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IMPROVING PATIENT ACCESS TO A PUBLIC HOSPITAL COMPLEX USING AGENT SIMULATION

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ABSTRACT

This paper uses agent based simulation to assess the effect of redesigning the points of access to a major public hospital complex in Chile, where nearly 15,000 people will pass through daily. The study is carried out by simulating pedestrian traffic in order to calculate density maps and service levels in hospital access and ramps. The simulation allows us to evaluate the flow of people and assess the layout performance, by identifying high patient flow areas and congested pedestrian traffic zones. By using this approach, it is possible to suggest changes to the original design and to improve pedestrian flow at hospital access points and ramps. The suggested changes reveal that pedestrian indicators could be improved, which in turn would improve the level of satisfaction of patients, relatives, and hospital personnel. A higher satisfaction level would help to reduce stress linked to hospital facilities and crowded spaces.

1 INTRODUCTION

In recent years, pedestrian traffic management has become an increasingly important matter as population density has increased in major cities. Growing population density requires more and bigger buildings to be built. This affects traffic and the accessibility of public spaces, which were designed for smaller flows of people. This leads to an increase in accidents and higher risks in case of evacuation (Lo, Zhao, Liu, and Coping 2008; Davidich, Geiss, Mayer, Pfaffinger, and Royer 2013).

In developed countries, pedestrian traffic systems are included as an important part of planning and layout design. These systems focus on resource effectiveness, pedestrian safety and the convenience of the building (Løvås 1994).

For this study a simulation model was developed that could predict the flow and behavior of pedestrians for a projected public hospital complex in Chile, where nearly 15,000 persons will arrive daily. This hospital complex design includes an area of 253,793 square meters in three buildings: Exequiel Gonzalez Hospital (EGH) a children's hospital with 200 beds, Barros Luco Hospital (BLH) an adult's hospital with 1,000 beds, and an outpatient center, which will be called Barros Luco Hospital Complex.

The main purposes of the study are: to determine pedestrian density maps; saturation areas; the pedestrian flow at entrances and service levels in the access points and ramps of the projected Barros Luco Hospital Complex in Chile; to identify the high patient flow areas and the areas most congested by pedestrian traffic zones. This approach will allow us to suggest changes to improve the original design in terms of pedestrian flow management. The simulation model was built using the agent based modeling library of AnyLogic.

2 MATERIALS AND METHODS

2.1 Related work

The OECD considers pedestrian transportation to be simpler, more sustainable, and less costly than other forms of transport. Unlike any other transportation mode, a pedestrian's journey always begins and ends by foot (OECD 2011). Also, pedestrian systems have strategic, tactical, and operational decision levels (Wang, Lo, Liu, and Ma 2015). The increased number of publications related to pedestrian studies in the last decade, especially those related to pedestrian traffic, shows the concern about this subject. With respect to the approaches, simulation is the most widely used for quantitative analysis, followed by mathematical modeling (Alvarez, Mendez, and Martins 2015).

Simulation is one of the recommended troubleshooting tools of complex systems where mathematical modeling is not practical (Medina, Medina, and Gonzalez 2010). There are various sub-categories of simulation, including Monte Carlo Simulation, Dynamic Simulation of Systems, Discrete Event Simulation and Agent-Based Simulation (Wang, Li, Tussey, and Ross 2012; Velasquez, Rodriguez, and Jaen 2011).

The ability to predict how changes in the environment affect pedestrian flow is important for designers of buildings and other facilities. These changes may affect a pedestrian directly by diverting them from the preferred route, and indirectly by affecting other pedestrians (Torrens 2012; Dai, Li, and Liu 2013; Vizzari, Manenti, and Crociani 2013).

Alvarez (2015) conducted a review of the literature related to the quantitative representation of pedestrian flow studies. This was in order to explore the different techniques and approaches used and how they can be adapted to analyze the operating level of the pedestrian system. As it explored a clearly defined theme, a three-stage methodology was used: exhaustive search, summary review, and full text revision (Brailsford, Harper, Patel, and Pitt 2009). Alvarez (2015) study compiled the main approaches or methodologies used to solve the problem of managing pedestrian flow. This included simulation, which was the most considered technique (32%), followed by mathematical modeling (26%) and qualitative approach (25%). Simulation techniques have proven useful as an analytical tool to minimize the risk in decision-making, allowing the reduction of uncertainty relating to how different changes could affect the existing system (Aguilar, Martin, Castilla, Muñoz, and Moreno 2005). Among the articles using simulation as the main technique, 28% makes use of multi-agent systems, while 23% use cellular automata.

