SIMULATION OF EMERGENCY EGRESS USING WALKSIM: A CASE STUDY

By:
Dr. Mootaz Farid[1]
Dr. Hatem El Shafie[2]

ABSTRACT

Simulation enables us to model and test a design before it is built. A solution for testing designs for emergency egress is needed. WalkSim has the potential to fill this gap. WalkSim is a general pedestrian circulation simulation library which takes into account the level of comfort in architectural circulation elements. A study to explore the method of using WalkSim in testing building for emergency egress is needed. A case study in an academic campus is performed. It started with a survey of input parameters. Several design alternatives were suggested and a simulation model was built for each. Each simulation model was run. Simulated persons were passed through the simulated spaces and circulation elements. Data were collected from simulation blocks to give us statistics about queue accumulation, level of service (comfort), escape time, waiting time, potential injuries, etc. This enabled the quantitave comparison between the design alternatives and thus choosing one. The value of, and the mode of use of simulation of emergency egress with WalkSim is thus demonstrated.

KEYWORDS: architecture, simulation, WalkSim, emergency, egress, escape, queuing, buildings, computer, pedestrian, circulation, stairs, corridors, doors, service

1. INTRODUCTION

The destruction of the World Trade Center on the 11th of September has accentuated the importance of additional attention to the means of planning and architectural design for emergency egress from buildings. [1] The goal of this study is to investigate the use and value of WalkSim simulation modules in simulating emergency egress. WalkSim is a pedestrian simulation program developed by the second author [2, 3] and specialized in the simulation of architectural elements in the form of an

1. Associate Professor, Department of Architecture, Faculty of Engineering, Cairo University
2. Lecturer, Department of Architecture, Faculty of Engineering, Cairo University

interconnected taxonomy representing the building and through which people are moved and comfort and quality of service are monitored. [4-6]

1.1 Goal and Method

The goal of this study will be achieved through a case study of a building in an academic campus in the New Cairo City in Egypt. The building being studied is formed of a basement, a multi-function ground floor and two stories among which dinning halls are distributed. Each dinning hall is designed to handle 375 students.

The objective of this paper is to check the existing design – of the designated case study – from the emergency egress view and to minimize the time taken to evacuate the building by making the necessary minimal amount of design modifications.

The methodology used in this study is to check the various alternatives of escape routes [7] and to find out the time taken to safely evacuate the building in each alternative, with an eye on the level of comfort achieved in queuing areas and the time spent in waiting in each queue.

1.2 Simulation as a Design Aid

Design aids are divided into generative and analytical design aids. Analytical design aids [8] are classified into dynamic analysis (simulation), and. non dynamic analysis.

Non-dynamic analysis is much simpler than simulation and consists of checking rules and evaluation formulae that operate on a fixed situation. That is, non-dynamic analysis is only needed to be carried out once. An example of a non-dynamic problem [8] is the calculation of construction costs of a building depending on the bill of quantities and given prices.

Simulation (dynamic analysis), on the other hand, is a much more powerful method. Using simulation, a model of the activity in progress can be run on a computer and by studying the consequences of the activity the design can be altered to be suitable for the activity.

The history of simulation may be tracked down to World War II when John Von

Neuman used it for solving neutron diffusion problems.

Simulation [9] is defined as the duplication of the essence of the system or activity without actually attaining reality itself. Central to simulation is the systems approach which is defined as to develop a manipulative model which will appear to have the same behavioral characteristics as the real system.

Simulation being an experimental problem solving technique, its objective is to obtain reliable estimates of system (building) performance at reasonable cost. Simulation involves the process of solving the equations representing the system step by step with increasing values of time [10].

Simulation is needed when one or more steps of the scientific method could not be performed. The four steps of scientific method being: Observation, hypothesis, prediction and experimentation for validation [11]. Experimentation is always impractical or impossible in the case of queuing spaces design. Simulation is thus needed. In addition, most queuing area design processes have no mathematical analytical solution due to the inexistence of a steady-state (necessary for analytical solutions) and continuous fluctuations and randomness in the system. On the other hand simulation can cope with all of this and thus it is suitable for the problem.

Frequently with architectural systems, it is uneconomical, impractical or impossible to perform an experiment with the actual system. Observations of post performance of buildings may not be available, however, there may be sufficient information to build a hypotheses about the probability distributions of some of the variables over time or about estimates of their trends over time.

Formulating a mathematical analytical model is often impossible in the case of queuing areas in buildings (and generally in architectural problems) since steady-state (necessary for analytical solution) is never reached [12] and the queue is either of a relatively short duration; and starts from a zero state (such as doctors waiting rooms) and is subject to irregular, if definable, fluctuations in respect of time (such as a supermarket group of queues) [12]

Prediction is the most important motive for using computer simulation. Most queuing problems in buildings are so complex that no analytical solution exists to these

problems [12].

