of Wireless Body Area Networks (WBAN) based on Internet of Thing, in which it allows monitoring and treating patients, generating enormous challenges in the performance and security of such devices, being that WBANs can be wearable or implanted under the skin. Essentially it has been applied to cardiovascular monitoring, body temperature, blood glucose monitoring, stress monitoring, rehabilitation and therapy [12].

Another line of research has focused on the use of artificial intelligence to drive the operation of smart machines to coordinate and manage their financial, professional, and people's health goals through the development of Human Digital Twin concept (HDT). This concept refers to a human-specific smart machine dedicated to aligning human goals with the smart machines supporting her. HDT monitor human Artificial Intelligence space and based on the human's response to various machine actions, allows anticipating the human response in certain contexts to ensure the alignment of targets of various machines with human targets. The basis of this learning is in the interaction between both human and machine entities [13]. The concept of human digital twins has also been applied to maintain human health, through tracking fitness-related measurements describing the behavior of athletes over time. Activities related to food, physical activity, hours of sleep, etc. are registered. The digital twin records the historical behaviour and subsequently allows evaluating the training against optimal standards, as well as issuing recommendations to improve the athlete's performance [14].

Special emphasis has been placed on the application of this paradigm in the analysis of hospital units, going from traditional operating schemes to systems based on information technology, making use of the Internet of Things, body sensor networks, modelling, simulation and

artificial intelligence. These elements are the basis for the design of hospital units of the future that allow improving the quality of patient care, and define a virtual entity called Hospital Twin. Which allows to trace patient pathways, collect information, monitor their behavior and predict future outcomes. Allowing to offer the right care, in the right place at the right time. It also allows evaluating lines of action in the face of unexpected events and their impact on the hospital unit [15]. The development of the application of digital twins has wide potential, proposals have been developed in various sectors, but in the case of the health sector, three main lines of action are identified: 1) development of intelligent medical units (Tween Hospital), 2) development of a digital twin of the human body to simulate possible treatments and scenarios for a disease (Human Tween) and 3) development of devices that allow monitoring the health status of people at all times.

## 2.2. Multiparadigm Simulation

The multi-paradigm simulation approach allows different simulation methods to be combined simultaneously, each with a particular objective, but which together enable the simulation model to be enhanced. The fact of having large amounts of information has made it possible to greatly strengthen the simulation models. In the same way simulation, which has been a widely used technique, is now powered by the elements of machine learning and artificial intelligence. This generates much more robust and dynamic inputs for the simulation model, and in the same way, these models allow the calibration of artificial intelligence applications to strengthen prospective decision-making.

### Discrete Simulation

By simulating discrete events it is possible to evaluate the operational feasibility of the proposal, in existing operational processes or in the design of new products/processes. One of the advantages of discrete simulation is that it allows the operation of a system to be simulated in a controlled environment and its possible failures to be identified through the analysis of feasible scenarios [16]. The discrete simulation approach is based on the mapping of an operational process based on activities. Seeking to consider a standard process and its possible behavior in a controlled environment (Figure 2).

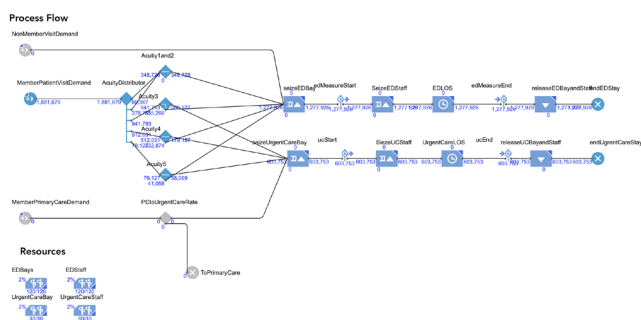


Figure 2. Discrete event approach. Source: AnyLogic®.