Agent-based models are composed of three elements: agents, the environment, and the rules of interaction (Stainsby, Taboada, and Luque 2009). Agents represent the model's active elements (animals, people, organizations, among others). The environment is the abstract representation of the real space in which the group of agents move and interact. The level of granularity or precision with which the environment must be modeled depends on the specific need, and can be a multidimensional Cartesian grid representation or a simple graph. The interaction rules between agents help ensure a safe, effective and comfortable system for pedestrians and it is one of the most important aspects of an intelligent transport system (Liu, Lo, Ma, and Wang 2014).

In summary, building an agent-based simulation models on actual information sampled from observations of pedestrian processes is a promising approach for modeling pedestrian behavior, which has not been explored much to date (Ma, Lo, Song, Wang, Zhang, and Liao 2013). It allows the movement of people to be considered and highlights the importance of certain variables in behavior of specific social groups. This approach is used to represent pedestrian behavior in the Barros Luco Hospital Complex project.

2.2 Methodology for simulation development

For a complete and orderly simulation study, the methodology for modeling patient flow in the new hospital site is based on the seven steps method proposed in Law (2015).

3 STAGES OF THE SIMULATION MODEL

3.1 Formulating the problem

The main objectives of the study are to determine pedestrian density maps and service levels in the access points and ramps in the projected Barros Luco Hospital Complex in Chile, to identify high patient flow areas and congested pedestrian traffic zones. To this end, the following performance measures were considered: (1) Pedestrian density in walkways; (2) saturation of areas of the complex; (3) pedestrian flow at entrances to the complex and (4) service level in walkways.

3.2 Conceptual model

To simulate pedestrian flow, it is necessary to know the distribution of the different services and departments within the hospital complex. Figure 1 shows the flow diagram for the process to be followed by a patient or staff when entering and exiting the compound. Pedestrians and staff walk towards to the hospital complex they wish to access, and they enter through the subway station access. People enter using the ramp towards the hospital's central hall (second floor) or the pedestrian walkways on the hospital's ground floor. If heading towards the Emergency Department (ED), depending on whether the patient of the emergency is an adult or a child, they will go to a different location. Adult emergencies must go to Barros Luco Hospital and child emergencies must go to the Exequiel Gonzalez Hospital.