Researchers are thus forced to turn to numerical analysis and to computer simulation in order to be able to fragment complex problems into smaller interacting subsystems and to be able to build mathematical logical models that are stochastic (random) in nature.

2. THE INITIAL DESIGN

The study started with an "Initial Design". Two alternatives of escape routes combinations were tested within this design. From the close examination of the two alternatives design recommendations emerged, which formed the "Proposed Design". In the proposed design the exits door that leads to the service area was increased to two doors. Also the two 3 meter width stairs in the service areas were replaced by four 2 meter width stairs. The proposed design was then tested.

3. THE MODELS

The building components were modeled using simulation blocks [2] of the WalkSim library. Each block represents an architectural element, e.g. a door block, a stair case block, a waiting area (queue) block, etc. The blocks are interconnected together to form a taxonomy representing the circulation system of the building. The path of the students from a dining hall till they end up outside of the building is emphasized.

Three models were built: Alternative A, B and the Proposed Design as follows.

3.1 Alternative A

Alternative A tests the initial design (Fig. 1) when the Escape Route 3 is not used.

Alternative A thus simulates 2 concurrent escape routes :

- Escape route 1: through dinning hall entrance doors
- Escape route 2: through the lavatories area

Escape route 3 was ignored in this alternative for several reasons, which are:

a- It has been observed in many public buildings in Egypt that specialized escape routes are ignorantly blocked by using them as storage areas, or by shutting them by lock and key for security reasons.

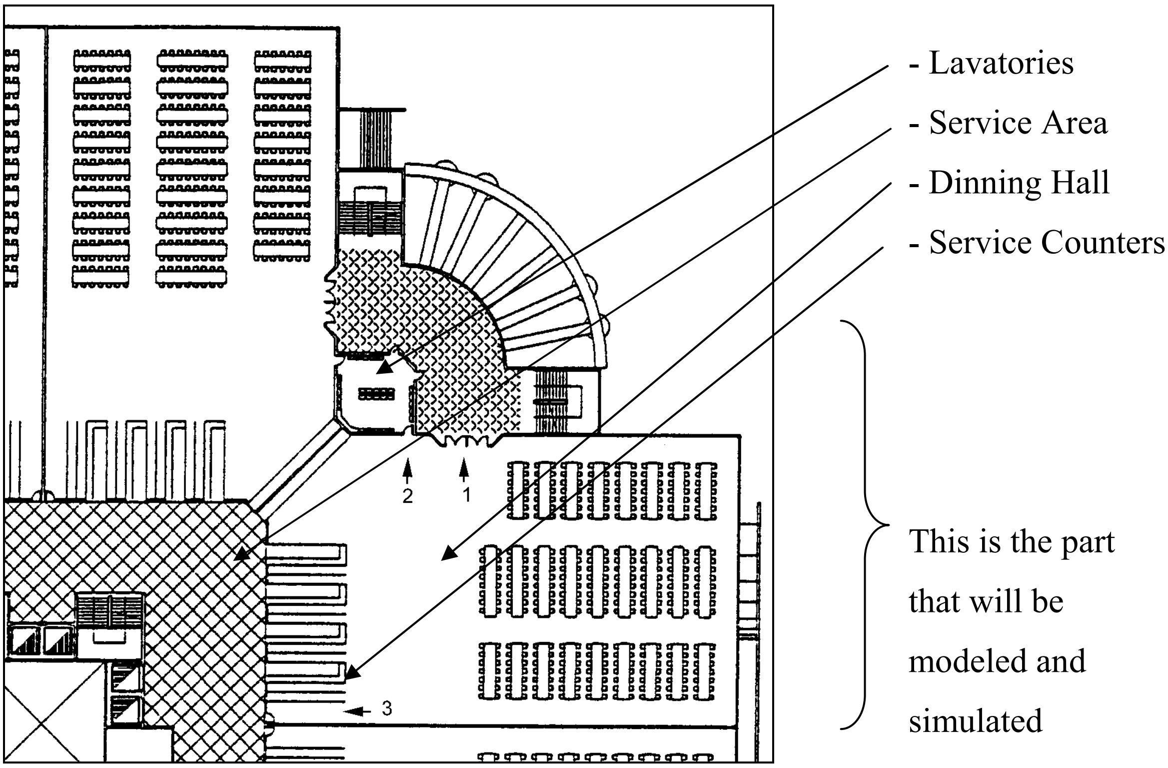

Fig. 1. The Initial Design (First & Second Floors Plan) indicating the escape routes. This design has two large stair cases in the central core (left).

b- Unless the students are trained on emergence escape, and informed to use this route, the usage of this route will be very light. This is because of the tendency of people to escape via the route they came from. [1, 7, 13-15]

The following architectural circulation elements were modeled and simulated in alternative A:

- A second floor dinning hall and a first floor one
- One half of the second floor lavatories area, and the same for the first floor
- A single stair case leading from the second floor to the ground floor
- One half of an entrance hall
- One half of the external approach