In the case of health sector, the discrete simulation approach has multiple applications, from improving the operation of health units and validating care models, to the monitoring and economic evaluation of medicines and supplies. Discrete models are a fundamental branch of the economic evaluation of health technologies, in recent years their application has been expanded to improve the management of hospital units, operating rooms or emergency areas.

### Dynamic Simulation

Dynamic systems modelling is a tool that allows taking into account the behavior of a system and its interaction between its parts to robustly project expected trajectories of variables of interest. As well as designing intervention policies to achieve the desired objectives in the final path. The foundation of dynamic simulation is based on solving differential equations that represent the behavior of a variables of interest over time, taking into account its interaction with a set of auxiliary variables, causal relationships, and flows. The general approach of a dynamic model is through a differential equation given certain initial conditions.

$$\frac{dy}{dx} = f(x, y), \text{ with } y(x_0) = y_0 \tag{1}$$

The objective is to identify the expected trajectory of a state variable of the differential equation. Since not all differential equations have a procedure to find the analytical solution, it is necessary to resort to the application of numerical methods for its solution. In the case of the application of dynamic systems to systems related to human activity, the approach known as Systems Dynamics was developed, which is a methodology for the analysis and temporal modelling in complex environments [17] (Figure 3).

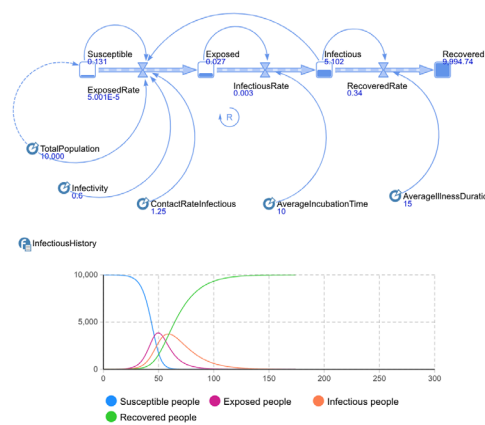


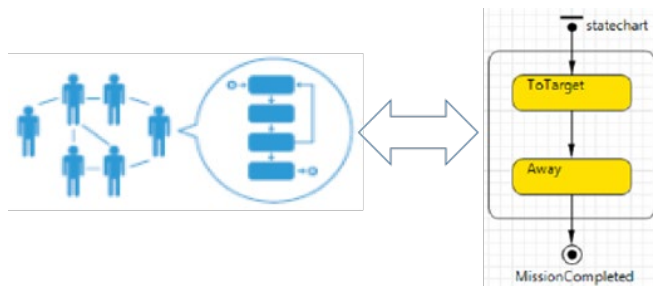
Figure 3. The Systems Dynamics approach. Source: AnyLogic®.

The Systems Dynamics methodology considers the behavior over time of a level variable, flows and the related environment. In the case of the health sector, dynamic models are widely used in epidemiological models, modelling the behaviour of a disease and as an essential element for the design of economic evaluation studies.

**Agent Based Simulation**

The agent-based simulation approach has been recently applied, due to the need to delve into the behaviour of the systems modelled through simulation. Essentially considering the interaction between agents participating in the operation of a system, elements not considered in the traditional approaches. Advances such as object-oriented programming and the development of state graphs, as well as improvements in processing speed, facilitated the implementation of these models in various fields.

In this approach it is possible to establish the interrelationships between key agents in the operation of the system. These agents are governed by rules and these rules define their behaviour in a controlled and modeler-defined environment [18]. The interaction of an unlimited number of agents through their individual behaviours generates the dynamics of the system (Figure 4).