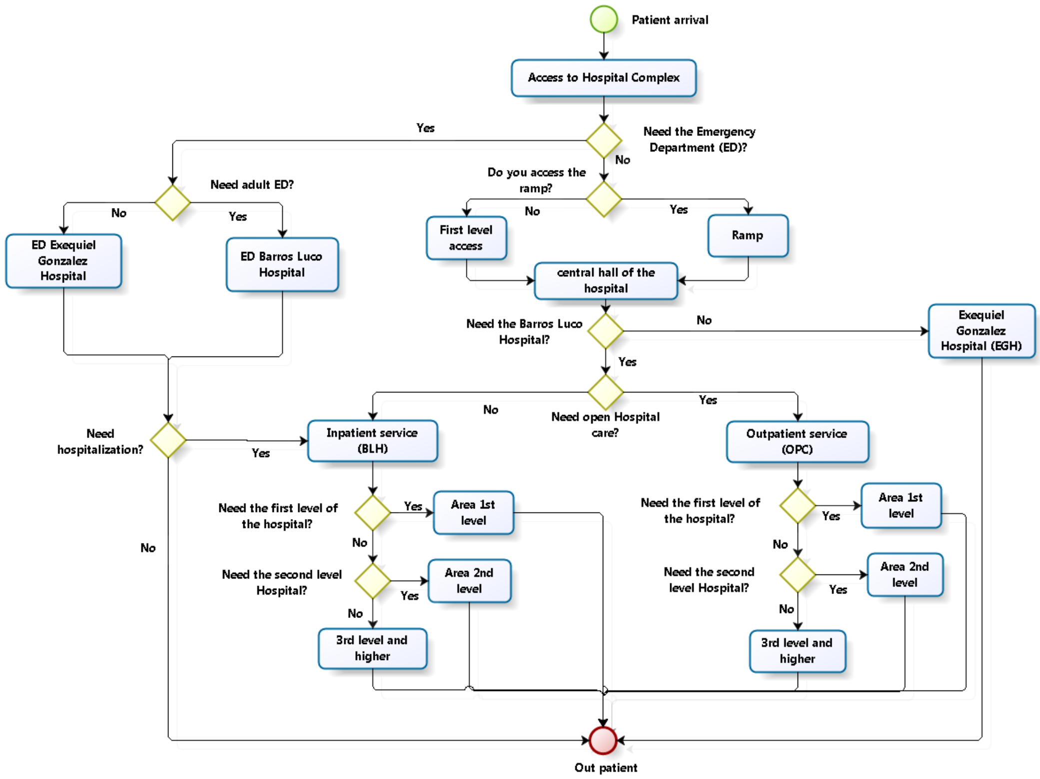

Figure 1: Flow chart of the Barros Luco Hospital Complex.

All patient and staff traffic accessing to BLH, EGH or OPC was considered for the model according to the relevant clinical service destination. This distribution is described in Table 1. The access points considered for patient and staff arrival to the hospital complex include the ramp and central hall, the access points to outpatient or inpatient services including six stairways and six elevators, leading to final destinations on other levels. Simulation schedules were between 7:00 am to 5:00 pm, the which is the time of highest patient-flow. Two flows schedules were considered for staff, one for entry between 6:00 and 8:00 am, and one for exit, from 5:00 to 7:00 pm.

Table 1: Distribution of patients and staff.

BARROS LUCO HOSPITAL COMPLEX					**Patient stay (minutes)**		
Area	**Levels**	**Clinical services**	**Patients/day**	**Workers/day**	**minimum**	**maximum**	**average**
Outpatient service (OPC)	1st Floor	Imaging	369	96	15	90	52
		Traumatology	397	66	15	60	37
		Hospital day	94	9	60	240	150
	2nd Floor	Admission and Sampling	306	61	10	40	25
		Dermatology, Hematology, Mental Health	427	68	10	60	35
	3rd Floor and above		2,204	572	15	60	37
Inpatient service (BLH)		1st Floor	611	316	30	180	105
		2nd Floor	489	260			
		3rd Floor and above	1,345	414			
		Emergency	330	47	90	240	165
Hospital Exequiel Gonzalez (EGH)		Inpatient and outpatient service	3,000	500	30	180	105

The conceptual model was validated in meetings with the staff in charge of the Standardization Project of the Barros Luco Hospital Complex, and staff of the South Metropolitan Health Service (the owner of the hospital complex), together with the professional group of the Advanced Process Simulation Center (CASP) of the Universidad del Bío-Bío.

The different flows and activity times were analyzed, as well as the places where they occur, to see if they were consistent with reality. The input data was thoroughly analyzed to provide reliable data for the computing model.

3.3 Simulation model

To build the simulation model of the hospital compound with the AnyLogic simulation software, it was necessary to model the design layout based on CAD the drawings provided by the Health Service, and to include each resource in the design, such as access ramps, elevators, and escalators, among others. Movement sequences for each part of the pedestrian flow mentioned in the conceptual model were created and included, as well as the demand for several clinical services and care areas, patient arrival times, companions and staff. The average walking speed for people was set to 1 meter per second for all patients and staff members in the complex.

Figure 2 shows the plant distribution of the first and second floor of the hospital grounds, identifying pedestrian density measurement points:

1. Patient and staff entry points, through the subway access
2. Access walkways and ramp to central hall of the hospital.
3. Barros Luco Hospital access ramp.
4. Outpatient Center access point.
5. Exequiel Gonzalez Hospital access.

Points a, b and c in Figure 2 represent access to the upper and lower floors of outpatient care of the OPC, and points d, e and f are the entrances to the upper and lower floors of the inpatient care of the BLH. It is estimated that 40 % of people enter using the stairs and 60% use the elevators.

