A simulation game of patient transportation

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Abstract. The handling of patients is a complex process. The training and education of patient transportation workers are meant to ensure efficiency and health outcomes. A simulation game, joined by personnel with working experience or prospective professionals in the healthcare system, is a life-like medium for improving decision makings in non-rational operation management. However, few examples are known in regard to synthesizing complex systems, such as clinical facilities, into healthcare simulation games. In order to fill this gap, this work proposes the adopt theory and reports the development of a simulation game that reconciles patient handling with the support of different types of simulation techniques. The simulation game has a physical entity simulator as its back-end and a panel of command and control for each player as its front end. The physical entity simulator is based on the interactions of mobile agents. Agent-based modeling targets the correct level of representation of the operative environment. The simulation game is tested with managers who have more than 10-years of working experience with patient flow management in pediatric care. Reflections from players indicate that modeling and abstraction using an agent model is an efficient synthesis of complex systems. The theory, methods, and results of this study are expected to contribute to the development of simulation games that can be applied in health service provision, in general, and in patient transportation, in particular.

Keywords. Gaming, Simulation, Pediatric, Patient, Logistics.

1.1 Introduction

The first constructive model of a dynamic multi-agent system was the Schelling Segregation Model for investigating housing and neighborhood preferences [1]. Since then, agent-based modeling has been used as a tool for problem-solving or attaining a better understanding of complex social-technical systems. Not only is agent-based modeling relied upon for understanding emergence, but it also provides an analytical way of optimizing engineering systems, such as logistics and transportation [2], healthcare [3], ecosystems [4], and others [5, 6] to obtain exact solutions.

The simulation could be an explicit paradigm of how a modeler perceives a 'system' philosophically, such as discrete-event simulation, system dynamics and agent-based modeling [7]. As modern forms of hybrid simulation games, agent-based modeling and social simulation are combined with the classical gaming simulation approaches [8, 9]. Among the different techniques, individual-based models are innovative in their encapsulation of beliefs, desires, and intentions of individuals in a decentralized delivery structure. The modeling of agents' attributes, rules, and their environment recreates the decision making processes in various network topologies, enabling the occurrence that is hard to define on a personal scale. This makes agent-based modeling a suitable language for developing business simulation games that are carried out by autonomous, decentralized and objective-oriented ownership entities.

The simulation game (SG), together with simulations, serious games and participatory simulations, could be highly physical models for validating agent systems and operational archetypes. Anand et al. [10] positioned agent-based modeling and participatory SG with regards to the data and information collection for defining environments. In particular, SG fits the anatomy of an agent system given its capacity to encapsulate interdependencies and dynamic natures. It also adds more value to design future-proof systems without sufficient data or evidence. Linking the agent models with role-playing games is demonstrated to be a powerful planning tool for city management in Ligtenberg et al.'s works [11]. In addition to urban planning, serious games, driven by a computer simulation, are an assistive technology for the training and education of skill sets related to production [12] and manufacturing business management [13]. For safety engineering, simulation and games could be used as instrumental and educational methods in order to develop skills and competencies in escalating situations [14].

The literature contains few gamified logistical simulations in the patient transportation subject domain. Most works with simulation models, developed during research into pediatric emergency care, are redistributing the values in the existing service network by optimizing operation management [15]. The simulation models show the promises in healthcare management. However, without gamification, the simulation might not be able to facilitate the training and learning at the relational and extended abstract levels in the Structure of the Observed Learning Outcome (SOLO) taxonomy [16]. This type of engineering simulation that solely computes a process might hinder the activation of learners, the validation of effective strategies, social relations, as well as the possibility of investigating real-time decision-making processes that involve human factors. The integration of simulation and game might recreate the formal and informal organizational structures in clinical environments but with reduced complexity and a higher level of engagement. Therefore, the following research questions become the central interests of this paper:

- How do we theorize SG for the better handling of business management?
- What is the correct level of modelling and abstraction in SG [17]?

In this work, we propose the adopt theory intended to constructively align the development of SG for the adequate training and education of non-technical skills observing the trend of contemporary logistics applications moving forward. Following this, we look into the development of an SG for patient transportation to connect the empirical findings with the proposed framework. The design of the SG keeps an open perspective on the different viewpoints and activates participants in their peer-learning experiences.

