Lecture Notes in Intelligent Transportation and Infrastructure
Series Editor: Janusz Kacprzyk

Alberto Ochoa-Zezzatti
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Technological and Industrial Applications Associated with Intelligent Logistics

Springer

Lecture Notes in Intelligent Transportation and Infrastructure

Series Editor

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ISSN 2523-3440 ISSN 2523-3459 (electronic)
Lecture Notes in Intelligent Transportation and Infrastructure
ISBN 978-3-030-68654-3 ISBN 978-3-030-68655-0 (eBook)
https://doi.org/10.1007/978-3-030-68655-0

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Introduction

This book is a novel, innovative, and adequate source of information that compiles interdisciplinary perspectives about diverse issues related to Intelligent Logistics in Industry 4.0 including Artificial Intelligent applications associated with Logistics 4.0 on different ways about Intelligent Optimization, Industrial Applications on real world, Social applications and Technology applications each one with a different perspective about the correct solution of this kind of methodologies. This book is a collective effort to introduce new ideas and paradigms from a variety of perspectives using innovative techniques related to Bioinspired Algorithms, metaheuristics, and methodologies associated with Logistics 4.0. An innovative and specialized book on optimization considers different aspects to realize this "Intelligent Optimization" and tries to improve with innovative techniques and methodologies different daily aspects of our lives, in each one of them it is possible to understand the necessity to improve scenarios, distances, time, costs, spaces, and a plethora of features associated with the modern life (labor associated with organize, kept, and delivery of goods, materials, people, life issues, or products).

We received manuscripts from renowned researchers from all around the world associated with Theoretical foundations of Intelligent Logistics to understand many paradigms on different Optimization implementation kinds. In addition, we received many manuscripts with expertise on improving optimization related to Logistics 4.0 of deliveries associated with products and services, Optimization of different elements in the time and location, Social Applications to enjoy our life of a better way to improve the life in a Smart City, and finally, Technologies Applications of diverse ways to increase our Life Quality. The book starts with a part entitled Industrial Logistics featuring seven chapters on the theoretical and mathematical ideas related to the correct implementation of a diverse range of Intelligent Logistics optimization algorithms and Logistics 4.0 applications in real world. The first chapter of this section is "Determining and Applying Productive, Environmental and Economical Indicators and Indexes to a Cyber Physical System for Greening Process of Supply Chain" which aboard that a company that transports goods to supply customers usually needs to plan the routes that the fleet must follow, since transportation means a high percentage of the value added to products outside their store using a model called pret-a-porter. Therefore, it causes them to go back to it once a product in their mobile store runs out since the customer is waiting for them at the store. The chapter "The Difficulties and Complications of Children When Going to a Zoo and Should Interact with the Colors of the Information in It: An Approach Based on the Use of a Humanoid NAO Robot in an Application for "Smart Cities"", determines as in nowadays that the health industry utilizes critical machines to treat and diagnose illness in patients. In a large majority of hospitals that treat patients with color blindness, especially children, mobile applications are beginning to be used to improve the quality of life of these patients in environments that require information associated with safety colors or the level of extinction of a species, such as in zoos; then, they choose to have many components of their critical machines stored inside a warehouse in the hospital. The chapter "Optimization of Route Planning for the Package Delivery Problem Using Fuzzy Clustering" is explains that nowadays, warehouse operations, specifically order picking process, are receiving close attention of researches due to the need of companies in minimizing operational costs. Finally, the last chapter in this part is "State of the Art for the Creation of a Methodology for the Proper Location of Urban Truck Stops on Route 2A" which determines that in these times, the human factor is key to improve order preparation processes—which is why it is necessary to determine a correct bus stop-. For example, in a Smart City associated with a line of replacement processes for different pieces of equipment or devices—which must be purchased in a specialized store-, it is necessary to find the best bus route in each case to minimize the time consumed, and that this does not affect the continuity of the assembly in small workshops specialized in automotive parts.

The third part is named Humanitarian Logistics, featuring five chapters related to different comparatives of Humanitarian Logistics and Intelligent Logistics Models in the search to improve resources in diverse aspects of companies and to improve our lives. The first chapter of this section is "Financial Analysis Over the Smartest Companies" and in this research chapter is focused the problem of the distribution of escape routes in a public space. The chapter "Simulating Crowd Movements During Emergency Fire Situations: Mexico City Airport Simulation Case" details as in several societies of emerging economies, increasingly large community linked to the scalability and adjustment of components to resolve a problem of Humanitarian Logistics. In the research chapter "Modular Framework for Crowd Simulation "Menge" from a Production Warehouse Simulation Perspective", many industrial sectors use 3D components design customization to improve aspects of competitiveness. In the chapter "Mobile Application for the Detection of COVID19 Suspicious Cases in Mexico Using an Intelligent Model of Virtual Patients". In hospitals with an excessive number of patients and the decrease of medical services associated with other diseases, we propose the use of an intelligent model of virtual patients that allows students of health sciences to practice in an adequate and valid way the detection of various symptoms that affect the health of the population in a

Smart City. The next chapter "Humanitarian Logistics for the Optimal and Timely Evacuation in High Buildings Within a Smart City Using an Adaptive Metaheuristic Context" explains about the analysis concerning the accommodation of safe escapes in a building inside a structure for their respective distribution, verifying the option of finding the correct stow model and accommodation of humanitarian logistics.