3.2 Alternative B

This alternative tests the initial design (Fig. 1) if the Escape route 3 (through the service area) will be used. This alternative is based on the same floor plans as the

Initial Design. Thus, Alternative B simulates the following 3 concurrent escape routes:

- Escape route 1: through dinning hall entrance doors
- Escape route 2: through the lavatories area
- Escape route 3: through service area

In Alternative B the following architectural elements were modeled:

- A second floor dinning hall and a first floor one
- One half of the second floor lavatories area, and the same for the first floor
- A single stair case leading from the second floor to the ground floor
- One half of an entrance hall
- One half of the external approach
- The door leading to the service area
- One quarter of a stair case along the escape route in the service area (Route 3).
- One quarter of a corridor and an external stair case along the escape route within the service area (Route 3) in the basement.

3.3 The Proposed Design

This alternative (Fig. 2) improves on Alternative B by strengthening Escape Route 3 and supposing that enough training and guidance will be given to the students to use

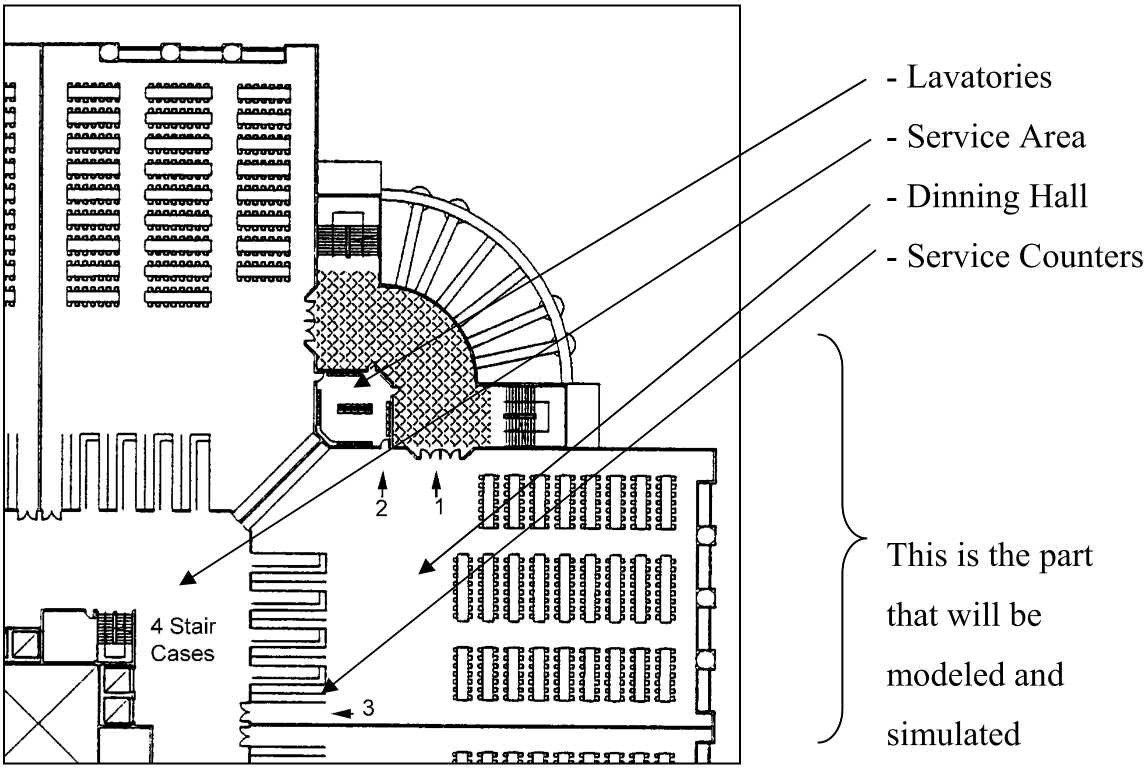

Fig. 2. The Proposed Design (First & Second Floors Plan). In the central core (left) the two large stair cases were replaced by four smaller stair cases. Escape route 3 was equipped by a double door.

this route; however the doors of this route were given a lower speed to represent the natural tendency to escape along the entrance route. The exit door that leads to the service area was increased to two doors. Also the two 3 meter width stairs in the service areas were replaced by four 2 meter width stairs

In The Proposed Design the following was modeled:

- A second floor dinning hall and a first floor one
- One half of the second floor lavatories area, and the same for the first floor
- A single stair case leading from the second floor to the ground floor
- One half of an entrance hall
- One half of the external approach
- Two doors leading to the service area (Route 3).
- One half of a stair case along the escape route within the service area (Route 3).
- One quarter of a corridor and an external stair case along the escape route within the service area (Route 3).

