Agent-Based Model to Simulate Outpatient Consultations at the "Hospital de Clínicas"

Work-in-Progress Paper

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***Abstract*—The "Hospital de Clínicas" is one of the busiest hospitals in Paraguay, with an average of 1150 outpatient per day. Usually, patients have to wait a very long time to be treated, causing anger and discomfort. This paper presents an agent-based model of the process of outpatient consultation for the Department of Internal Medicine. The goal is to have a better understanding of the process and evaluating different solutions to reduce the patient waiting time.**

Keywords- agent-based model; Simulation; consultations; patient flow; outpatient.

I. Introduction

Patient waiting time is a significant topic in medical institutions, and has considerable effects on patient's satisfaction. In special, long waiting times and long queues of patients are the most prominent problems [1].

These problems also affect the Paraguayan "Hospital de Clínicas" (CH). The CH has more than 45 medical specialties; and it is one of the largest, complex, and busiest hospitals of Paraguay. The Statistics Department from the Hospital reported that 17,270 attentions were recorded for outpatient in the first half of January 2016. These numbers imply an average of 1,150 visits per day [2].

During a survey it was found that patients in the outpatient area must wait several hours before being treated. Patients line up in two different places: cash register and admission.

In order to understand the process of outpatient consultation and evaluate different solutions aimed at reducing patient waiting time, we proposed to simulate that process. This paper presents an agent-based model (ABM) for the process for the outpatient consultation at the Department of Internal Medicine of the CH.

ABM is an approach to model systems comprised of individual, autonomous, interacting "agents". Agent-based modeling offers ways to more easily model individual behaviors and also how these behaviors affect others [3]. ABM offers some advantages such as: an increased detail in experiments based in simulation, a transparent learning process, and the ability to control and easily modify individual behaviors [4].

ABM has seen a tremendous growth in many areas over 15 years and more recently in hospital and healthcare settings. One of the primary applications of ABM to hospital environments examines patient flow in Emergency Departments (ED)[5][6].

An evolving literature exists regarding applying ABM, alone or together with other technique, to the operations of ED. In general, this literature addresses system-level performance dynamics, quantified in terms of patient safety [7], economic indicators [7][8], staff workload and scheduling [5][9], and patient flows.

More recently, other works have modeled improvements to patient flow using an ABM running on High Performance Computing resources [10]. The ABM was built with NetLogo. More extensive considerations of ABMs for patient flow in EDs were developed by the same researchers [11][12], including the use of an ABM within a decision support system for EDs [4].

For the topic of outpatient consultations, we found works that use the discrete event simulation models, which implies that the status of the system only changes due to certain events, such as a request for a consultation or completing a consultation [13]. One of the most popular softwares used is Arena, which is used to develop the simulation model in order to examine the patient flow, especially the waiting time [14].

The rest of the paper is organized as it follows. In Section II, we explain the process performed by a patient to make an appointment at the CH. Section III presents the method to be used for the model. Section IV describes the simulation model proposed and Section V presents the conclusion of this project.

II. Current System in Outpatients Consultation

In this section we will describe the current process to request an appointment with the Internal Medicine doctor, which is shown in Fig. 1:

1) Request a service: At the beginning of the day, box officials receive the schedule established for the doctors at seven o'clock a.m., which contains the number of patients to be treated in each deparment. Patients line up to request a service (waiting time to request a service: t_{wrs}) and pay when it is necessary. The officials proceed to register and give the return receipt for the payment (Time for register a required service: t_{rs}).

proceed to call patients (health care Time: t_m). If it is the First Consultation, doctors fill data about patients, such as treatment forms, prescriptions, and other sheets. Doctors may requiere patients a next appointment or discharge them. Doctors inform nurses next appointments. Once all the patients have been served, doctors return health records to nursing. Officers pick up records and leave them in the Central Record.