In fourth part, which is named E-commerce, Marketing and Mobile Application of Logistics Including Human Factor, are described five chapters related to technologies associated with Intelligent Logistics and Logistics 4.0. The first chapter of this part is "Using Machine Learning to Predict Online Buying Behaviour, Wholesale and Fashion Marketing at Zara, an Analysis Including Z Generation" which presents a problem solved by social modeling, associated with the adequate choice of colors to issues and their distribution in a Fashion Market using a range of 64 colors to specify different features related to the principal attributes of an issue adequate to represent the symbolic capital of a modern society. In the chapter "Analysis of Mental Fatigue Under Delivery Pressure and Considering Creativity and Precision to Organize and Distribute a Diorama to Represent Social Issues Based on Cultural Algorithms" details how mental fatigue is a decisive aspect in the creation of collectible issues, especially in a growing collecting community—mainly from emerging economies—which collects and buys "dioramas and click toys among others", that is, scalable and adjustable collectibles composed of many pieces; this type of paper toys and dioramas have been used for educational purposes. In the chapter "Medicine Inventory Control System Through Fuzzy Logic and Genetic Algorithms: Applied to a Biopharmaceutical" is described a novel research focused on the main economic activities in a Smart City; in another chapter named "Technical Analysis of Shipments in an Automotive Company to Forecast Sales Volumes" is proposed the implementation of an order picking algorithm for the optimization of the packing and distribution of car component products. Finally, in this section is presented "Distributed Programming Applied for the Optimization of Hydraulic Networks Through a Web Application", which proposes new ideas related to web applications by means of an Advanced Selection of systems, which is fundamental for the operational improvement and logistics global supply chain.

And finally, in the part entitled Diverse Kind of Logistics in Amalgamed Application Domains grouped nine different chapters related to solutions derived of specific aspects which try to improve daily activities on Optimization with real applications to amalgamed social topics. In the chapter "What is the Best Location of a Smart Airport in Juarez, Mexico?" is described, as the latter includes, customizing the user interface, as well as the way the system retrieves and processes cases afterward to distribute original products in a novel supply chain and its respective Intelligent Logistics. The purpose of the chapter "Colombian Coffee Price Forecast via LSTM Neural Networks" is to propose a conceptual order picking model to increase the commercialization of coffee in Colombia, through the sequential analysis of activities such as distribution in the warehouse, preparation, packing of orders, and the issuance of orders to final customers. The next chapter "Some Pragmatic Prevention's Guidelines Regarding SARS-CoV-2 and COVID-19 in Latin-America Inspired by Mixed Machine Learning Techniques and Artificial Mathematical Intelligence. Case Study: Colombia" details that due to the worldwide strengthening of the health sector, it presents itself as a challenge for the companies that comprise it to immerse themselves in processes of continuous improvement that contribute to increasing the satisfaction of the needs of its customers, as well as achieving a better positioning in the market. In the chapter "A Drone System for Detecting, Classifying and Monitoring Solid Wastes Using Computer Vision Techniques in the Context of a Smart Cities Logistics Systems" is proposed that the freshness, flavor, good presentation, and nutritional value of fruits and vegetables diminish as time passes until the food begins to lose them completely. That is why the correct implementation of supply chains is a subject of great interest for companies dedicated to the rotation of food marketing. The next chapter "Geo-Referenced Correlation for a Fire in a Smart City Urban Forest Using Hybrid Drone Data and Satellite Images" determines that the purpose of this research is to understand a Multivariable optimization associated with the path of a group of vehicles integrated in an Ecological Community and determine the optimal route involve speed, storage, and travel resources including time of charge for determining the cost-benefit linked to safety in case of a disaster as a wildfire at a Natural Park in a Smart City and considering that most of the drivers in such an ecological community own an electric car, which is coupled with a travel plan associated with the electric power charging point in a Smart City. In the chapter "Evaluation of Drones for Inspection and Control in Industry 4.0" is analyzed that Internet sales have increased exponentially in the last decade. Much of the internet sales are of physical products in urban areas that require product delivery transportation with a tight delivery lead time using drones for this purpose. And finally, in the chapter "Uncertain Analysis Based on Milk-Runs Systems Using Bayesian Networks" is a important considering that one of the most common operations in warehouses of package delivery companies (e.g., UPS or FedEx) is to pack the products in trucks in order to locally deliver them to the customers. The products are generally packed in rectangular-shaped boxes of different dimensions; in addition in the chapter "Implementation of an Intelligent Visual Recognition System for the Proper Classification of Solid Waste Using a Mobile Application in a Smart City" explains a model of ecological support to groutier people with shady hair linked to Greenpeace—which allows a better identification of solid waste and its correct and adequate separation, using a smart mobile application for recycling within the Z generation—to improve the lives of citizens in their environment within a smart city. The last chapter of this part is "Logistics on the Designing of an Electronic Colorblindness Application for Early Colorblindness Detection in Children by Using a Modified Ishihara Test", which describes the social inclusion with colorblindness.

It is important to state that the chapters were selected following a rigorous analysis done by the book editors, and each chapter was double or triple-blind peer-reviewed by at least two experts in the area. This would not have been possible without the valuable help of the Editorial Advisory Board. The content of the chapters included in this book is the sole responsibility of the authors. The views, opinions, or positions expressed by the chapter authors are solely those of the authors, and do not necessarily reflect the views, opinions, or positions of the editors. All trademarks, trade names, service marks, and logos referenced in the chapters of this book belong to their respective companies.