**Figure 4.** The Agent Based approach. Source: AnyLogic®.

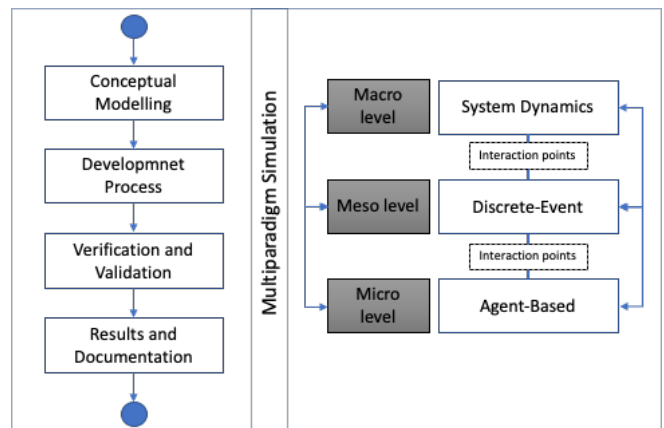
It is possible to specify the behaviour of agents in different ways, generally agents can transit between different states, their actions and reactions will depend on the state they are in. In some cases, the agent's behaviour is defined based on rules defined through the occurrence of special events. The objective of agent interaction is to capture emergent properties of the system that would not be observed if the agents acted in an individual manner. Many times, it is possible to model the behaviour of the agents and the environment in which they interact using traditional methods.

**Multiparadigm Approach**

The evolution of the simulation methodologies has been generated based on the problems addressed as well as the computing capacity. In recent years, it has been possible to integrate agent-based, dynamic and discrete simulation approaches into a unified paradigm. The need for increasingly robust models has motivated to integrate

different approaches in simulation models. Further the technological development allows count and processes large amounts of information as well as great computing capacity, allowing connectivity and interaction between approaches of modelling [19].

The integration of these approaches does not always include all approaches, it is necessary to define the object of study, the purpose of the model as well as the methodology by which the problem will be addressed. This will allow defining the stages of model development, from a modular approach. Defining the participation of a certain simulation approach and the key point, how information will be shared between modules and how they interact with each other. The build of the simulation model from the multi-paradigm approach starts from a problematic situation and its conceptualization, followed by a stage of development, verification and validation, and finally analysis of the model's results. At each stage it is necessary to define the simulation approach that will be used to generate outputs that can be the final result or inputs for another module of the general model, it is an iterative process [19] (Figure 5).



**Figure 5.** Multiparadigm Simulation

The selection of the simulation approach to be used in each module of the general model should be based on the perspective in which want to build the model. From the perspective of the problem to be addressed, the system perspective or the simulation methodology. In building the overall model, the input and output of each approach and its connection between them must be considered (Table 3).

**Table 3.** Selection criteria of the simulation paradigm

Perspective	Discrete Event	System Dynamics	Agent Based
<b>Problem/Criteria</b>	Operational tactical	Strategic Flows	Any level Rules
Scope level	Queues	Aggregated level	Mode detailed level
Situation	Detailed level		
Required resolution			
<b>System/criteria</b>	Meso-micro level	Meso-macro level	Any abstraction level

	Discrete Holding (queues)	Continuous Stock-rate	System process control
<b>Methodology/criteria</b>	Process centric	Top-down	Bottom-up
Modelling approach	Entity	Feedback	Agent
Object	Discrete	Continuous	Discrete
Time			

Source: Adapted from [19].

An essential point of the multi-paradigm approach is the type of relationship that the modules of the general model can have through the interaction points or input and output variables. This relationship can be through the substitution of variables between approaches, aggregation/disaggregation or causal relationships. In turn, generating aggregation or elimination of agents or entities, flow control, trigger event or state-chart control.

In health sector, the application of the multiparadigm approach adapts naturally given the characteristics of the problems that arise in this sector. One of the fields of application that has had a great boom is in the evaluation of health technologies. The concept of prospective health technology assessment has been developed based on multiparadigm simulation. It allows making early decisions regarding innovative health technologies (drugs or devices) in particular in medical decisions, health economic evaluations, health care simulation and multiparadigm modelling [20].

The basis of this proposal is the application of hybrid simulation models to predict the expected effects of health technologies, identifying their strengths and weaknesses in a specific health system. The macro level (top-down) would be governed by systems dynamics models, the meso level (workflow) would be designed by simulating discrete events, and the micro level (individual level bottom-up) would be governed by agent-based simulation. This perspective allows modelling for health decision-making through the “what if” and “how to” approaches to achieve specific objectives [20-22].