4. THE SIMULATION

The simulation process tries -- within limits -- to produce a real life situation. [16-19]. In small time intervals, simulated students (pedestrians) are passed between the various interconnected blocks with controlled flow and service times. Each block represents an architectural element (e.g. a waiting area, a stair flight, a door, etc.). The whole model is built to represent what would actually happen when the building is built. Doing so, close monitoring to the aspects of flow is carried out to identify problems within the design. All timings were measured in seconds and all timings were taken after the complete awareness of the students of the emergency situation.

5. GUIDELINES USED IN THE STUDY

After the models were built (Fig. 3-4) a process of filling in the parameters for each model was undertaken. The following part shows the guide lines that we used in the input parameters of the blocks of the models.

5.1 The Arrival Process

At the start of the simulation-run all students are assumed to be well informed that an emergency situation is occurring and that they have to leave the building at once.

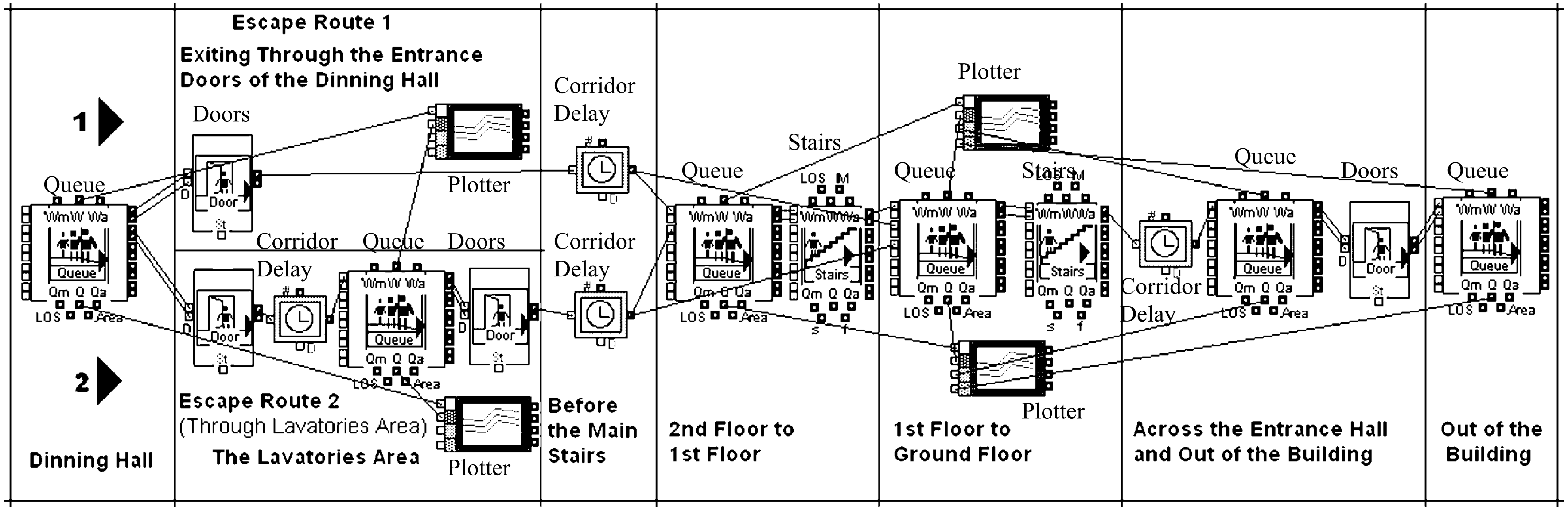

Fig. 3. A schematic of "Alternative A" using WalkSim blocks. Architectural circulation elements are represented by blocks simulating their performance. Blocks are interconnected and then parameters of each block are set before running the model. Plotter modules – the ones with thick border – are added to draw graphs of key results in selected spaces. For more information revise reference [2].