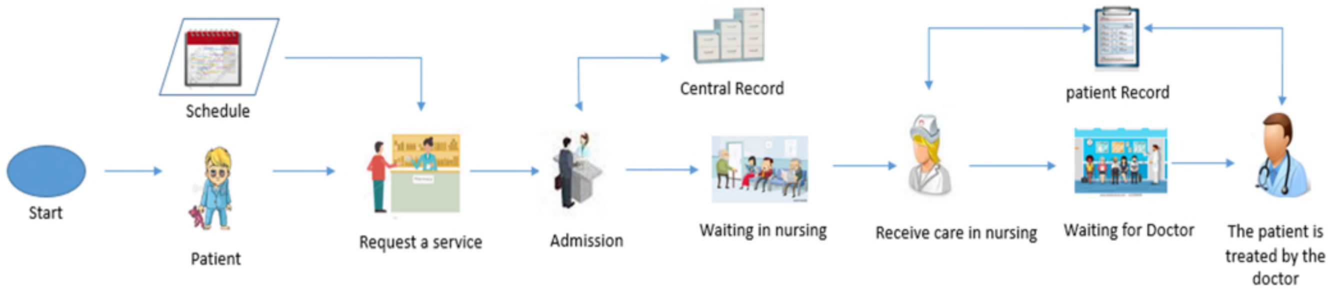

Figure 1. Process to request an appointment for Internal Medicine

2) Admission: After request a service, patients go to admission office and line up again to signing (waiting time in admission or signing: t_{wa}). Here, patients present their identity card or passport and the receipt obtained in the cash register. Officials ask what type of consultation patients need: First Consultation, Control, Interconsultation (First consultation time: t_{af}; Control Time: t_{ac}, Interconsultation time: t_{ai}). In the First Consultation, officials fill the header of the patient record with name, surname, identity card number and other extra information. If it is not the First Consultation, patients give their record number. This number is recorded in the receipt (time to sign a patient: t_a). When a certain amount of record numbers are collected, the official goes to the Central Record to collect the records and take them to the nursing. The last process is repeated until they have engaged all patients.

3) Waiting in nursing: After signing, patients go to nursing and wait for the nurse call (Waiting time in nursing: t_{wn}).

4) Receive care in nursing: Here nurse registers the patient physical data (weight, height) and vital signs (blood pressure) (time nursing care: t_e). Then, patient is assigned to a doctor. After this, patient waits for the medical consultation (medical consultation standby time: T_{wmc}). In case a patient with previous appointment arrives, nurse checks the appointment and give him a certificate of his appointment. Then, this patient goes to the cash register and admission in order to confirm his appointment.

5) Waiting for Doctor: After received care in nursing, in the waiting room, patients wait to be called by the doctor.

6) The patient is treated by the doctor: Doctors first go to the waiting room and take the records of patients assigned for that day. Then, they go to their consulting room and

III. METHOD

Agent-based simulation (ABS), or agent-based modeling (ABM), is a modeling and computational framework for simulating dynamic processes that involves autonomous agents [4].

Agent-based modeling offers ways of easily modeling individual behaviors and how behaviors affect others in ways that have not been available before. There is much interest in developing agent-based model for many application problem domains. Applications range from modeling agent behavior the spread of epidemics, to project the future needs of the healthcare system. Progress in the area suggests that ABS promises to have far-reaching effects on the way that businesses use computers to support decision-making and researchers use agent-based models as electronic laboratories to help in discovery [3].

Agent-based simulation (ABS) is an approach to model systems comprised of individual, autonomous, interacting "agents". The interaction is a key characteristic since the smallest element defines the functionality of the system. Such interaction data has incredible potential to address complex features and dynamics of the objective system. Agent-based modeling offers ways to model individual behaviors more easily and to see how behaviors affect others in ways that have not been available before [3]. Furthermore, in the micro-level, the spatial agent-based simulator is not a design for any specific application. Instead, it is just a general behavioral simulator to simulate interaction among the smallest components of the Internal Medicine health system.