The multi-paradigm approach has also been applied for the analysis of financial impact as well as the definition of cost-effective strategies for the treatment of chronic diseases. Using system dynamics to characterize the evolution of the state of health, body weight and diagnosis. Once the disease (diabetes) develops, individuals are grouped into agents that undergo different treatments based on the patient's history. Finally, discrete modelling is integrated to characterize the patient's progression through the health care process, evaluating its impact on the health system [23].

### 3. Digital Health Public Emergency System

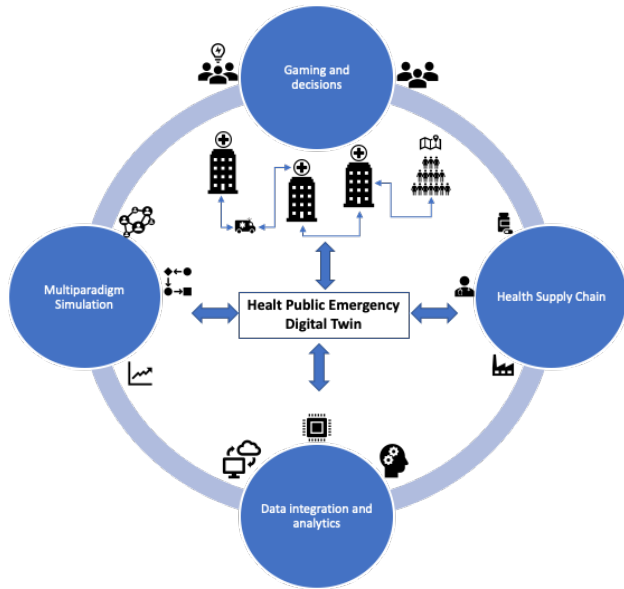
Based on the conceptual framework developed in the previous section, a transition scheme is proposed towards the use of a model based on digital twins and multiparadigm simulation for the management of health resources in the presence of public health emergencies.

In this proposal, only the operation of high specialty hospitals is considered, assuming high complexity in the

treatment of patients. The integration of the network of high specialty services through digital twins is considered, including their physical operation, as well as the monitoring and control of the supply of supplies and medicines, medical equipment, ambulances and human resources. Through multiparadigm simulation, it is proposed to simulate the operation before signs of the start of a health emergency in order to plan the correct management of resources. In this context, discrete simulation will allow modelling the operation within hospital units as Hospital Twins, dynamic simulation will allow modelling the behaviour of population and disease and the agent-based approach will allow modelling the interaction between the main agents involved in a public health emergency and their respective expected behaviors.

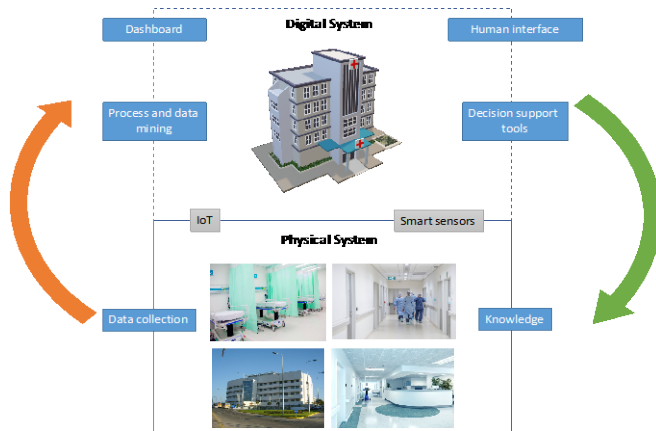
The proposed integration of the digital model approach and multi-paradigm modelling starts from the structuring of the actors of the system to be modelled. In this case, we start from the general case where highly specialized health units are considered as the main agents. The occurrence of a public health emergency is considered as an exogenous variable. The physical system that is sought to be represented virtually is the operation of a system of Digital Health Public Emergency System (DHPES) integrated for the next components (Figure 6):