1.2 Theorizing Simulation Game

An SG is an autonomous, (de)centralized, objective-oriented, proactive and translational/transdisciplinary social interaction for the adoption of effective strategies in the service network, as Figure 1 presents. The first four elements reflect how the objects model and the perspectives of the participants are reflected. The last element is producing output from running SG.

It is essential to theorize SG for the cumulative knowledge observed behind the empirical studies. In addition to the fundamental elements that all SG contain [18], the adopt theory explains the required characteristics

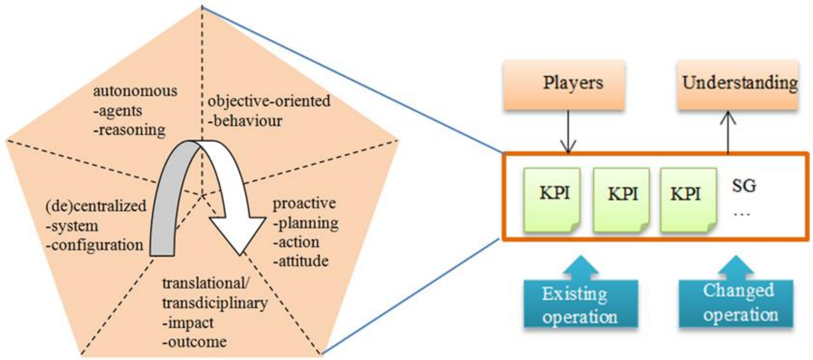

Fig. 1.1. *Adopt* theory

for the better handling of current business challenges. An SG being autonomous means that players, enabled by the SG, have control over their behavior to solve a management puzzle. The decisions are free to break boundaries and formulate new social bonds in the simulated reality. An SG being (de)centralized means that players are situated in a service network topology with the delegation, encouraging communication between teammates. An SG could be of a centralized form if the network deploys centralized authority rather than parallel functioning. An SG being objective-oriented means that operational archetypes, such as balancing, optimization, and prioritization, are present in rational agents. Therein, we have many utility strategies to choose from and program in simulation vendors, such as the one used in this work, AnyLogic. An SG being proactive means that players are exposed to adverse, or an unexpected event, which is mostly for the sake of learning objectives, since improved awareness of risks facilitates process improvement in safety and quality management [19]. Non-punitive response to adverse events is a significant improvement of the safety culture in the healthcare organization [20]. An SG being translational/transdisciplinary means that the SG could be for research, education or a hybrid of both, which becomes the enabler for participants' successful engagements in different disciplines, academia and/or non-academia.

A simulation game is used to simulate an existing real system and process [17]. An SG designed to teach, elaborate, and perform research and training on a target group and particular context [21] is considered to be the continuation of the theory into a content science. Performance indicators provide stimuli for changed behaviors or organizational models.

1.3 Simulation game design

1.3.1 Physical simulation

This SG for patient transportation is developed based on the multi-agent language. Fig. 1.2 presents the semantic. This is the run-time semantic of Unified Modelling Language, a frequently chosen formalism for the description of object-oriented simulation models. This set of classes specifies the attributes and operations of agents. Agents are goal-oriented, and their triggering behaviors include simulating patients, selecting higher-level destinations and assigning ambulances. The activity inaugurates as long as the local hospitals disseminate requests for transfer and end when the patient arrives at a destination by a maintained ambulance. The transfer only happens to severe and critically ill patients.

The SG will get participants to recognize the environment and activate them to achieve the intended learning outcomes. We implement the following rationale. Different players as first-line managers in the line organization have different access to information. The SG starts with patient admission, which is followed by the triage process. Hospital congestion levels are calculated based on the number of admitted patients, the number of delayed patients and bed capacity. If the decision is made to relocate the patient to another hospital, the player, as logistical manager, has to call the ambulance dispatcher for a patient transportation service. Patients will not be allowed admittance when all beds are full. Only station managers and the dispatcher may use ambulances. Bed utilization is only visible to the person responsible for hospital logistics. Due to information asymmetry, decisions correspond to the exact conditions of the stakeholders. The second rationale is that transportation coordination is the only focus, rather than processes inside hospitals. The user is encouraged to reduce healthcare impacts by balancing flows of patients and ambulances. A combined physical simulator and the players' abilities to exert impacts recognize the adopt theory as proposed.