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Simulating Crowd Movements During Emergency Fire Situations: Mexico City Airport Simulation Case

Roberto Contreras-Masse, Alberto Ochoa-Zezzatti, Vicente García, and Ana Moheno

Abstract Flying is the first choice when traveling long distances. With several options available for passengers, it is noticed an increase of passengers every year, then airports become more crowded, but, how well prepared are in case of a fire emergency? In this paper, we research a fire situation forcing to evacuate Gate 75 at Mexico City airport. Using Menge crowd simulator movement engine, we use four classes of agents to simulate different passenger movements as well as different moving speeds based on sex and complexion. In our results bottlenecks were detected and improvements to gate layout were suggested. Then, another simulation set was run with the proposed changes to determine how affects the evacuation times. In order to have a successful change, it most improves at least 10% evacuation time, without changing agents' classes, cardinality or speed.

Keywords Crowd simulation · Airport · Fire emergency · Improvement

1 Introduction

Mexico City International Airport (often referenced and abbreviated as AICM in Spanish, or MEX due to IATA airport code) is the busiest and largest airport in Mexico. In 2018, more than 47 million passengers landed or depart from this airport, and 2019 suggest a raising number [1]. Comparing June 2019 and 2018, there is a 6.3% increase of passengers. AICM has two terminals. Terminal 1 is the oldest and original one and Terminal 2 was built by 2006, currently handling near 1.7 million passengers per month. Terminal 2 is divided in two large connected aisles, north zone is for international gates (Gate 52 to 62), and south zone (gate 63 to gate 74) to serve domestic flights. Both zones provide 23 gates and one common gate (gate 75) for remote terminals (Fig. 1).

Gate 75 is divided in 4 areas in two floors. Gate 75A and 75B are in upper level, Gate 75C and 75D are in lower level. The access among floors is conveyed by single

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A. Ochoa-Zezzatti et al. (eds.), *Technological and Industrial Applications Associated with Intelligent Logistics*, Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-3-030-68655-0_15

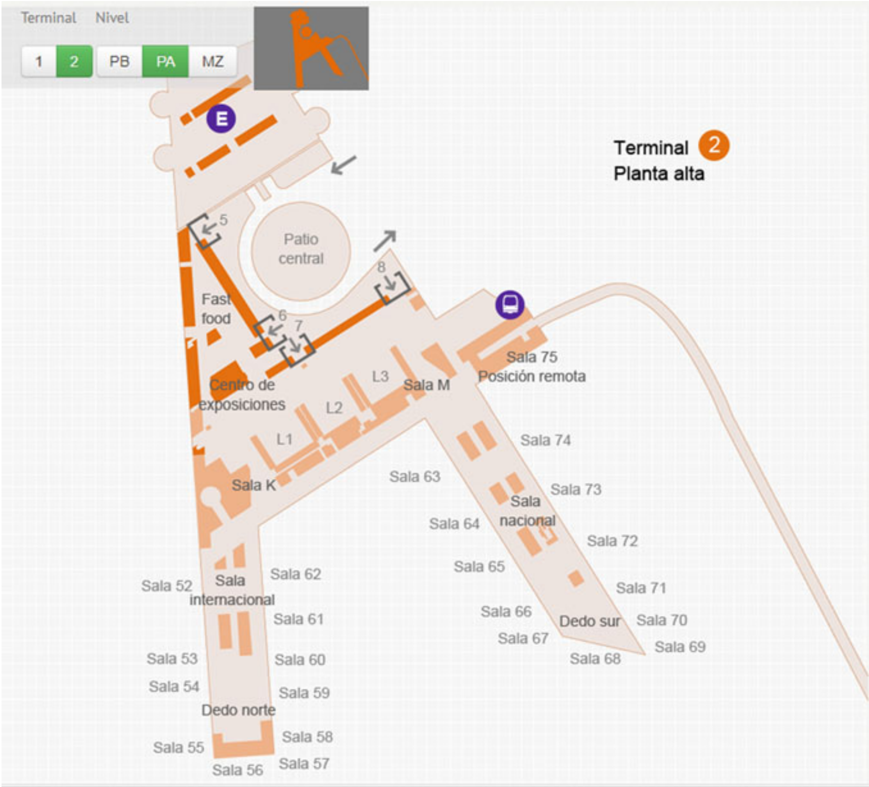

Fig. 1 Terminal 2 departures of AICM. *Source* AICM

narrow ramp of about 2 meters wide. Ramp walls are tempered glasses, providing a sense of amplitude and open space while going down. Most of the human flow goes from upper level to lower level. At each gate (75A-D) there are 3 counters, meaning, in the best-case scenario, airport can server 12 flights boarding at the same time, plus any delay that may happen due by weather or airline fault.

1.1 Specific Crowd at Gate 75

The number of daily departures from Gate 75 is numerous. There is no precise statistics about traffic at Gate 75, however, it can be estimated by just being familiar with that place. Flight departures served by this gate are usually for small planes, Embraer 170, 190, ATR42, ATR72. Also, Terminal two host few airlines (Aeromexico, Delta, Copa, Aeromar y Wingo) national and international. Fleet served at Gate 75 corresponds to Aeromexico Connect and Aeromar equipment (Aircraft E170 carries 76 passengers, E190 has 99 seats, while ATR-72 has 72 seats, ATR-42 has 48 seats). Based on public flight status, it is possible to gather the number of flights departed by day from this specific gate, as shown in Table 1. Using an average number of seats per airline and flights per period, it is possible to estimate number of passengers around.