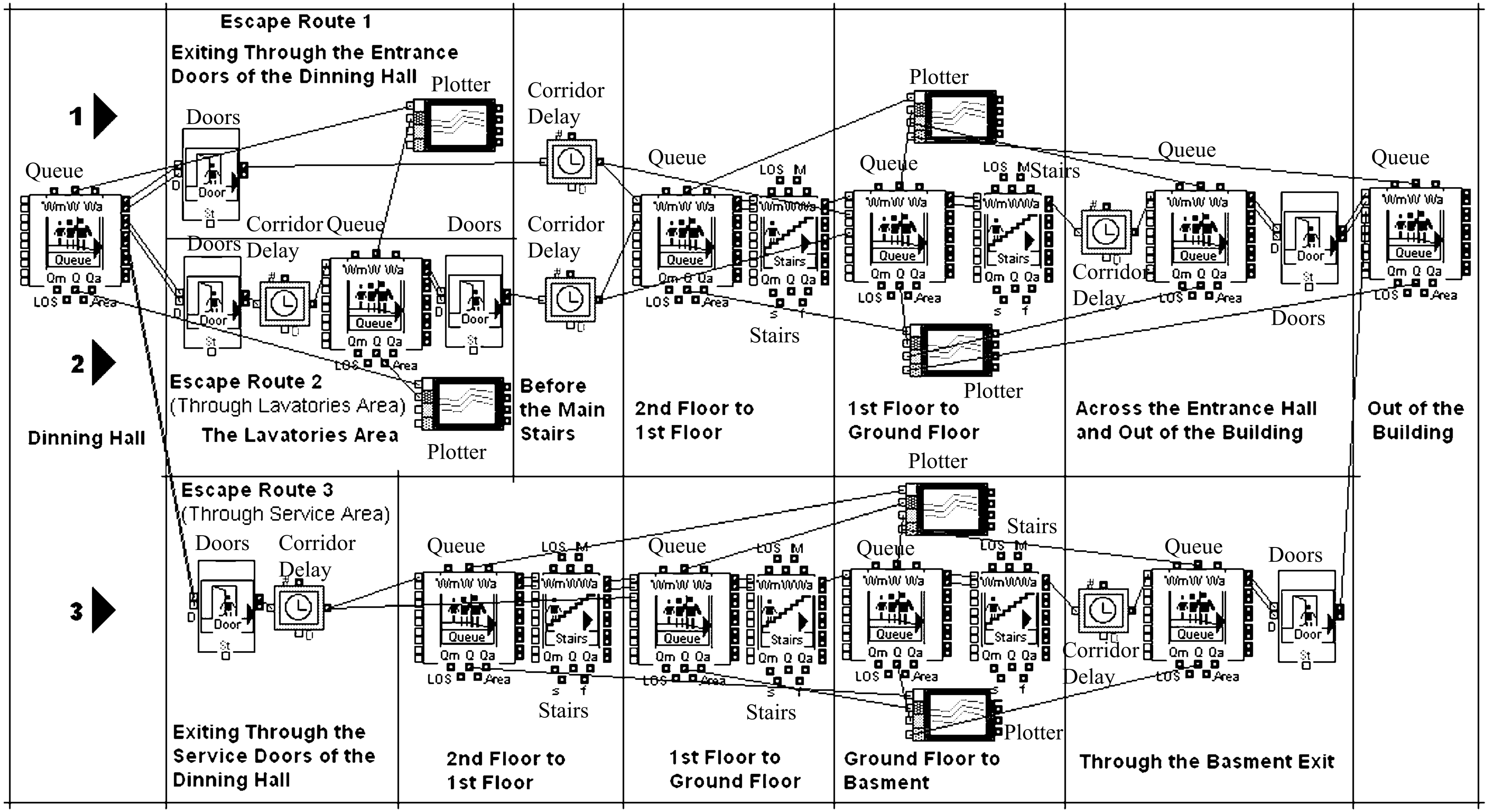

Fig. 4. Schematic of "Alternative B" and the "Proposed Design" using WalkSim blocks. Though the schematic is the same for both of the alternatives, differences exist in the parameters of the blocks, in the Proposed Design, escape route 3 was strengthened.

Thus all the students are assumed to have formed a huge bulk queue in each dinning hall. This is simulated by a queue block which is full with 375 persons ready to escape.

5.2 The Doors

Swing door (0.9m) were used, giving a flow rate of about 40-60 ped/min. [4, 6, 20]. Since the users are young, strong and non-carriers, the upper range was used in all but the door(s) before the escape route passing by the service area (Route 3). This door(s) was reduced in its service rate to simulate the reluctance of students to using an escape route other than the route they have came to the dinning hall through. This door was increased to 2 doors in the Proposed Design. Figure 5 shows a sample screen for the input and output of the computer simulation program. Table 1 shows the input parameters of the doors modules.

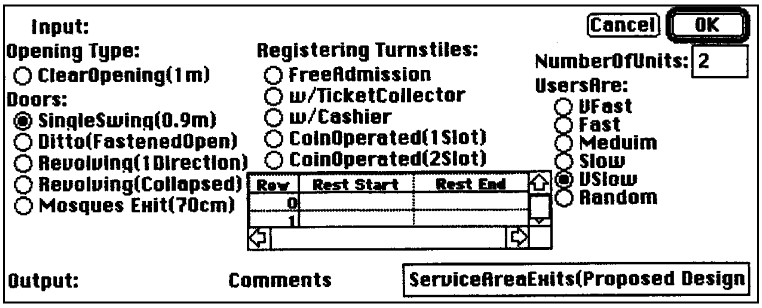

Fig. 5. A sample screen of the input parameters that specify the performance of the doors and its users

Table 1. Input parameters of the doors modules.

Space	Door Type	No. of Door Unites	Users Speed
Dinning Halls	Single Swing-0.9m	4	Very Fast
Entrance Doors for Lavatories	Single Swing-0.9m	1	Very Fast
Exit Doors (Main Entrance)	Single Swing-0.9m	3	Very Fast
Service Area Exit Doors	Single Swing-0.9m	1	Very Slow
Service Area Exits (Proposed Design)	Single Swing-0.9m	2	Very Slow

5.3 The Queues

Queues formed before the escape doors (dinning hall doors, lavatories doors, and service area doors) and before each stair flight.

