Designing a Model for Flu Propagation in Emergency Departments

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***Abstract*—Influenza is an acute viral infection that primarily attacks the upper respiratory tract. The disease occurs worldwide and spreads very quickly in populations, especially in crowded circumstances like Emergency Departments (ED). Influenza can be spread in three main ways, all of which are very feasible in ED environments: by the airborne route, by contaminated surfaces or from direct personal contact such as a handshake. Our research uses Agent Based Modeling and Simulation techniques to build the model and the simulation of the transmission of flu virus contact in ED. The simulator allows us to build virtual scenarios with the aim of understanding the phenomenon of flu transmission and the potential impact of the implementation of different policies in propagation rates. This work is an expansion of the previous one carried on by other members of our research group, with the aim of developing a more flexible and reasonable healthcare system simulation and modeling.**

Keywords- Emergency department Simulator; Agent based modeling and simulation; Influenza propagation.

I. INTRODUCTION

Influenza, known as the flu, is a respiratory infection caused by a virus. According to the Centers for Disease Control (CDC), the burden of Influenza during the 2017–2018 season was the highest since the 2009 pandemic, resulting in more than 22.7 million medical visits, 959,000 hospitalizations, and 79,400 deaths in the United States [1]. The flu virus usually spreads from person to person through coughing or sneezing. The flu can be contacted by touching a surface that includes the flu virus on it and then touching the nose or eyes [2]. Infection with the influenza virus can cause significant morbidity and mortality. This is specifically true in vulnerable populations with an underlying disease in an indoor situation like Emergency Department areas.

Emergency Departments are one of the most complex and dynamic healthcare systems, receiving an increasing demand, and usually being overcrowded. ED has a continuous activity, operating 24 hours a day every day of the year. The existence of a communicable disease within the emergency services, especially a seasonal contagious disease [3], can have a negative influence on the service offered, and increases the risk of both, the infection of health personnel and of worsening of the underlying disease of the patients attended in the ED. The resource planning of ED is complex because its activity is not linear, and it varies depending on time, day of the week, and season. Simulation becomes an important tool for modeling complex systems that include many elements, a large number of interdependencies among such elements, and/or considerable variability [4]. Discrete Event Simulation (DES), System Dynamics (SD), and Agent-Based Modeling and Simulation (ABMS) are the main three approaches used in the simulation of healthcare systems. However, the ability of ABMS to represent both human intention and interaction, makes it a better-suited approach than DES and SD for modeling systems like healthcare one, that are based on human behavior and interaction [5][6].

A solid example of an Agent-Based Model for Hospital Emergency Departments is presented in [7], which has been designed following a system analysis performed at different hospitals, under the advice of healthcare professionals with many years of experience. Agents are modeled using Moore state machines that interact inside a specified environment, enabling the study of the dynamics of complex systems without having challenges in getting exhaustive system definitions that are required by other modeling approaches. The validity of the model and the simulator for representing the real system have been checked applying the verification and validation process recommended by [8]. High Performance Computing (HPC) has been used due to the specific features of the model (a great number and variety of agents), the amount of data to be computed and finally the number of executions of the Simulator needed in the experiment.

In [9], the authors use such Emergency Department ABMS as the core component of a decision support system that aids healthcare managers to make the best-informed decisions possible, and causing better use of resources, achieving a more efficient and improved patient care system. A Length of Stay (LoS) index is used to evaluate the efficiency of ED. Among others, the experiment let to conclude that the estimated patient LoS can be reduced using a larger number of ED Staff, and/or more experienced ED staff, and/or the modularity in the ED different sections.

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The aim of our work is to develop a model and a simulator that, used as Decision Support System, aids the administrators and heads of the ED to get additional knowledge about how the flu virus propagates, how it can influence over the patients ongoing treatment and the effects over sanitary staff, with the purpose of identifying strategies of improvement.

The remainder of this article is organized as follows. Section 2 presents the Emergency Department Simulation. The Flu Propagation Model is detailed in Section 3. Finally, Section 4 closes this paper with conclusions and future work.

II. Emergency Department Simulation

The Emergency Department is a healthcare unit that offers immediate care to patients, also called the emergency room, emergency ward, accident & emergency department, or casualty department [10]. ED is one of the most complex and dynamic areas in a hospital. Its activity is not linear and depends on several factors, including human behavior.