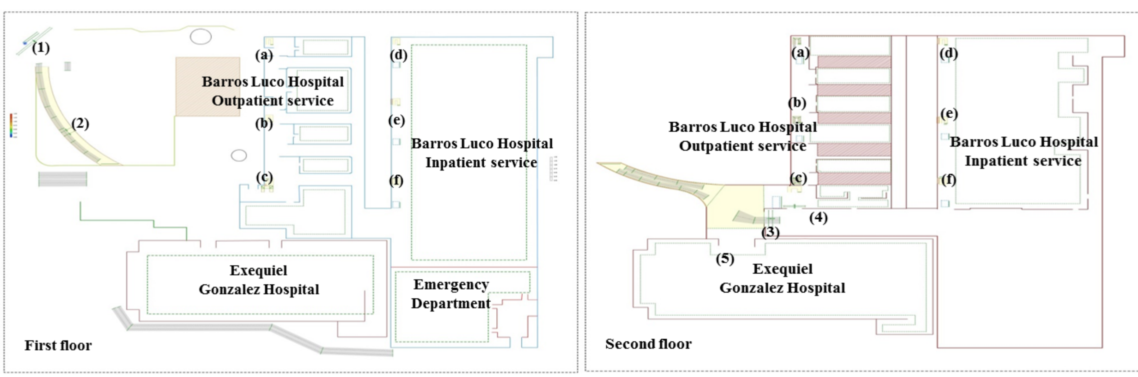

Figure 2: Simulation model of movement towards the Barros Luco Hospital Complex.

3.4 Simulation validation

Verification was performed while the model was developed using the AnyLogic software, checking for no wrong syntax or blocking of the simulated flows. The model was validated in a meeting with the Project Team of the Barros Luco Complex, including the Project Manager, Head of Implementation, IT Engineers, Doctors and Nurses, who are members of the South Metropolitan Health Service (SSMS), as well as the CASP professional group. Analysis of the simulation performance indicators was performed comparing them to actual data from a similar nearby hospital.

3.5 Criteria to assess services in walkways

Table 2 describes pedestrian service-level criteria established by the USA National Research Council, using the Transportation Research Board (TRB) and the Highway Capacity Manual (HCM). The measurement scale in Figure 3 shows the density of people per square meter. This scale will be used to assess the service-level of the density maps provided by the pedestrian flow simulation model using the AnyLogic software. The pedestrian flow model was used to calculate the density. The volume, density, and speed are related, as seen in the equation (1) below, which is also known as the fundamental equation for continuous flow.

$$K = q/\bar{V}_e \tag{1}$$

Where: K = Pedestrian density (people per square meter).
q = Pedestrian flow rate (people per second per meter).
$\bar{V}_e$ = Average walking space speed (meters per second).

The Highway Capacity Manual (TRB 2010), for the analysis of pedestrian traffic on sidewalks and pedestrian paths, the pattern found by Fruin (1971), as shown in equation (2), was used. It uses a free flow walking speed of 1.43 meters per second for unidirectional flow and 1.36 meters per second for bidirectional flow.

$$\bar{V}_e = 1.43 - 0.35K \text{ (for unidirectional flow)}. \quad \bar{V}_e = 1.36 - 0.34K \text{ (for bidirectional flow)}. \tag{2}$$

Table 2: Level of service in pedestrian walkways.

Level of Service	Color Scale	Pedestrian Density (people/m^2)	Pedestrian Space (m^2/people)
A	Blue	> 0.18	> 5.6
B	Light Blue	> 0.27 – 0.18	> 3.7 – 5.6
C	Green	> 0.45 – 0.27	> 2.2 – 3.7
D	Yellow	> 0.71 – 0.45	> 1.4 – 2.2
E	Orange	> 1.33 – 0.71	> 0.75 – 1.4
F	Red	≤ 1.33	≤ 0.75

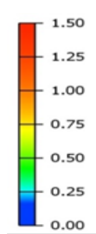

Figure 3: Density measurement scale.

3.6 Experimental design

Simulation results were obtained for an average day of service using the built computational model. First, density maps were created for each level of the Barros Luco Hospital to determine the occupancy rate of each of system area and then assess the service levels. Figure 4 shows the density map of the first and second floor of the hospital complex, in which 4 areas of greater pedestrian traffic were identified.