Comfort in pedestrian circulation elements is measured by a measure called “Levels of Service” (LOS) [4, 6]. In our case all but the less critical queuing areas were designed with level of service E (LOS E). Although this is not a particularly comfortable level of service, it will be reached anyway since the arrival pattern is expected to be an abrupt bulk arrival [20]. The simulation program was set to keep the area constant, and thus the area was not changed according to the accumulation of students, which allowed the LOS to vary according to the accumulation. Figure 6 shows a sample queue block with its input parameters and outputs. These include the accumulation of the queue, the statistics of the waiting time, the percentage of occurrence of each LOS, and the potential number of injuries (if any). Table 2 shows the input parameters of queue modules representing various parts of the simulated building.

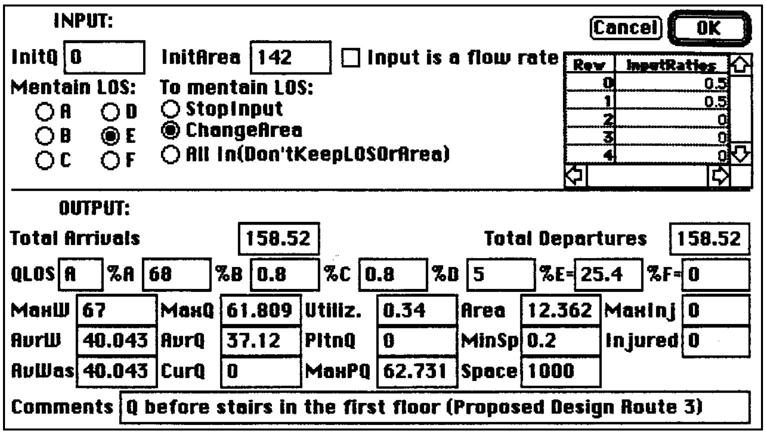

Fig. 6. A sample queue module showing input parameters and output (results).

5.4 Stair Cases

Bulk arrival [4] that immediately exceeds the available stairs capacity is expected. It is, therefore, recommended to consider LOS E from the start. LOS E being with volume in the range of 13 to 17 PFM (pedestrian per foot width per minute). 16 PFM was chosen as the users are young and rather ordered. This is equivalent to 52.25 ped/min./m, giving a service time of about 1.14 sec/ped per meter width. This time was used in all stair cases.

While descending, the delay at stairs was adjusted to a medium delay of 0.383 sec/riser. Though slow, this speed is expected at crowded conditions. While ascending, the delay was adjusted to a low delay of 0.3077 second/riser.

Table 2. Input parameters of queue modules representing various parts of the simulated building

Alternative	Name of Space	Initial Queue	Initial Area m2	LOS to Maintain	Change Area to Maintain LOS	All in (LOS and Area are not maintained)	Input Ratios from Each Source
All	The Dining Hall	375	400	C	✔		Single
A	Queue Before Stairs in the Second Floor	0	106	D		✔	1:1
	Queue Before Stairs in the First Floor	0	106	E		✔	1:1:1
All	Gathering Outside the Building	0	9	C	✔		Single
B	Queue Before Stairs in the Second Floor	0	106	D		✔	1:1
	Queue Before Stairs in the First Floor	0	106	E		✔	1:1:1
	Gathering Outside the Building	0	9	C	✔		1:1
B-Route 3	Queue Before Stairs in the Second Floor	0	142	E	✔		Single
	Queue Before Stairs in the First Floor	0	142	E	✔		1:1
	Queue Before Stairs in the Ground Floor	0	142	E	✔		Single
Pro-posed	The Dining Hall	375	400	C	✔		Single
	Queue Before Stairs in the Second Floor	0	106	D		✔	1:1
	Queue Before Stairs in the First Floor	0	106	E		✔	1:1:1
Proposed Route 3	Queue Before Stairs in the Second Floor	0	142	E	✔		Single
	Queue Before Stairs in the First Floor	0	142	E	✔		1:1
	Queue Before Stairs in the Ground Floor	0	142	E	✔		Single

5.5 Corridors (Walkways)

Level of service D [4] was used. Since the users are young and agile the upper range of speed allowed by this LOS (1.17 m/sec) was chosen. All walking delays were calculated according to this speed.

6. RESULTS, CONCLUSIONS AND RECOMMENDATIONS

1- Simulation helped us to better understand the system. An example of this was that it helped us understand that four smaller stairs in the central core were better than two larger ones. This actually led to better escape time in the Proposed Design. Better understanding of the system led to the suggestion of the addition of emergency fire doors between adjacent dinning halls. These are in order to be used in case any escape route is blocked by the cause of emergency (e.g. fire).