Decentralized service system topology. The urban road transportation network physically connects the caregivers — the duration of transportation on the road network is based on geographical spatial representation. Duration of service in the hospitals is assumed to follow exponential distributions. The dispersed operational costs, as well as patients' waiting and travel times, are aggregated and visualized in the information retrieval system. The reactions of the user can exert influences on patient waiting lists, travel time, waiting time and fleet operation in the service network. The topology is changeable but is usually predefined by the SG instructor, and

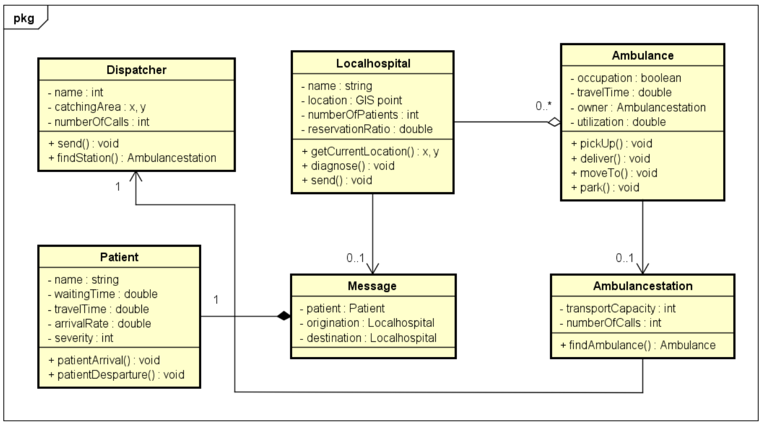

Fig. 1.2. Multi-agent language for specifying attributes, operations and the interdependency

simulation inputs might vary across sessions.

Autonomous agents. Agents place in the continuous space of the infrastructure network and resources in the healthcare delivery. The road network connects the hospitals. Vehicles operate between the hospitals, local health centers and ambulance stations. The vehicle is assumed to find the shortest path between locations, adapting to the threshold of the response time. In addition to programmed rules, the communication between the person responsible for hospital logistics, the dispatcher and the ambulance stations can be affected by the states of agents. Since agent behavior in the model depends on the decisions and access to resources of the players, the transportation is based on not only the states of resources but also the players' command and control in a timely and appropriate manner.

Objective-oriented behaviors. Ground ambulances are active mobile resource units and can have different fleet sizes at different hospitals. The fleets are the message receivers of transportation proposals and react according to the order. The ambulances are modeled as non-hierarchically operated. The fleets have access to the information of the road network and identify the road segments that minimize travel times. A routing subagent is embedded within the ambulance agent to receive the proposal and motivate the vehicle. As Fig. 1.3 presents, the SG is designed in AnyLogic, a simulation integrated development environment that enables insights and optimizations in business applications and the integration of personal digital assistants that allow the players to record their decisions in different scenarios.

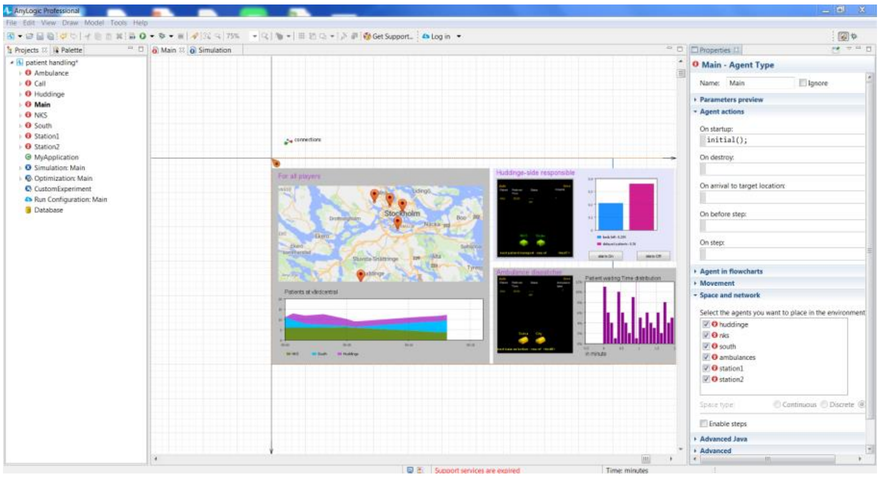

Fig. 1.3. Canvas of SG design, based on AnyLogic

1.3.2 Command and control

The SG is computer-managed with full participation from the learners. Control panels allow the players to enter content into the SG. The control panel for each user is explicitly outlined with information retrieval and decision-making interactions based on real patient transportation [Figure 3]. The command and control of players can manipulate autonomous agents between states in the simulation at runtime.