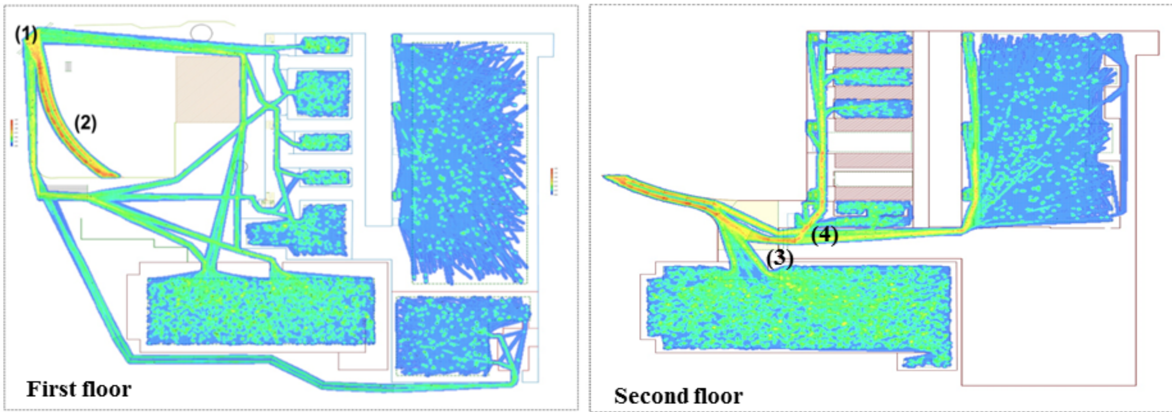

Figure 4: Density map of the site first and second floor Barros Luco Hospital Complex.

Figures 5 and 6 show the pedestrian flows in the first level of the complex. Figure 5 shows the flow from the subway station access and Figure 6 shows the flow on the access ramp. Figure 7 shows the flow of patients in the central hall on the hospital's second floor and Figure 8 shows the flow in the outpatient care access point. The busiest times for pedestrian traffic for all measurement points is between 7:00 am and 9:00 am, which are the times that employee arrive to begin their work shift and when patients arrive for their clinical services.

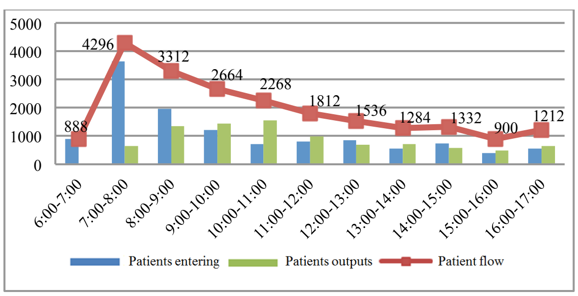

Figure 5: Pedestrians in the subway access.

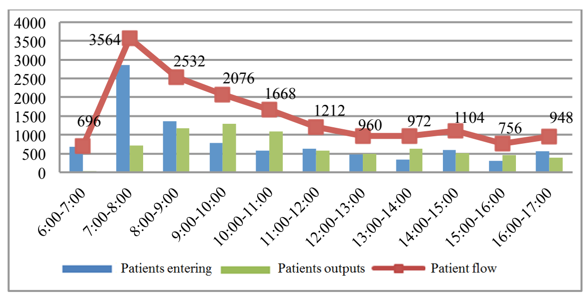

Figure 6: Pedestrians in the ramp.

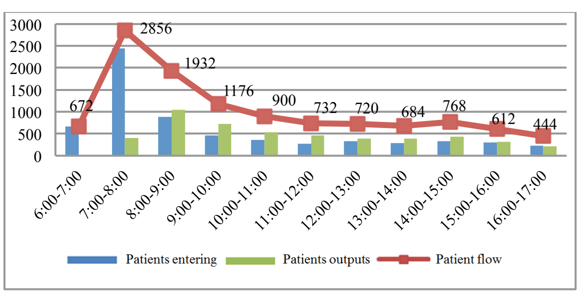

Figure 7: Pedestrian flow in the hall.