Simulation becomes an important tool for modeling complex systems that include many elements, a large number of interdependencies among such elements, and/or considerable variability [4]. It is impossible to model all the functionalities of such a complex system because there are lots of factors that can influence the different components and worth noting. Actually, it is useful to make a very abstract perception in mind from the considered real world. Moreover, we have to choose a proper methodology to find a better answer to our problems.

Discrete Event Simulation, System Dynamics, and Agent-Based Modeling and Simulation are the main three approaches used in the simulation of healthcare systems. DES simulates just the significant events of a system. It frequently is characterized by a series of tokens that hold up in turn for a service provider that forms them some time they proceed on to another portion of the system [7]. SD, which is used to simulate large systems, began to be used as a simulation method in healthcare operational supervision later than DES. An SD simulation is based on continuous space and does not model individuals, it simulates the whole system along time.

Healthcare systems are based on human interactions, and the ability of ABMS to represent both, human intention and interaction, makes it an appealing approach, while DES and SD are not well-suited approaches to model them [5][6]. A clear illustration of the potential use of ABMS in ED modeling is shown in [11].

Agent-Based Modeling and Simulation is considered as a systemic approach with a bottom-up architecture that can be used as a productive method to get the macro-level point of view from the micro-level evolution of agent interactions [12], [13]. The main components of an agent-based model are environment, agents, and interactions [14].

We based our model on a previous Emergency Department model (ED-Simulator) that has been developed as part of previous research work [7][9][13] by our research group, High Performance Computing for Efficient Applications and Simulation (HPC4EAS), of the Universitat Autònoma de Barcelona (UAB). Such model has been designed with the participation of ED staff from the Hospital of Mataro (Hospital of medium size that gives care service to an influence area of 250,000 people attending 110,000 patients/year in the ED), and the Hospital of Sabadell (one of large size that gives care service to an influence area of 500,000 people attending 160,000 patients/year in the ED). It is a pure Agent-Based Model, formed entirely of the rules governing the behavior of the individual agents which populate an ED.

Two kinds of agents have been identified, active, and passive. Active agents represent people, who act upon their own initiative: 1) patients; 2) admission staff (who receive patients just when they arrive at the ED); 3) sanitarian technicians (who help certain patients to move from one place to another of the ED); 4) triage and emergency nurses (the former receive patients after their admission for establishing their priority level and the latter are involved in the diagnosis and treatment phase); 5) and doctors. Passive agents represent systems that are solely reactive, such as the loudspeaker system (that is used by ED staff to communicate with patients that are in the waiting rooms), patient information system, pneumatic pipes (that are used to send the trials from the diagnostic zone to labs), and central diagnostic services (radiology service and laboratories).

As it is shown in Figure 1, ED is divided into different zones in which different types of agents may act, maintaining interactions that also may be different. Such interactions are carried out through communication. For this reason, the model includes both an environment and a communication model.

The input of our model are the patients who arrive to get emergency services. According to the Spanish Triage System [15], very similar to the Canadian Triage System, after the patient arrival, and the registration by the admission staff has been completed, based on the severity of their situation in triage, patients are categorized taking into account their priority level. There are 5 different values, level 1 is for the most critical situation and it is named resuscitation, and level 5 is for the least critical one (non-urgent).

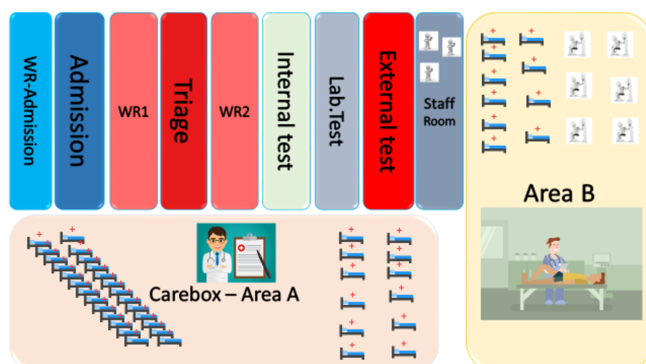

Figure 1. Different areas in Emergency Department.

There are different areas in EDs Spanish standard (Figure 1): Admissions Area, Triage Area, Diagnosis-Treatment Zone, Waiting Rooms, and etc. After triage, patients with diagnosed acuity level 1, 2, and 3 are treated separately and allocated in Area A, and patients 4 and 5 are treated in a separate area identified as Area B. The admissions and triage sections apply the same healthcare staff, but doctors and nurses are different for Area A and B [13].