Ambulance dispatcher. As Fig. 1.4 presents, the transportation proposals are generated from hospitals. They proceed to the ambulance dispatcher after spatial locations are set up on the cartographic representation. The population of agents is created with relevant attributes and operates for patient transportation. The transportation proposal is defined by the hospital manager based on the endurance of the patient. Referring and receiving hospitals could apply to a specialized hospital in the network. The ambulance dispatcher is informed by the time-stamped receipt and holds information about the seriousness (through an on-off alarm by a hospital) and circumstance of the patient. The hospitals might transmit alarms to the dispatcher in conditions of reduced bed capacity or a large number of delayed patients. The ambulance dispatcher is responsible for communicating the transportation proposal to a selected ambulance station by taking into consideration the transportation capacity.

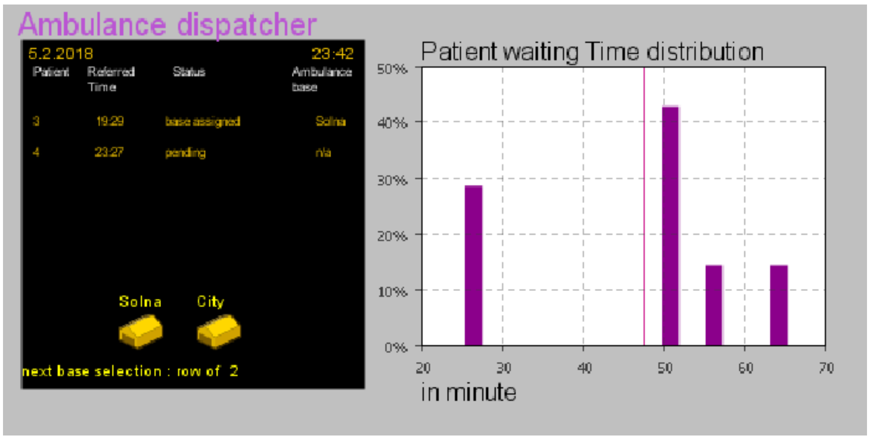

Fig. 1.4. Control panel for the ambulance dispatcher

Ambulance station manager. As Fig. 1.5 presents, ambulance in-and-out flows are the system behavior of patient transportation with spatial diversities. The operative conditions of ambulances between the hospital and the ambulance station are determined by a set of rules, including the response time threshold (9 minutes) and the maintenance time window (after five rolls or 120 minutes) in this network. The threshold is achievable by adapting the route and speed of the vehicle. The number of delayed patients might increase if all the ambulances dight up. Proposals are subject to different urgencies, origins, and destinations. Vehicular operation strategy is subject to the player's recognition of capacity, resource availability, and demand. An efficiency-oriented operation strategy might achieve a substantive reduction in the length of the waiting list but require extreme rolls of the ambulance faculty.

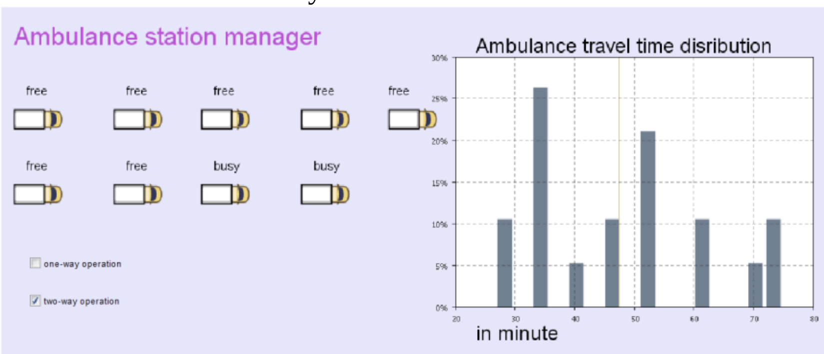

Fig. 1.5. Control panel for the ambulance station manager

Hospital logistics manager. As Fig. 1.6 presents, the hospital has the standard medical pathway of triage, diagnosis, and discharge. The triage reveals the acute situations of the patients. The hospital makes decisions regarding further treatment or hospitalization. In case of further treatment, the recipient hospital has to be suggested to the ambulance dispatcher. Information regarding the recipient hospital and the status of the patient is updated as long as the transport proposal is made.