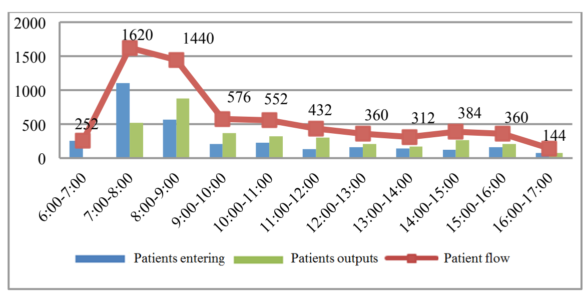

Figure 8: Pedestrian flow in outpatient care.

Based on the simulation model developed, the highest pedestrian flow rate for all measuring points were identified, as well as pedestrian densities and service levels for each walkway. The results are shown in Table 3. These results helped identify two areas of higher saturation in walkways in the subway access and central hall ramp of the hospital's second floor, service level "E". Here pedestrians' walking speeds are restricted, there isn't enough space to have a slow lane, the number is pedestrians in the area is as much as the design volumes can allow, and causes bottlenecks and flow interruptions.

Table 3: Analysis of pedestrian service level.

Measurement point	Pedestrian flow rate, (people/hm)	Average walking speed, (m/h)	Pedestrian density, (people/m^2)	Service Level
	q	$\bar{V}_e$	K	
(1) Subway Access	4,296	3,304	1.30	E
(2) BLH Ramp	3,564	3,724	0.95	E
(3) BLH Hall	2,856	4,028	0.70	D
(4) Outpatient Center	1,620	4,450	0.36	C

3.7 Results

After the base simulation model was presented in a first assessment to the project managers of the hospital complex, they agreed to make improvements and changes in both the design layout of the hospital as well as in the pedestrian flows to different service areas. The changes are listed below:

1. Two hospital access points were considered: the subway access with 60% of the arrivals and bus arrivals, accounting for 40% of the flow.
2. A lateral ramp to Exequiel Gonzalez Hospital was added to allow for movement from the pedestrian access point at the bus stop to the central hall on the 2nd floor.
3. Inside the facilities, 30% of people will use the stairs and 70% will use the elevators.
4. Hospital personnel arrive at the complex during the period between 6:00 and 9:00 am.

Figure 9 displays the new design of the first level hospital complex. Traffic measurement points are identified:

1. Patient and staff entry points, through the subway access.
2. Patients and Staff entry arrival (Bus Access).
3. Access walkways and ramp to central hall of the hospital.
4. Traffic Measurement at Exequiel Gonzalez Hospital ramp.
5. Barros Luco Hospital access ramp.
6. Outpatient Center access point.
7. Exequiel Gonzalez Hospital access.

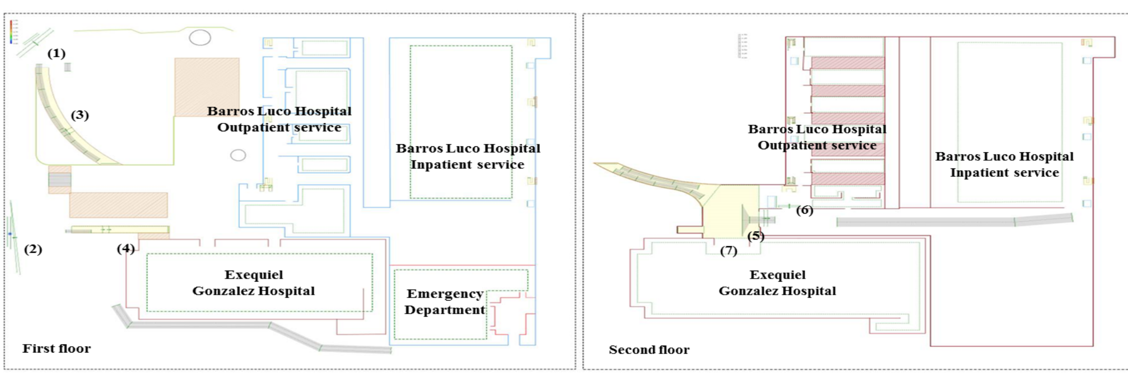

Figure 9: Simulation model of the 1st and 2nd floor of Barros Luco Hospital Complex.