III. FLU PROPAGATION MODEL

In order to create a contact propagation model of flu by ABMS method, we will define all actors involved in the ED process and their specific function and behavior such as: doctors, nurses, admission staff, laboratory technicians, auxiliary personnel, cleaning staff, patients and companions. Also, the following terms and items will be defined: ”Transmission vector” as any agent capable of transmitting the flu virus, ”Susceptible” as any agent that has a risk to acquire the influenza infection, and ”Prevention policies” as behaviors performed by members of the sanitary staff in order to attempt to control the rate of propagation of flu and other contagion infections.

We propose four types of contact transmission in which a transmission vector is required:

a) Direct transmission: flu virus is transmitted from a transmission vector to another susceptible agent.
b) Semi-direct transmission: a transmission vector spreads the virus to an immune person and then s/he spreads that to a susceptible person.
c) Semi-indirect transmission: once a passive agent is infected by flu virus, then another passive agent touches it, and after a chain of contagion, an active agent is in contact with that.
d) Indirect transmission: when a transmission vector touches medical equipment or objects in the ED environment, and flu virus is transmitted to the object, later, a susceptible agent (patient or healthcare staff) has contact with the same object and acquires the microorganism.

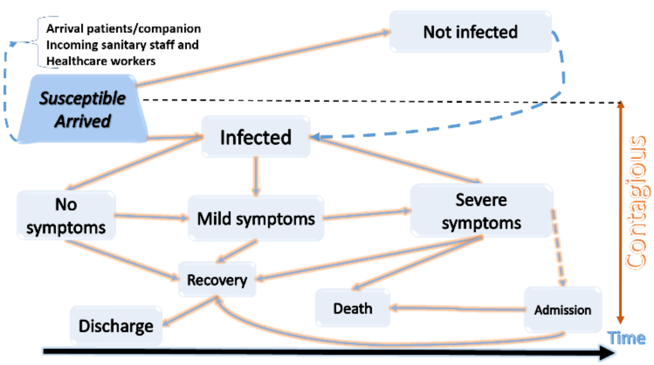

Figure 2. Flu severity and propagation possibilities evolution in ED.

As stated before, the aim of this research is to understand how the influenza is influencing and changing the acuity level of the patient, how it is affecting sanitary staff, and consequently, how this is changing the behavior of the ED. If we apply for a screening at the entry point of incoming individuals, we may find different types of individuals. People with a negative test result will be categorized as 'not infected'. Obviously, they are susceptible to get infected. Then, based on the results, we can categorize positive people with 'no symptom', 'mild symptom', and 'severe symptom' [16]. Figure 2 shows the different states of flu virus infection, in its lifecycle in a host patient.

In [17] the authors show the probability of MRSA infection in ED, and how many people are involved with MRSA contamination. However, in our research, the idea is not only how the propagation of the flu virus in ED is, but also how this propagation is affecting people. Affecting people or patients means that the acuity level of them could improve gradually if there was not any flu infection. If patients are exposed to a flu virus contamination, they will require more attention and more use of ED resources like health care staff, facilities, care boxes, etc. As a result, the LoS will be higher and ED will become closer to saturation. In some cases, this leads to overcrowd, and overcrowd means more risk of epidemic and propagation in the area. In this situation, the relative position of the body influences human thermal plume (e.g., a seated inclination of the body), which is considered to affect the air velocity of convective flows around a human being, and hence the ability to carry small droplets [18]. As an indoor area, every section of ED has a strong potential of getting infected by flu, and being beneath high risk of flu propagation. Places, where patients type 1, 2 and 3 have been held, have almost no risk, because they have no contact with others, and in addition they have not been waiting in any queue before admission. Contrary to that, patients with acuity level 4 or 5 spend long time in the waiting rooms and ED wards. So, probably they have a highest possibility to get infected. Figure 3 shows the different probabilities of risk infection for each section of the treatment process in ED.

The risk of propagation of the different areas in the ED also depends on the number of individuals that stay in. It is high in zones like waiting rooms, ED wards and admission zone, and low in triages room, examination room or care boxes. Flu propagation is being facilitated in limited (indoor) areas, so, quantifying the probabilities of the virus transmission in some specific areas like waiting rooms, wards, etc, is expected in this research, and this can also be considered as a framework because of its independent behavior [19]. Consequently, calculation leads to be more complicated. The key point that arises here is to find the relationship between the size of an indoor area and the propagation of infection there, and how many people should be there in max to minimize or reduce the rate of contagious. Therefore, some new variables like fragility and the ratio of area size per capita have to be added to our previous model. Fragility is an index that indicates how fragile anybody is: as more fragile anybody is, the more severe will be the flu infection. There are some indicators for each individual to show the amount of being at risk for getting an infection in a contagious situation.