Fig. 1.6. Control panel for the hospital logistics manager

1.4 Use case example

The SG addresses an open, multi-dimensional system with many perspectives. The dimensions and perspectives implemented in the use case include:

- Productivity at the regional level
- Resource availability of providers
- Sustainability of the working environment

The use case incorporates a comparison of two fleet distribution strategies: a) two-way distribution (an ambulance has a fixed owner ambulance base for maintenance); and b) one-way distribution (ambulances are free from return point restrictions). The first scenario recreates a situation in which ambulances need to recycle especially used staff at their owners' location, whereas the second scenario allows for punctuality in any healthcare infrastructure. The second scenario is expected to be more flexible and productive concerning patient wait and travel time savings; however, the practice might not be in the best interest of ambulance base managers because it is more likely to generate extreme rolls on the faculty.

Local health centers that send a certain proportion of received patients to specialized hospitals are in the residential areas of Farsta, Hagsätra, Högdalen, Huddinge, Sätra, Teleponplan, and Liljeholmen. Farsta and Hagsätra are highlighted by the darker grey in presentation-the local health centers there prioritize more the faster discharge of patients. The three main hospitals that send and receive patients during role-playing are located in Solna, Södermalm, and Huddinge. The ambulance stations are placed in the city centers and Solna. The physical model is parametrized before the operation. Switching between operation strategies for circulating the ambulances is possible at runtime, including the one-way and the two-way operation strategies. A full hospital can send a maximum of 3 alarms to the station dashboard so that the station manager is prompted to attain capacity for that hospital first. These pieces of information and materials present to the participants working with daily operative management of patient flow through the pediatric emergency department of Karolinska University Hospital at Solna, Stockholm. The scenarios are intended to be close to actual experiences. This consideration is to facilitate the flow with personnel in healthcare systems that are more used to recognize the patterns in their day-to-day patient handlings. The instructor initiates the SG with the patient arrival and priority patterns of the 2017 operating year to contemplate the aspects of patient movement and, explicitly, of need-based assessments on a typical working day.

Statistical approximations generate patient flows. The details of statistical approval would not included in this work.

Participants are recommended to reflect upon the following points as intended learning outcomes after an operation of 72 hours in the model unit:

- Describe the complexity of healthcare practice.
- Associate operational strategies and their relevance to the indicators.
- Speculate what types of insights could be obtained for patient flows and resources.

The one-way operation strategy saves on patient waiting time and fleet utilization. In the two-way scenario, the number of patients with prolonged hospital stays is nearly 15 during peak hours [Fig. 1.7]. However, this is reduced to below 15 in the one-way scenario for almost all secondary intermediate facilities. The latter also experiences a reduced utilization of the fleet. Although the utilization variation is still considerable, the one-way operation strategy is preferred about reducing waiting times without adding vehicles.

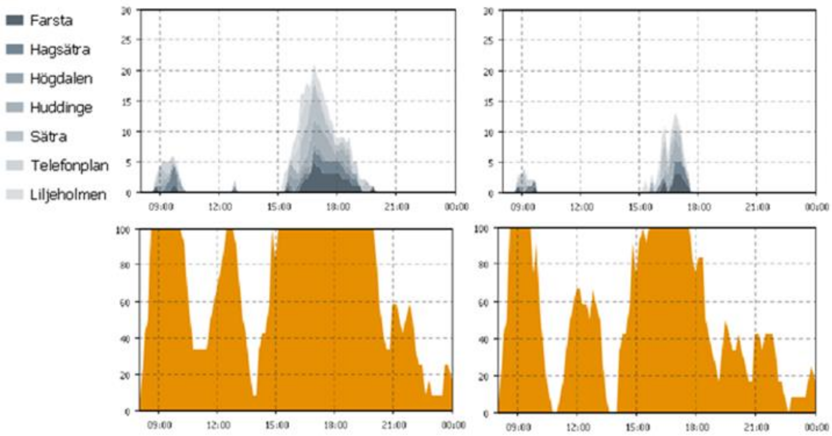

Fig. 1.7. Comparing run experiments. top-left: an hour-by-hour count of patient waiting times in the two-way scenario; top-right: an hour-by-hour count of patient waiting times in the one-way scenario; bottom-left: an hour-by-hour fleet utilization ratio (in percentages) in the two-way scenario; bottom-right: an hour-by-hour fleet utilization ratio (in percentages) in the one-way scenario.