The reasons why ABS was selected to model a department of Internal Medicine of the HC in this study are: (1) In a department Internal Medicine system, agents have dynamic relationships with other agents. For example, patients have dynamic relationships with nurses, preceptors, doctors and patients. These dynamic relationships are important to consider and, by their nature, well suited to be modeled as part of agent-based model. (2) The agents have a spatial component to their behaviors and interactions, i.e., most of the agents in outpatient consultation need to move around and the spatial location is one of the key states which determines their potential interacting object and state transferring. (3) A large number of agents, agent interactions and agent states are important for information extraction. In a department of outpatient consultation, services are provided via multiple interactions, patients pass through a department of Internal Medicine. These interactions can deeply reflect the functionality of the target system. (4) Model reusability.

The first step of the job is to make a conceptual model of system operation, from which the computer model is capable of simulating the system. We are planning to use the simulation environment and high-level platform called Netlogo.

IV. OUTPATIENT CONSULTATION MODEL

A collection of information that is presented in this paper proposes a working model that aims to reduce waiting times for patients attending the CH.

1) *Active agents:* During the collection of information they are the active agents representing individuals and entities acting on their own initiative.
   - Box official: administrative staff to which the patient comes to get a receipt.
   - Admission official: administrative staff to which the patient comes for a slot, update their personal data and request the opening or searching for the medical record.
   - Nurse: health personnel which is called by the patient to carry out pre-outpatient activities.
   - Doctor: the doctor fills data about the patient, such as treatment forms, prescriptions, and other sheets. The doctor may assign the patient to a medical appointment, discharge the patient, or ask her to return after a certain period of time.
   - Central recorder officer: administrative staff in charge of saving the medical records of patients.
   - Patient: person who comes for treatment.

2) *State variables:* Agents move from one place to another interacting with other agents. During this time as a result of interactions each agent changes its state. This behavior is perfectly represented by a state machine, so we have chosen a state machine to model all agents. Specifically, the agents are represented by a Moore machine.

An initial set of state variables defined through the round of interviews with doctors is based on the minimum amount of information necessary to model each patient and staff. Such initial set of state variables is shown in Table 1.

TABLE I. INITIAL SELECTION OF STATE VARIABLES AND THEIR VALUES.

Variables	Values
Name / identifier <id>	Unique per agent
Location <location>	Admission; consultancy room; waiting room; nursing; central file; patient records.
Action	Idle; requesting information from; giving information to; searching; moving to.
Physical condition	Hemodynamic-constant; Bartel index.
Symptoms	Healthy; cardiac/respiratory arrest; severe/moderate trauma; headache.
Communication skills	Low: medium: high
Level of exprerience (Staff)	Low: medium: high.

3) *Inputs:* The entries represent all the ways that an agent can accumulate information. In the case of a person, this represents everything that the person sees, hears, smells, tastes, or feels, but really most entries represent vision or sounds, those entries are communication received by the agent. The next state of an agent depends on the current state.

4) *Outputs*: the agents are represented by Moore machines, each state can only have a different output. Some of the outputs where used of the simulator wants to analyze are waiting time of each stage (e.g waiting time for service request: T_{wrs}, time service record: t_{rs}, time of admission: t_a, waiting time in admission or signing: t_{wa}, first: t_{af}, control: t_{ac}, interconsultation: t_{ai}, waiting time in nursing: t_{wn}, time nursing care t_{we}, medical consultation standby time: T_{wmc}, while health care: t_{wm} and others).

5) *State transitions:* At each time step the state machine moves to the next state. This may be another state or the same before the transition. The next state the machine takes is dependent on the input during that state. The input may be more accurately described as an input vector (I) that contains a number of input variables, each one may take a number of different values. As this is a Moore machine, the output depends only on the state, so each state has its own output, although various states may have outputs that are identical. Again, the output is more accurately described as an output vector (O), a collection of output variables, each with a number of defined possible values. Transitions between states are dependent on the current state at time t (S_t) and the input at time t (I_t) [4].

6) *Passive agents:* Passive individuals do not act alone, but react to the actions of the active individuals. These liabilities agents do not have the same complexity as the active agents, as they are not entities that move by the department. An example of a passive agente is a computer system.