- Medical units' network of DHPES: Integrated network of medical units to which patient referrals can be made.
- Module for collecting and analysing information: Collection and processing of information in real time of the public health emergency in order to quantify the demand for health services and the supply capacity.
- Operation module of the supply chain: Optimization of the supply chain to be able to supply health services. Includes medicines, supplies, human resources and health devices.
- Scenario generation module (multi-paradigm simulation): Generation of prospective scenarios according to the information provided in real time on the public health emergency as well as possible cost-effective lines of action.
- Game and decision module: Interface through which decision-makers can intervene in the generation of games (action-consequence) to decide on the best alternatives to implement over time.



**Figure 6.** Digital Health Public Emergency System

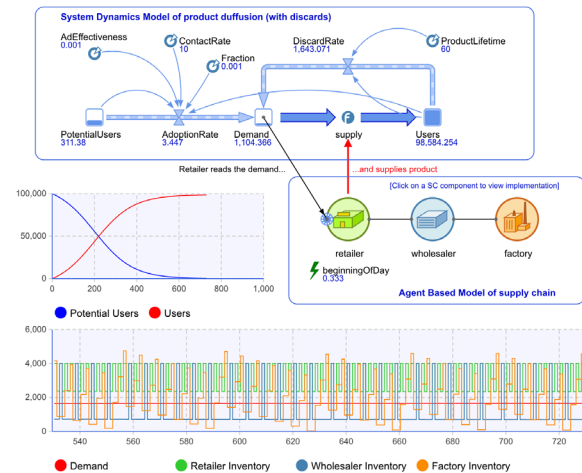
The design of the digital twin seeks to generate virtual instances that emulate the real operation of the provision of highly specialized public services. This operation includes the supply of medications, supplies, devices and equipment. And the management of human resources and financial resources in the event of a contingency. In a second stage of analysis is considered the collection of information in real time during the emergency, about the operation of the system. This allows to generate based on historical data from past cases what was the behavior of high-specialty services in a public health emergency situation or what would be the behavior of the digital twin before a simulated scenario. At this level of analysis, it is necessary to have the operation of Hospital Twins that represent the medical units that will operate in the network of DHPES (Figure 7).



**Figure 7.** Hospitals Twins.

Each medical unit that is part of the DHPES network will be integrated as an individual Twin Hospital, with its respective operation as an DHPES smart cell. Each unit will be an exact replica in the digital system of the operation of the physical units, allowing information to be integrated in real time through smart devices that allow monitoring the demand and provision of health services, as well as the evolution of the state of health of the patients. The information collected will be integrated through data and process mining, generating real-time dashboards, like so traceability of each patient (it is highly important in emergencies caused by epidemics). In the same way of DHPES, each Hospital Twin will have an interface that allows the interaction of decision makers with the digital system and in turn extract knowledge to define prospective lines of action.

The integration of supply chain optimization is a crucial point because if the provision of supplies, medicines and devices is not guaranteed in an efficient way, health services cannot be provided efficiently. The management of the supply chain through direct connectivity with suppliers and with the financial areas, will allow the provision of services not to be interrupted in any moment. At this stage, the integration of supply chain performance criteria as well as optimization methods for its operation is crucial for the correct operation of the DHPES (Figure 8).