2- This study shows that the total escape time of the students (obtained by adding the most critical waiting times) in **Alternative A** is less than 6 minutes (346 seconds) while the total escape time of **Alternative B** (with its additional Escape Route 3) is about 5 minutes (309 seconds). Enhancements to Escape Route 3 resulted in the **Proposed Design** with its approximate 4.5 minutes (281 seconds) total escape time. Figures 7-8 show sample charts that are drawn by the system showing queue accumulation and waiting time.

3- Tables 3-4 summarize the results and compares Alternative A, B, and the Proposed Design.

Table 3. Comparison of the results of the simulation of the three alternatives with respect to queue accumulation in various parts of the building. Queues represent the pedestrian accumulation resulting from the escape from 2 dinning halls that are above each other.

Name of Waiting Area	Queue Accumulation (Pedestrians)					
	Alternative A		Alternative B		Proposed Design	
	Max	Avrg.	Max	Avrg.	Max	Avrg.
Before 2nd Floor Stairs	183	92	161	81	141	71
Before 1st Floor Stairs	344	218	299	190	265	169
Route 3: Before 2nd Floor Stairs	N/A	N/A	4	2	31	16
Route 3: Before 1st Floor Stairs	N/A	N/A	36	19	62	37
Route 3: Before Ground Floor Stairs	N/A	N/A	0.44	0.34	20	10

4- Although the difference in escape time between Alternative A & B is not at all big (37 sec. difference), it is recommended to keep on the Escape Route 3

because it provides a safe alternative escape route in case any route is blocked by the cause of emergency.

Table 4. Comparison of the results of the simulation of the three alternatives with respect to time

Space	Alternative A			Alternative B			Proposed Design		
	Max. Wait. Time	Average	Evacuation Time	Max. Wait. Time	Average	Evacuation Time	Max. Wait. Time	Average	Evacuation Time
Dinning Hall	-	-	76	-	-	67	-	-	61
Before 2nd Floor Stairs	76	38	164	67	33	146	59	29	129
Before 1st Floor Stairs	142	90	319	124	78	281	110	69	252
Route 3: Before 2nd Floor Stairs	N/A	N/A	N/A	7	3.5	95	40	20	111
Route 3: Before 1st Floor Stairs	N/A	N/A	N/A	60	31	168	67	40	184
Route 3: Before Ground Floor Stairs	N/A	N/A	N/A	1	0.56	182	25	12	221
Total Escape Time			346			309			281

5- It is also recommended to increase the number of doors leading to Route 3 to two doors per dinning hall (the **Proposed Design**). As a consequence of increasing the doors, the stairs (along Route 3) should be increased to four 2 meter width stain. This would strengthen the role of Route 3 as an alternative escape route.

6- It is recommended that a method of automated calculation of the total evacuation time be developed in the WalkSim framework. Though all the data for the calculation of the total evacuation time resulted from the simulation-run, there is not a way in the WalkSim to add these times to produce the total evacuation time. This can be implemented by modifying door modules to record the time for the first arrival and departure and the time for the last arrival and departure. Then by putting a door module in the beginning and the end of the model and subtracting the time of first arrival in the beginning of the model

from the time of last departure in the end of the model, the total evacuation time can be calculated.