A combination of patient age (ag), acuity level (al), underlying diseases (ud), etc. play a role to generate the fragility index of each person: Fr(p)=f(ag,al,ud)

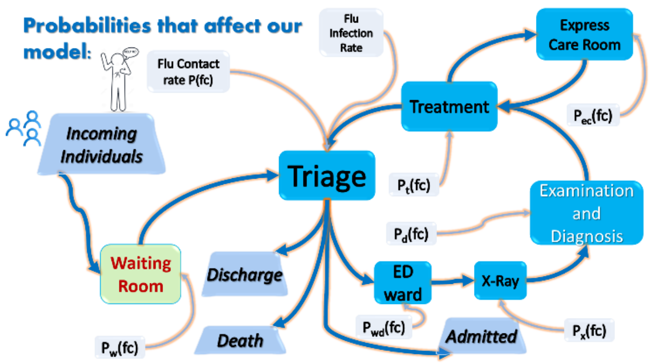

Figure 3. Flu severity and propagation possibilities evolution in ED.

As Figure 3 shows, there are different possibilities of getting the flu virus based on the flu contact rate of each area inside the ED:

$$P(getFlu): \{ P_t(fc), P_{ec}(fc), P_d(fc), P_{wd}(fc), P_w(fc), P_x(fc)\}$$

Moreover, Flu Contact rate *P(fc)*, Flu Infection rate is also calculated. *P(fc)* holds the probability of flu transmission in triage. We use $P_t(fc)$ to represent the probability of flu contact rate in the process of treatment. Pec(fc) shows the possibility of transmission in express care room, Pd(fc) represents the probability of propagation in the examination room, Pwd(fc) is the propagation probability in wards, Pw(fc) shows the probability in the waiting room and Px(fc) is for x-ray and labs. There is another variable named 'status' for each agent (active/passive) with the following possible values: Susceptible or non-carrier, Carrier, Infected, and Recovered. We can categorize patients into two parts. The first part includes patients who do not have a clear possibility of being carriers or infected with the flu virus. In this case, the healthcare staff assumes that this patient is non-carrier; and the second part is those patients who are known or can be assumed to be carriers or infected with the flu.

The authors in [17] conclude that some preventive facilities like isolation of patients can avoid the transmission of MRSA bacteria between patients. However, in flu not only physical contact between patients should be banned, but also they have to use some facial masks or facial shields because the flu virus is also airborne. Actually, as a result, we aim to limit the probability for propagation of flu in the ED, and, by taking some preventive actions in EDs, the number of patients who contact the flu can be reduced. On the other hand, the single best way to prevent seasonal flu is to be vaccinated each year, but good health habits, like covering one's cough and washing hands, often can help stop the spread of germs and prevent respiratory illnesses like the flu.

$$P(AgainstFlu)=f(Vaccinate,Handwashing,SanitizeHand, IsolatedMaterial,MedicalMask,MedicalShield,SocialDistancing, AreaSizeCapita)$$

There are passive indicators that are assumed to affect the propagation rate in an indoor area. We hypothesize that the flu transmission rate in Emergency Departments may be influenced by area temperature (T), humidity (H), air pressure (P), air condition speed (AS), air condition direction (AD), air pollution in ED (AP), UV radiation (UV), airborne particles in ED (AbP), etc. So, we can assume a strong correlation among these indicators:

$$C\ (FluTransmissionRate)= f\ (T, H, P, AS, AD, AP, UV, AbP)$$

IV. Conclusion and Future Works

In this paper, we opened a new idea on our group's previous work in the area of modeling and simulating the emergency department. Although we have experience in simulating MRSA in our ED-simulator, in this research we are initiating, to model and simulate how influenza propagates in different areas of an ED, how it influences patients underlying diseases, and furthermore, what are its effects on healthcare staff.

Our journey started with initiation and investigation on the topic area, and it continues with data gathering and problem articulation. Then, we initiate a conceptual model for our idea, and it will continue with model design and implementation, the model calibration, validation and verification. Finally, we will be able to analyze the results. The resemblance of this virus's lifecycle and its effects on ED with some other diseases like Covid19, Chickenpox, Mycoplasma pneumonia is also hypothesized.

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