It is important to notice Gate 75 was remodeled and enhanced in 2016 going from 2,000 m^2 to 9,000 m^2 in passenger space. But this space is not only for standing people; it has chairs, glass walls, few steps, restrooms, ramps and counters. Although this effort made, gate 75 is always crowded and busy under normal circumstances, worsen by flight delays. As there are two floors, each one has 4,500 m^2. In Figs. 2 and 3 can be seen the facilities as was thought in contrast with real and current conditions. Also, by personal experience being a regular user of this airport, it is noticed there are not evacuation paths, there is not enough space to walk to upper level through single ramp when there is people going down floor, and there are not emergency exits. Adding to this panorama, there are restaurants located at the beginning of gate (where is the passage to main building), kitchen equipped meaning gas and fire.

Table 1 Estimated passengers at Gate 75

Airline	Avg. Pax	Number of flights per shift		
		6-11:59a	12-5:59p	6-11:59p
AM Connect	87	52	50	28
Aeromar	55	13	8	4
Total Pax		5239	47900	2656
Grand Total				12685

Fig. 2 Gate 75 upper floor panoramic view. *Source* Notimex

Fig. 3 Gate 75 upper floor normal crowd 2019. *Source* Personal footage

The purpose of this manuscript is to study the human crowd movement in this particular gate in the case of an emergency event such as fire and propose an improvement in the layout to do evacuations faster. Earthquakes are not taken in consideration because in case of this event the right thing to do is stay in safe places instead of run. Fire, in the other hand, is a situation that people is not familiar, making people run.

This manuscript is organized in sections. Section 2 present the literature review and provides context for the study. Section 3 models the venue and establish the conditions, variables and restrictions of our simulation and test improvements options. Section 4 discusses the results, proposes a new layout and compare simulation results. Section 5 provides conclusions and future work.

2 Literature Review

From all emergency events, fire is the center of life safety prevention and reaction projects. Studies in human behavior includes awareness, beliefs, attitudes, motivations and decisions, taking in consideration also mimic others [2]. There is a typical timeline of people response when there is a fire emergency. This timeline is divided in pre-evacuation period and movement period. During pre-evacuation period starting by ignition, alarms may or not may go off. People will spend time seeking information, such as source of fire, how big it is, processing the information to enter evacuation decision step. If a decision to evacuate is made, protection of self and others will play in conjunction of seek an escape route, starting the movement period.

The protective action decision model (PADM) developed by Lindell et al. provides a general framework to explain decision making flow in emergencies. It takes different sources of inputs, have a stage of pre-decisional process, adds a layer of perceptions and finally decision making based on those variables [3].

In PADM, inputs are from a vast array of channels, including environmental cues, information channels, information sources. Also, there are behavioral sources and personal beliefs involved, like social context, person personal training, personality, or even physical characteristics as age, body type, agility, weight, or height. Group behavior is other important observation. The affiliative behavior (how humans tend to form groups during evacuation), capacity to help others, and convergence clusters are few of behaviors observed during a fire emergency. Michael Bratman provides a methodology for decision according to beliefs, desires and intentions (BDI) based on cognitive model of humans, in artificial intelligence field, useful for simulations [4] for agent based simulation (ABS). There is also social force models (SFM) as the proposed by Helbing and Molnar to describe pedestrian motion, arguing that a limited number of parameters can simulate individuals and their displacements better when considering SFM [5, 6] and applied in studies for airport passengers movements simulation [7, 8].

The Distinct Element Method is used in Crowd Behavior Simulator for Disaster Evacuation, Proposed by Rahman considers person density in perception domain of an individual, function switching actions and physical plus psychological field perception [9]. Standard field of vision is about 124 degrees, using both eyes, while focusing on objects and symbols narrows it to 60 degrees in binocular vision as shown in Fig. 4.

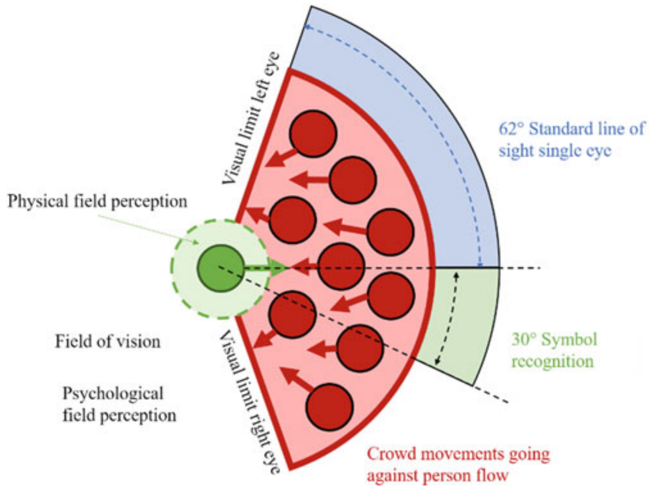

Fig. 4 Person perception in crowd movements with field of vision. *Source* Adapted from [9]

The estimated evacuation time can be calculated using Togawa equation [10], which indicates the elapsed time in seconds to evacuate equals number of people (N), output width in meters (A), the experimental constant (K) 1.3 people/meter-second, total distance to travel in meters (D) and horizontal speed of 0.6 m/s, stairs 0.4 m/s.