7) Environment: Without the environment there is no place where agents can interact with each other. In this model the environment is the outpatient department of Internal Medicine. The operation of outpatient hospital is based on processes consisting of different stages or phases in which each patient is passing from its admission into service.

A generic outline of a department outpatient Internal Medicine is shown in Fig. 2. The areas represented in boxes were explained above.

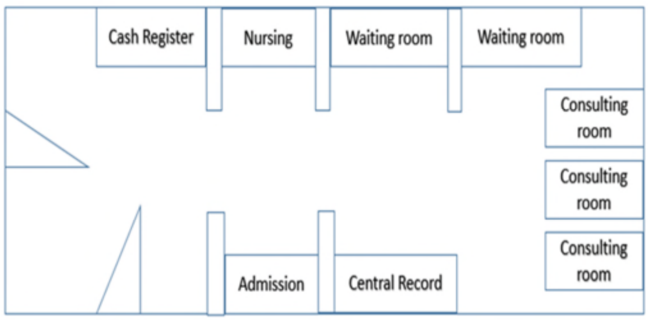

Figure 2. Representation of the environment of an outpatient department.

V. SIMULATION

The simulation provides a safer and more efficient way to try new techniques and processes with the goal of improving the efficiency of the outpatient management. A sufficiently complete model can be used to test and ensure real system changes without compromising real people. In addition, a simulation can be used to test a much too large sample set to study in a department consultation, and also can be done in a much smaller amount of time.

The advantages of using simulation is that it allows the automatic search for scenarios that provide the best solutions to a set of constraints and future states.

As the basis of a support system decision to reduce waiting time for patients is to develop a simulator that will have to run multiple simulations with combinations of different parameter values, each combination of values representing a different scenario simulation. There are a large number of combinations of values that constitutes the parameter space. In equation (1) the parameters that can generate a large number of different scenarios observed.

$$n_{scenarios} = n_{number\_admissions} * n_{time\_admissions} * n_{number\_signings} * n_{time\_signings} * n_{number\_nursing} * n_{time\_nursing} * n_{number\_doctor} * n_{time\_doctor} \quad (1)$$

With the simple model used in the simulator, there is a very large number of combinations of parameter values, large enough so that there is the possibility of launching each one manually. Therefore, parametric simulations, a way in which the simulator launch a set of simulations, with all combinations of values of the different parameters are required.

In general, the time to compute a time interval of a simulation based on agents is the product of time it takes to simulate the actions of an agent within the world of simulation in this step. In the model described agents in the simulation are the hospital staff and patients.

The simulator will be conducted by time. Time is divided into discrete, identical intervals and period each time step the agents operating system.

Each time step is divided into two phases. Assuming that the simulator this at time t, the phases are:

First, each agent processes the inputs of the last phase, (I_{t-1}) and according to that input and the state as it was during the last step (S_{t-1}) and changes to its new state S_t. Second, each agent emits its output to its current state, O_t. This output is input using receivers to switch to the next state.

At each time step, each agent changes state. It may change to the same state it was in the previous state, but there is nonetheless a change.

The metrics that are to be used for each state input I_t and output O_t are: waiting time to request a service: $t_{wrs,}$ Time for register a required service: t_{rs}, time admission: $t_{a,}$ waiting time in admission or signing: $t_{wa,}$ First consultation time: t_{af}, Control Time: t_{ac}, Interconsultation time: $t_{ai,}$ waiting time in nursing: $t_{wn,}$ time nursing care: $t_{e,}$ medical consultation Standby time: $T_{wmc,}$ health care Time: t_m

The machine simulation has been chosen as the basis for when the simulator is implemented because NetLogo has all the features needed to implement a model of this type. NetLogo is a simulation environment agent-based model. NetLogo provides a basis for machine simulation agent-based system.

There are no preliminary results available yet, but we want to implement the simulator to verify the proposed model, obtain the different scenarios to see which one is the best to reduce the waiting time of patients.