Figure 10 shows the density map of the 1st floor of the hospital site. Four heavy traffic zones were measured on the first floor of the hospital's density maps. A density map was obtained for the second floor, during simulation between 6:00 am and 5:00 pm.

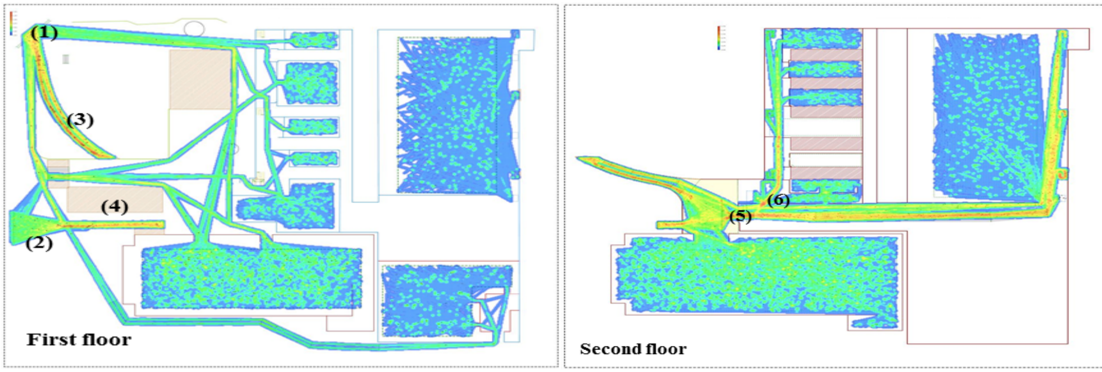

Figure 10: Density map of Barros Luco Hospital Complex.

The heaviest pedestrian flow in the subway is between 7:00 and 9:00 am, of 2,700 people per hour. Figure 11 also shows an increase in pedestrian flow from 12:00 onwards, due to the amount of people visiting patients in the inpatient services. Figure 12 shows the behavior of people entering BLH from the bus stop, in which the highest pedestrian volume is between 7:00 and 08:00 am, of 1,128 people per hour. Traffic per hour measured at the access ramp to the central hall of BLH shows that between 7:00 and 9:00 am there is a flow of up to 1800 people per hour, as seen in Figure 13. Pedestrian traffic per hour on the ramp on the side of the EGH, seen in Figure 14, shows that highest flow is between 7:00 and 8:00 am, of up to 1,296 people per hour. On the hospital's second floor, 2 areas of pedestrian flow were measured, at the central access hall and outpatient care department's pedestrian access point. Neither point showed significant variations in the peak flow of people during the day, being consistent to the service levels of the base simulation scenario.

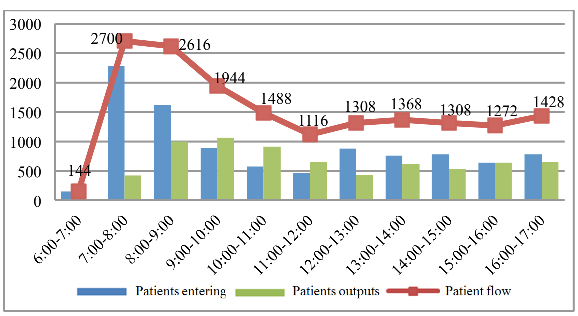

Figure 11: Pedestrians from subway access.

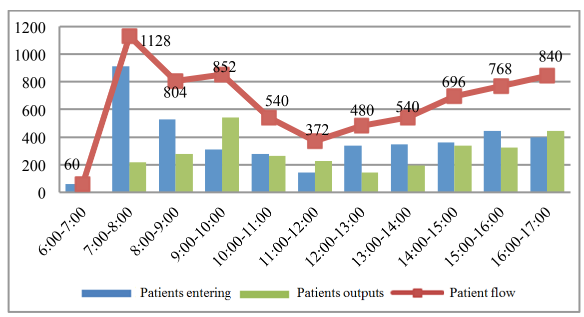

Figure 12: Pedestrians from bus access.