$$T = \frac{N}{AK} + \frac{D}{V} \tag{1}$$

However, as it can be observed in Fig. 6, we need to consider two additional evacuation times, one coming out from the ramp and evacuation of Gate 75B. Thus, our Eq. (1) changes to

$$T = \sum_{t=0}^{n} \left(\frac{N_i}{A_i K} + \frac{D_i}{V} \right) \tag{2}$$

Togawa's observations works well during an evacuation under normal circumstances; the process is conveyed in organized form and most likely, practiced by employees. When there is a threat to life like fire in a public building, non-trained persons will try to escape in accelerated way and collisions may occur. This behavior is modeled by the Switching Action Function (SAF) proposed by Rahman [9] and studied in airports as:

$$\int_{t-\alpha_{sw}}^{t} f_{sw}(\tau) g_{sw}(t-\tau)\, d\tau \tag{3}$$

Where f_{sw} is SAF, f_{sw} is the input function with population density number in the perception domain of person *i*, and g_{sw} is the unit response function reflecting the delay to switch course of action. Rahman proposed to use the exponentially decaying function for computational stability, $g(t) = e^{-t}$. This change of direction depicts how a person avoids collision.

Human velocity is not constant, it is impacted by factors such as age, ability to perform, body type, or even previous training. Datta et al. provides the mean and standard deviation of velocity for different classes. Table 2 shows those values [11].

Lastly, simulation is a great technique to observe and predict results with low cost and low investment. Menge framework is a flexible, low cost and extendable option for research. It realizes crowd movement simulation with a particular abstraction, decomposing the main problem in goal selection, plan computing, plan adaptation and spatial queries. The novelty is how adapts to obstacles and therefore, change the plan to reach the goal. Also, it transforms preferred velocity into a feasible velocity, considering other crowd agents during simulation. These agents' trajectories are computed by an initial value problem of type

$$x_i(t) = v_i(t) = V_i(t, \mathbb{C}(t)) \tag{4}$$

Table 2 2 Persons' evacuation velocity by class. *Source* [11]

Evacuee Class	Mean (m/s)	Std. Deviation (m/s)
Male child able (MCA)	1.08	0.26
Male child disable (MCD)	0.92	0.34
Male adult able (MAA)	1.24	0.45
Male adult disable (MAD)	1.06	0.26
Male elderly able (MEA)	1.05	0.15
Male elderly disable (MED)	0.91	0.13
Female child able (FCA)	1.08	0.26
Female child disable (FCD)	0.92	0.34
Female adult able (FAA)	1.30	0.38
Female adult disable (FAD)	1.06	0.26
Female elderly able (FEA)	1.04	0.16
Female elderly disable (FED)	0.89	0.14

where v_i is the instantaneous velocity of agent i at time t. Goal, Plan and Adaptation can be abstracted with the following mappings:

$$G_i : S_i \times \mathbb{R}^2 \to \mathbb{R}^2$$
$$P_i : t \times \mathbb{R}^2 \to \mathbb{R}^2$$
$$A_i : S_i \times \mathbb{R}^2 \to \mathbb{R}^2$$

These mappings are simplified to: $G_i : t \to \mathbb{R}^2$, $P_i : \mathbb{R}^2 \to \mathbb{R}^2$, and $A_i : \mathbb{R}^2 \to \mathbb{R}^2$. The velocity v_i can be substituted in (4) as:

$$v_i(t) = A_i(P_i(G_i(t))) \tag{5}$$

this simplification allows for orthogonal elements, specifying particular elements and relationships in a Behavioral Finite State Machine (BFMS), materialized in XML configuration files. Curtis presents Menge framework in a very good detail [12].

3 Modeling and Simulation

Gate 75 A to D has a two-level layout referred as upper layer (Gates 75A and B) and lower level (Gates 75 C and D). Both layers are above ground floor where is the access to airport tarmac and buses for remote positions. All access between levels and ground floor is by narrow ramps about 1.5 m width. To provide the feeling of open spaces, ramp walls are made of tempered glass. There are also elevators at the end of the building and elevators. It's important to notice in order to access ground