1.5 Discussion

An SG for active learning in the management of patient flows should help to construct a declarative knowledge base needed for deep learning and improving participants' knowledge and experiences related to non-technical skills. The SG will, however, not be a passive substation. A computer-based SG may add the perspectives of the game principals that own the model. Depositing these insulated understandings from fields into a game might distort the participant's acquirement of intended learning outcomes. The challenge in medical education is the role definition of the facilitator and game principal in the context of the teacher/learner/curriculum framework [22] – as resource material providers, game principals will provide proper adjuncts and prevent healthcare people from obtaining incorrect cues.

Prevising the performance of complex systems over time is difficult. The collective behavior of agents, as shown in Fig. 1.7, is not definable at the individual level. However, simulations could recreate clinical facilities and produce an emergence. The example of patient transportation shows that, even though micro-interaction is known and is common practice in patient handling, emergence could still arise with a list of delayed patients in hospitals, depending on how the players act in the simulated scenarios.

Based on discussions with physicians, the SG reproduces the way the pediatric emergency department of Karolinska University Hospital works on a daily basis, especially the fact that some patients are merely admitted into the emergency department without assured developments. This integration is vital to support the development of the tool in the practical context [23]. However, the delivery of patients is not like sending goods and parcels since the patients are not equivalent. For highly specialized hospitals, they tend to assign away patients already assessed and those that are just in need of some bed capacity; otherwise, they receive many more patients who require an individual health planning. For the hospital manager, the appearance of a person who needs a bed is sometimes required to move other patients already in-ward. The emphasis should be extended to training humanistic dimensions of care during medical education [24]. Practically, this means that internal and external transportations are linked to each other. These details are recommended for expanding the simulation. Nevertheless, the SG is simple enough and understandable since players can see their capacity and the needs of patients. A substantial abstraction of the realm, such as the agent system used in this work, does not compromise the recognition of one's role in a healthcare system and the delivery of the message that internal and external transportation are both critical and need to be managed properly.

Patient flow is an integral element of the planning of the healthcare system, and bed allocation is an intricate part of transportation. It would be useful to have different types of beds and tiers of movability, unmovability and moveable patients with reduced safety and quality. For people who are not used to computer games, design elements need to build up the narrative for the players to reconvene their situations. As the SG is being developed, not only the personnel who are part of the quality and safety control at the children's hospital but also the clinical leaders will be invited to this gaming exercise. The next step is to test the SG with a specialized transportation system. To develop an online version, launch the AnyLogic simulation from external applications arranged in such a way to replace the practice of multiple computers simultaneously viewing the same console game.

1.6 Conclusions

Simulation models provide meaningful scenarios in which the non-technical skills of managers, coordinators, and decision makers can be trained [25]. Through simulation gaming, passive learners in curriculum-based medical education have the possibility of being active during an interactive workshop. However, interaction with sophisticated computer simulations strains the limitations of cognitive processes [26]. Therefore, for pedagogical reasons, it is essential that guides of medical professionals are the foundations of gaming narratives. Learners could play an active role in their learning by choosing a topic from the intended learning outcomes. Thus, players would stay focused in the SG to make comparisons and contracts regarding the relationship between workload and safety care.

The growing expectations regarding productive care require tools of simulation, SG, serious games, participatory simulations and more for the training, education and hands-on sessions of managers in health care organizations. Such tools can improve non-technical skills about the validation of operation strategies, changed informal organizational structures or improved working environment and culture on a daily basis. In this work, an SG of patient transportation is created that involves an ambulance dispatcher, ambulance station manager, and hospital logistical manager. Autonomous human-machine agents, reasoning, and a decentralized system are applied to pursue translational outcomes. The correct level of abstraction is achievable without distorting the motivations.

A fully developed infrastructure, in the form of a cyber-physical system, will facilitate the understanding of interactions between technology and health and validate relevant operational models. Furthermore, it might facilitate the capacity planning of selecting ambulance station locations, which is commonly handled by a governing optimization algorithm, and the development of organizational models that could support the discussion of stakeholders with competing interests.

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