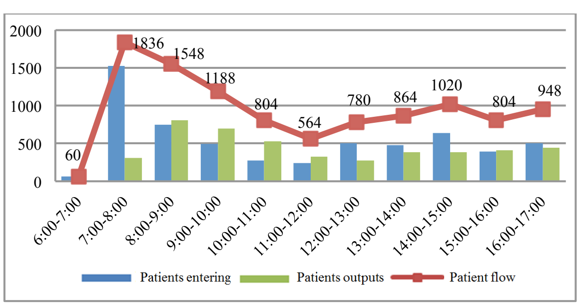

Figure 13: HBL Ramp.

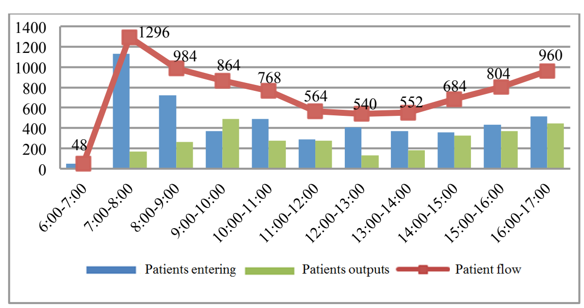

Figure 14: HEG Ramp.

Based on the flow of people per hour delivered by the simulation model of the hospital complex, the rate of pedestrian density and the level of service in the walkways were computed. The maximum flow in the subway access is 2,700 people per hour at a rate of 0.66 persons per square meter and service level D.

This is a reasonable fluent flow, with normal walking speed and passing of slower pedestrians is sometimes restricted.

In bus access, the perceived service level is B; at this level of service pedestrians have enough space to choose their own paths and walking speeds in the walkways available. Similarly, in the access ramp to the central hall of the Barros Luco Hospital and Exequiel Gonzalez Hospital, the service level is C, where there is enough space for pedestrians to choose their speed and to pass slower pedestrians. In the central hall and the outpatient area, service level is maintained similar to the base simulation model, where pedestrians have a constant flow at comfortable walking speeds. Table 4 describes each of the before mentioned data.

Table 4: Pedestrian service level analysis of the first floor.

Measurement point	Pedestrian flow rate (people/hm)	Average walking speed (m/h)	Pedestrian density (people/m^2)	Service level	Pedestrian space (m^2/people)
	Q	$\overline{V_e}$	K		Ω
(1) Subway access	2,700	4,087	0.66	D	1.51
(2) Bus Access	1,128	4,595	0.25	B	4.07
(3) BLH Ramp	1,836	4,383	0.42	C	2.39
(4) EGH Ramp	1,296	4,547	0.29	C	3.51
(5) BLH Hall	2,664	4,100	0.65	D	1.54
(6) Outpatient care	1,476	4,493	0.33	C	3.05

4 CONCLUSIONS

This paper assess, through agent based simulation, the effect that redesigning the access points will have on the pedestrian flow to a major public hospital complex in Chile, where nearly 15,000 persons will arrive daily. In order to evaluate the performance of the projected design the following performance measures were computed over a full day of operation: (1) Pedestrian density in walkways; (2) saturation of areas of the complex; (3) pedestrian flow at entrances to the complex and (4) service level in walkways.

The base simulation scenario of pedestrian flow with the initial layout of the hospital complex presented two areas of pedestrian saturation on the first floor: the subway access point and the ramp to the central hall of the BLH. The busiest times at these places were between 7:00 and 9:00 AM, mainly due to patient and staff arrival to the site. A maximum flow for both areas was determined: 1.3 people per square meter in the subway access and 0.96 people per square meter on the ramp, matching the density map provided by the simulation model. These densities provide service level E, which translates into a decrease in the normal pedestrian walking speed. There is not enough space to pass slower pedestrians as the flow reaches the pedestrian capacity limit.

A new simulation model was proposed based on changes in the layout of the complex, adding a new access point and a new ramp, as well as a new patient arrival mix, which improves the service level of the walkways and decreases pedestrian density during peak hours. The service level provided allows people to walk at normal speeds, being able to choose their paths without conflict or interactions between users of the Barros Luco Hospital Complex.

Future research should consider building a multi-agent model with vehicular interaction to assess walkways design through density, capacity, and service level of the entire system by integrating vehicle access. Assessing escape routes from hospital grounds is also suggested.

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