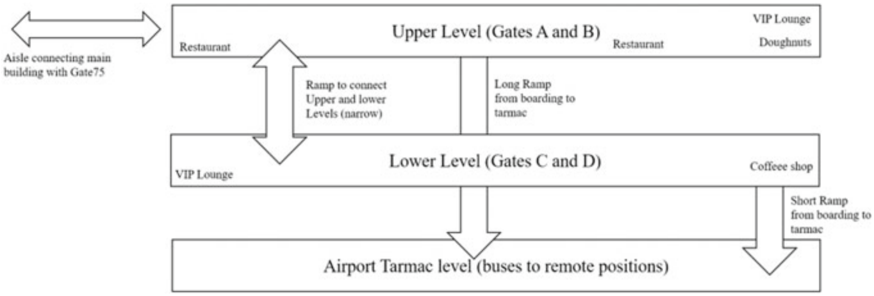

Fig. 5 75 lateral view schematics. *Source* own creation

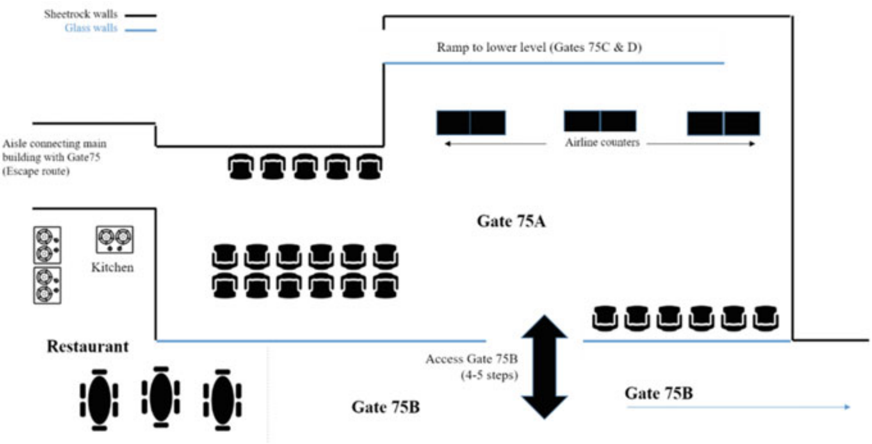

Fig. 6 Gate 75A floor plan. *Source* own creation

floor from upper level, people need to use ramp to lower level and stairs to ground floor. Our modeling of evacuation in case of fire emergency is based on upper level, Gate 75A where is the passage to main building. Figures 5 and 6 shows scenario schematic views. Figure 7 shows the natural evacuation plan and goal exit marker (goal flag).

3.1 Modeling Scene

Floor plan is modeled as Mange scene specifications, as stated by instructions and literature found [12]. We defined walls and waiting chairs as obstacles, using the coordinate system in tag Vertex. We need to define coordinates using center of screen as the origin (0,0). Each unit represents one meter. As an example, obstacle definition can be defined as:

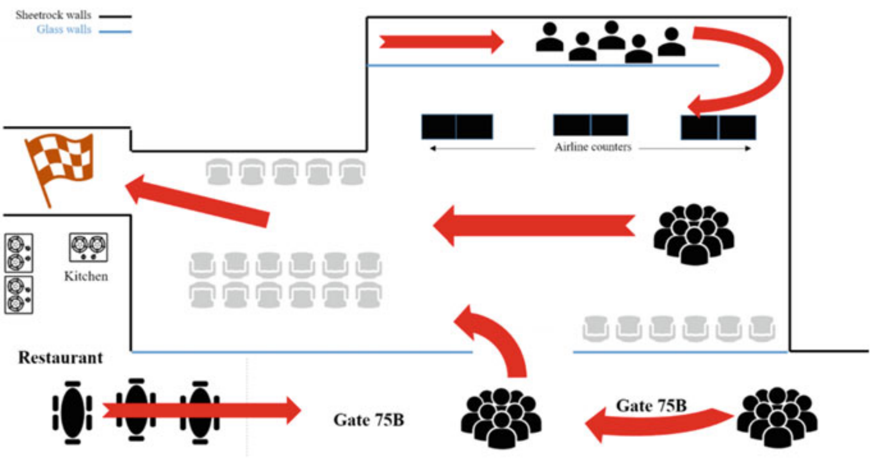

Fig. 7 Gate 75A evacuation. *Source* own creation

```
<ObstacleSet type="explicit" class="1">
    <!-- East wall definition -->
    <Obstacle closed="1">
        <Vertex p_x = "5" p_y = "-10"/>
            <Vertex p_x = "19" p_y = "-10"/>
            <Vertex p_x = "19" p_y = "6.5"/>
            <Vertex p_x = "1" p_y = "6.5"/>
            <Vertex p_x = "1" p_y = "4.5"/>
            <Vertex p_x = "17" p_y = "4.5"/>
            <Vertex p_x = "17" p_y = "-7"/>
            <Vertex p_x = "5" p_y = "-7"/>
    </Obstacle>
</ObstacleSet>
```

3.2 Modeling Persons

In crowd simulation, a person is often referred as agent, therefore, Menge uses same concept. We define four classes of agents in tag *AgentProfile*. All agents share the same algorithms for simulation, but each class has unique preferred speed, maximum

Table 3 Agents configuration

Evacuee Class	Speed (m/s)	Radius
Male adult big (MAB)	1.24	0.75
Male adult thin (MAT)	1.24	0.55
Female adult big (FAB)	1.30	0.65
Female adult thin (FAT)	1.06	0.45

speed and maximum acceleration, leveraging Table 2. Also, each class has different radius, corresponding to the space used. Maximum number of neighbors are 9, following SAF equation [9] solved as 9 persons in the vantage field of a person at a given time. Table 3 contains agents' configuration.

For our simulation, we define three groups of agents, (1) 40 Agents at the ramp arranged in single line, coming from lower level; (2) 70 Agents at Gate75A arranged in a grid; and (3) 100 Agents at Gate 75B arranged in hex lattice. Each group contains random agent classes generated by normal distributions.

3.3 Materials

For this research it was used AMD PRO A12-9800B R7, 12 Compute cores 4C + 8G laptop with 8.00 GB RAM (7.43 usable), 64-bit Windows 10 operating system, Menge v0.1 (Menge obtained from: http://gamma.cs.unc.edu/Menge/) and Matlab R2017b(9.3.0.713579).

3.4 Scenario Creation

Using the schema on Fig. 6, the model of Gate 75A is detailed as walls and obstacles. Our agents have to follow the escape route in stages. For agents coming out of the ramp we adjusted the maximum acceleration to 3.5 and reduce the speed in 14.4%, assuming a direct relation of one percent per slope degree. Ramp path follow two goals, first, reach main area of Gate 75A, and finally go to exit.

For agents escaping from Gate 75B, they don't need any adjustment, as the conditions are exactly the same as if they were in main Gate 75A. However, all agents need to pass through a narrow space that simulates the connection between 75A and 75B. Therefore, therefore, the escape goals are reach Gate 75A, then exit. Our Menge initial scenario is displayed in Fig. 8.