The run time of a simulation step, in an agent based model simulation, is the product of the time it takes to simulate the actions of an agent and the number of agents in the simulation world in this step. In the model described, agents in the simulation are the hospital staff and patients. During simulation, the hospital staff is fixed, does not enter or exit the simulation. On the other hand, patients are constantly in and out of the simulation. This changes the load of each time slot simulation basing on the equation (2) that calculates the running time T_i in step i, with the number of hospital staff h, the number patients in the simulation in step i and the runtime of a t_{agente} agent.

$$T_i = (h + p_i)T_{agente} \quad (2)$$

We assume that the runtime of an agent is a fixed value. In different simulations, the number of hospital staff can change, but during one simulation, the number of hospital staff is maintained. Concerning the number of patients, this can change from one simulation step to the other because there are patients in and out, but within each simulation step, this number is constant. For a simulation that takes n steps, equation (3) shows the formula.

$$T = (h_n + \sum_{k=1}^{n} p_k)\, T_{agente.} \qquad (3)$$

A good configuration made with the aim of reducing the waiting time for patients will also come with a shorter execution.

In order to generalize the process of all patients, the next status will be decided by probability distribution during simulation. The distribution model of the probability was based on the statistical data from the department outpatient Internal Medicine. Figure 1 indicates the general process-transfer strategy during the patients stay in department outpatient Internal Medicine, P1(%), P2(%), P3(%) and P_n (%) represent the probability of the next state transition separately. All of the probabilities follow some probability distributions. The probability density function of the distribution is decided by several key parameters based on the statistical analysis of doctor's decision and patient's behavior, the value of these parameters are estimated by a tuning process from real historical data of the specified department outpatient Internal Medicine. The uniform forms of the density functions are:

$$P_i = f\,(LoS, age, level) \qquad (4)$$

$$\sum_{i=1}^{n} P_i = 100\,\% \qquad (5)$$

$$P' = f'\,(ToT, age, level) \qquad (6)$$

$$\sum_{i=1}^{n} P'_i = 100\,\% \qquad (7)$$

where LoS is the patient's length of stay and age is the age of the patient, which also has big influence to the probability of status transition. Level is the acuity level of the patient and ToT is the type of test service or diagnosis by doctor. The functions f and f' are the probability density function.

These functions will be implemented by analyzing real historical data in tuning process. As the simulator is implementing the general model of the departments of outpatient Internal Medicine, the tuning/calibration process must be carried out for each one of them, in order to adjust its simulation parameters to the specific characteristics of each department (e.g., experience of the specific department staff).Therefore, combined with (1) - (10), every patient will show different behavior during the execution of the model because of the probability distribution and their own differences in body condition. But the statistical property of agents will reflect their common behavior.

VI. CONCLUSION AND FUTURE WORD

An agent-based simulation model of the process of outpatient's consultation in the Department of Internal Medicine of the CH was presented. With the development of this model we will be able to study the process of outpatient consultations and then propose a model aimed in reducing the waiting time in different stages of the process.

The simulation can be used as an important component of a system of decision support to help hospital administrators and the people responsible of the outpatient department of Internal Medicine, aimed to achieve efficient and better patient care cycle.

This work will help reduce the patient waiting time and provide additional knowledge on programming admission of patients and doctors. It will also help to optimize resources, among other situations.

Our future work is to implement the simulator with the Netlogo tool, examine, analyze and validate the data produced by the simulator. Then, we will examine the different scenarios in the department of Internal Medicine to improve waiting times for patients.

The first step of future work should be creating the computational model of the object; the next step of future work should be creating design of experiment, experiment execution and statistical analysis of simulation results. In order to validate the simulator, performing some real simulations of department of Internal Medicine is mandatory. Therefore, the future work should be validation. Some real historical data of department of Internal Medicine will be needed in order to perform the tuning process. This is due to the great number of parameters for the model, and the large number of agents and interactions between them. To increase the number of studied scenarios and reduce execution time as well, the use of high performance computing will be mandatory.

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