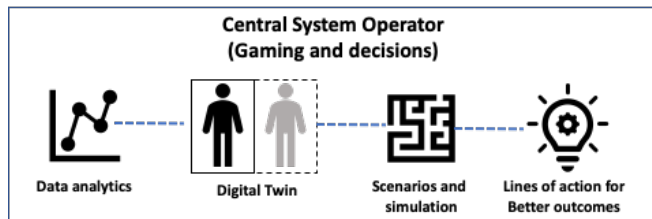


**Figure 8.** Health Supply Chain Optimization. Source: AnyLogic®.

Once the digital twin is in mirror mode operation, receiving real-time operation information from all units of DHPES, it is possible to enter the prediction stage of entire system. In this segment, the multi-paradigm simulation approach is of vital importance. It will allow the build of disruptive events that generate public health emergencies and that impact in the digital twin. In this case, the particularities of public health problems are more complex, considering the behavior of the population, the dynamic of



the disease, the care process, and the economic evaluation criteria of actions to follow based on cost-effectiveness measures. The multi-paradigm simulation approach is the fundamental basis of this stage. The games and decisions stage involve interaction with DHPES decision makers based on the information generated in real time and simulations of both potential problems and possible lines of action (Figure 9).



**Figure 9.** Central System Operator

Artificial intelligence tools are used to search for possible solutions to the possible simulated scenarios in the digital twin. In this case, it is necessary to have a Central System Operator that integrates the key results and has the power to make decisions about DHPES based on technical evidence.

## 4. Conclusions

The development of the industry in the world has advanced by leaps and bounds, high real-time connectivity, the development of smart sensors, as well as the capacity of cloud computing are disruptive elements in the way of producing, consuming and interacting. These advances have allowed the development of virtual systems that reflect the real-time operation of a physical system, which has been called digital twins. This concept goes beyond the vision of systems simulation, since it starts from the emulation of a real system but also there is a bidirectional relationship of information exchange between both systems.

The real system feeds the digital system and this in turn allows simulations to be carried out on possible scenarios, feasible behaviors of the system as well as its consequences, all in a virtual environment. Similarly, systems simulation paradigms have evolved, there are three generally used simulation approaches, discrete, dynamic, and agent-based simulation. They have been integrated into the construction of models that are much closer to reality, interacting through modular structures that share inputs and outputs, as variables or as entities.

The integration of both approaches, digital twins and multiparadigm simulation, is a natural process that looks for potential the use of digital technologies and artificial intelligence in decision making. The digital twin replicates the physical system, which is fed in real time by it, at the

design stage historical information is considered but at the implementation stage the flow of information between the digital twin and the physical system is bidirectional. In this stage, both approaches interact through the prediction of possible triggered scenarios based on early warning indicators collected by smart sensors. The multiparadigm simulation helps the digital twin to represent the possible scenarios that the real system would face, as well as its possible lines of action, evaluating pros and cons in a virtual environment.

The proposal in this document is based on the use of both approaches, digital twins and multiparadigm simulation, to be able to face disruptive situations that generate public health emergencies, such as natural disasters or epidemics. The great advantage of having a health system integrated into a virtual environment is that they allow generating any possible scenario as well as lines of action in the face of these contingencies. Another advantage of having a virtual system is that it feeds back into the physical system in real-time generating a high ability to react by the health system.

The conceptual framework for the construction of a digital twin of the health system must consider elements such as medical units, target population, the health supply chain, expected demand and capacity of system. In addition to having early warning measure in the system that allow the identification of health emergencies before they impact the system. This requires collect information in real-time through smart sensors throughout the system operation.

The utility of multi-paradigm simulation is integrated into the digital twin through the generation of scenarios in an emergency as well as lines of action evaluated based on reliable information, integrating artificial intelligence methodologies that facilitate decision-making. The multiparadigm simulation approach integrates the vision of digital twins for the health sector. The modelling of the population affected by the emergency, the behaviour of possible incidents to be addressed by the health system, and the operational simulation of the system in the event of contingencies as well as the interaction between related agents. The use of cutting-edge technologies for public health emergencies will allow for a better response to contingencies as well as optimally managing the resources available in a health system.

The present work is a first approach to the integration of both paradigms in a Digital Health Public Emergency System. It is necessary to implement this conceptual framework in the generation of virtual systems for the attention of sanitary emergencies and with this seek to reduce the impacts of disruptive events both in the health system how in people's lives. The development of a digital system of this nature requires knowledge and adaptation to the particular health system in which it wishes to be implemented.

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