Agent classes are also differentiated by color. These are the default colors available in Menge. It can be observed three crowds in Fig. 8. At top is the ramp where basically agents are displayed in a single row. This was intended as many people travel with bags, carry-ons, laptops, and are hesitant to leave their belongings behind. Same can

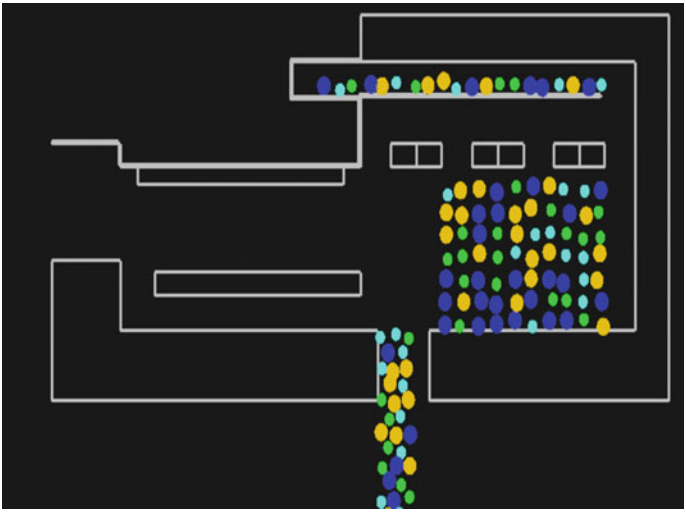

Fig. 8 Simulation 1. *Source* Menge Screenshot

be observed in the lower part of simulator, as there is space available at the right of passage from Gate 75B to 75A. Crowd in the center-right corresponds to agents in Gate 75A.

4 Results

Our simulation was executed until the point where 98% or more agents reached the goal. This limit is considered because when crowds dissipate, people tend to calm and start walking slowly as the danger perception lowers. Figure 9 has four screenshots from simulation. Step (a) shows the initial state. State (b) was taken at the moment where three agent groups collide. We observed few agents opted to go between wall and chairs. Also, agents at ramp had to turn around the glass wall and selected to move behind boarding counters, as there is room to reach the goal. Step (c) shows how Gate 75A is being cleared, but due to crowded space in the middle, there are agents stuck at first boarding counter. Step (d) shows a clear aisle but the corner between chairs and wall suggest being a spot where agents got slowed down.

That behavior was verified visually every time the simulation run, leading to suggest improvements. Our goal is to improve at least a 10% evacuation time. We propose as improvement with lowest cost, to remove chairs in the middle of the aisle. While this could be uncomfortable for passengers, it may improve evacuation time. Now, in order to test our suggestion, our new simulation removed the chairs and keep the same variables and goals as constants.

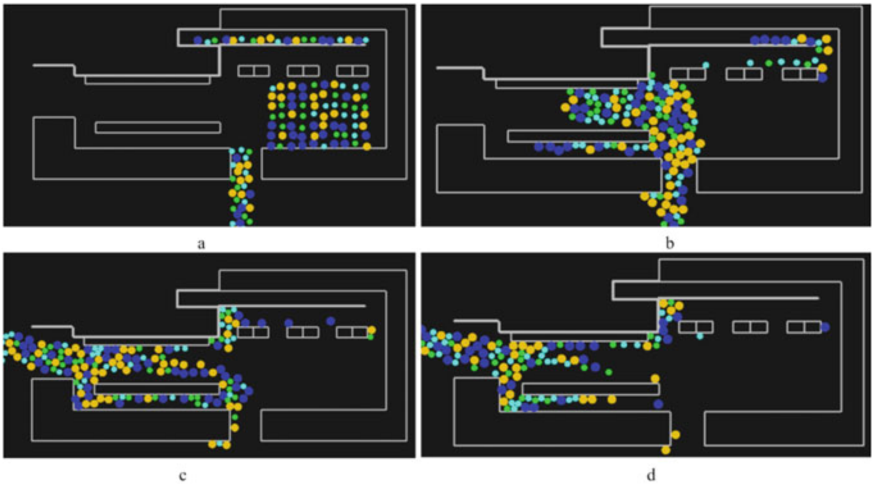

Fig. 9 Simulation 1 run. *Source* Menge Screenshot. **a** initital state; **b** three agent group collide; **c** clearing gate 75A; **d** clear aisle but congestion in corners

4.1 Improvements Simulation

Our simulation initial state is the same as original simulation, with clear aisle. Figure 10 has the screenshots from simulation run, this time with perspective (this is just to avoid confusion with simulation 1). Step (a) confirms the same state as

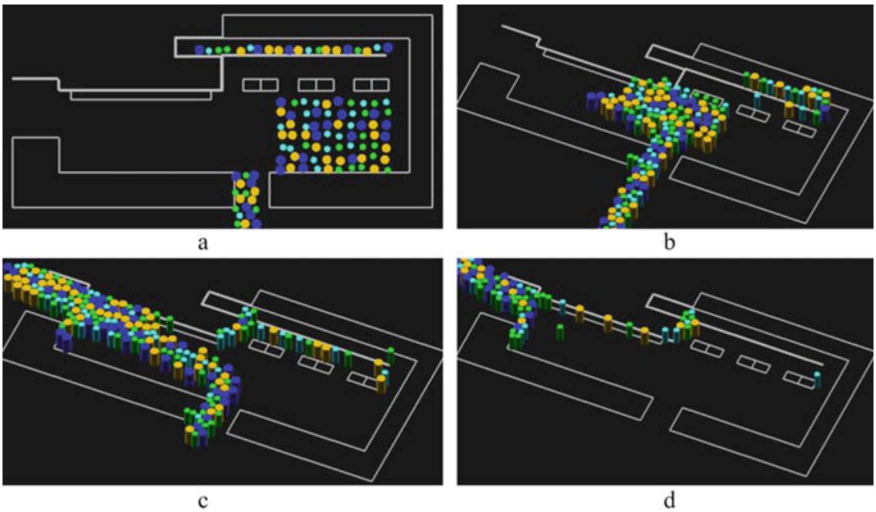

Fig. 10 Simulation 2 run. *Source* Menge Screenshot. **a** initial state, similar to simulation 1; **b** faster clearing; **c** fewer agents stuck; **d** faster clearing

Table 4 Simulation statistics

Feature	Simulation 1	Simulation 2	Difference	Improvement %
Maximum	61.7941	51.9729	16.2074	26.34
Minimum	55.0833	45.0324	3.5167	6.36
Average	58.6960	48.2722	10.4238	17.63
Std. Dev.	2.0791	2.0277	3.1514	4.9366

simulation 1. Step (b) showed a faster and smoother movement of agents toward the exit. However, agents at ramp presented almost same behavior as simulation 1. The difference was appreciated at step (c) where we can visually confirm there is few agents stuck in the problematic areas observed in simulation 1. this last part is observed in step (d).

Both simulations were running 100 times and the main results are in Table 4. Comparing simulation 1 vs simulation 2, we obtained a maximum performance improvement of 26.34% and a minimum improvement of 6.36%, while in average, the improvement was 17.63%. Figure 11 shows the comparison of simulated evacuation time (as simulation 1 and 2) and includes the difference in each run.

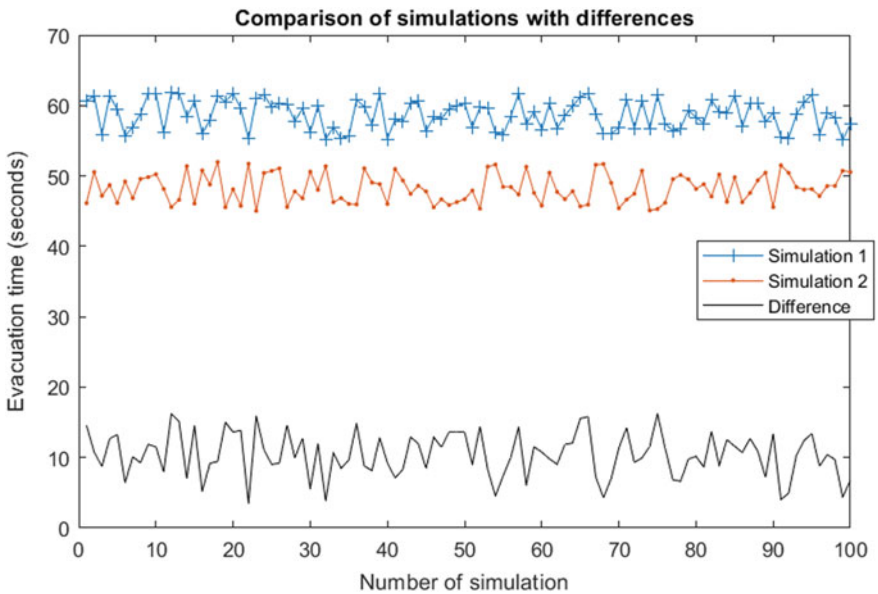

Fig. 11 Simulation comparison. *Source* Own creation

5 Conclusions and Future Research

Comparison of simulation for current layout and proposed changes to layout provides interesting findings that lead to the following conclusions. First, it was observed the benefit of simulation to measure and observe how an evacuation plan could result. In this research, we found Gate 75 has opportunities for improvement. The results observed show a bottleneck that is provoked by having chairs in the middle of an aisle. Also, the lack of escape routes in Gate 75B makes a natural evacuation path to the main building, forcing passengers to move to Gate 75A in order to escape.

Second, passengers coming from lower level through the ramp will have trouble to escape. This ramp in particular could introduce other problems during normal operations. As an example, it would be a problem when a gate change occurs, having to move a flight from Gate 75C or 75D to a boarding gate in the main building, while having other passengers move towards their right gate in the lower level. The ramp is so narrow that a collision will occur.

Third, using a crowd simulation software is convenient, as it allows to play with different hypothesis before deciding what to build. AICM is currently immerse in remodeling as it will add a new branch of gates in Terminal 2. Therefore, as construction company is changing layouts to accommodate the construction efforts, it would be convenient to do a quick simulation to find the best way to apply those changes while keeping the passengers safe and easy flow.

Last, we could observe how a small change in layout can improve evacuation times by more than 10%, testing this change is adequate and is valid to be implemented.

5.1 Future Research

This research has inspired us to continue to explore human crowd movements. As next steps we will use Menge in conjunction of better 3D-graphics engine such as Unity 3D to provide a more accurate representation of scenes. This is feasible due to Menge's architecture; the engine libraries can be called from other software packages.

Also, as a community service, this research is intended to be disclosed with authorities of AICM, so it can be used as an alternative for them to model different scenarios, not only for evacuation, but for passengers moving within terminals, simulation of flow to use free train between terminal buildings, or crowd attempting to check-in at airlines counters. The simulation scenarios are virtually endless. It is our best intention to inspire the main airport of Mexico to use this kind of technology and tools.

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