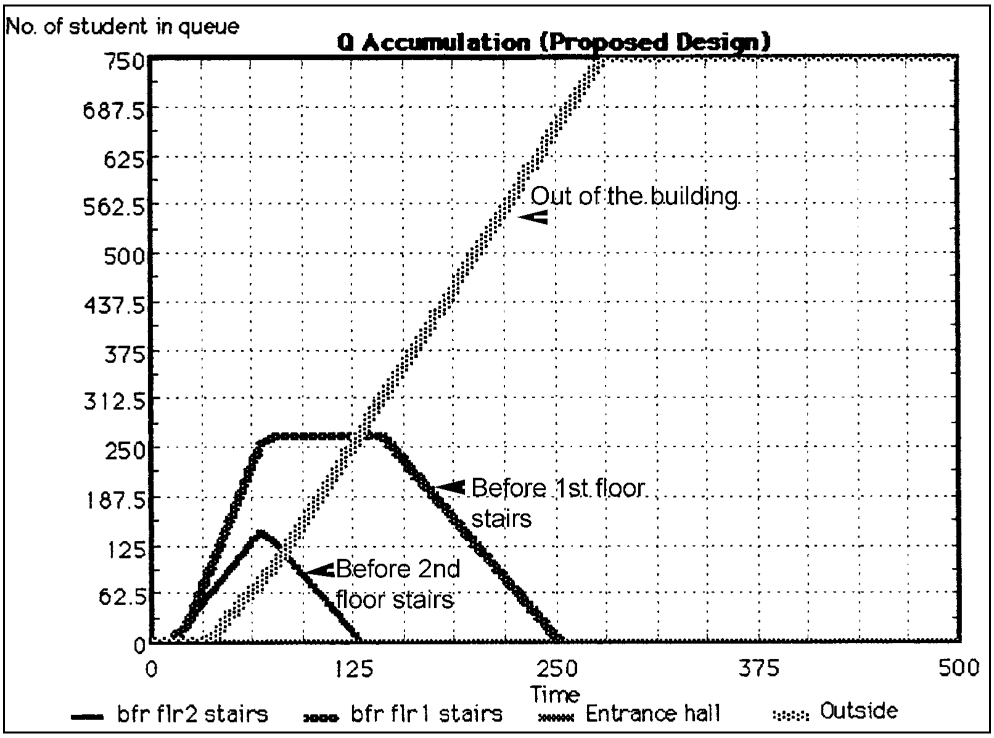

Fig. 7. Sample chart of queue accumulation in some chosen spaces of the building

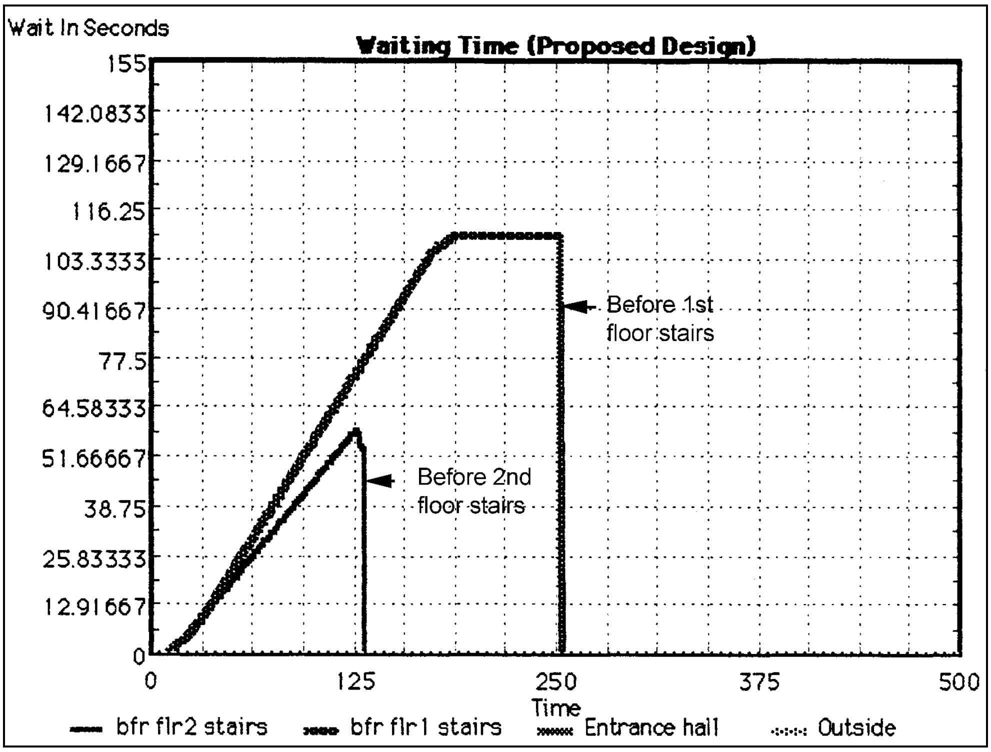

Fig. 8. Sample chart of waiting time in some chosen spaces of the building

7- Since the performance of pedestrians has shown reasonable consistency on both the urban and architectural levels, we may conclude that the same methodology may also apply on the urban level with further tweaking.

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محاكاة آداء الهروب الطارئ من المباني : دراسة حالة

يستكشف هذا البحث قيمة استخدام الحاسبات لمحاكاة الآداء الخاص بالهروب الإضطراري من المباني. ويعتبر اسلوب المحاكاة من الأساليب الفعالة في فهم أداء النظم والتنبؤ بالأداء في المستقبل. لذلك فقد تم الإعتماد على برمجيات محاكاة حركة المستخدمين في المباني والمسماة WalkSim وذلك بهدف استكشاف مدى فاعلية هذا الأسلوب لمحاكاة الأداء في الأزمات والهروب الإضطراري. وقد تم عمل دراسة حالة في مبنى جامعي. بدأت الدراسة بتحديد المدخلات، ثم تم اقتراح عدد من التعديلات (البدائل) للتصميم ومن ثم تم بناء نموذج محاكاة لكل بديل معماري. ثم تم تشغيل المحاكاة لكل من النماذج وذلك بتمرير الأشخاص من خلال الفراغات المعمارية وعناصر الحركة. وتم جمع معلومات من نماذج المحاكاة أثناء التشغيل مثل: تراكم المستخدمين في الفراغات المعمارية ومستوى الخدمة (الراحة) ومدة الهروب وزمن الإنتظار وعدد المصابين إن وجد. مكننا هذا من التقويم الكمي للبدائل المعمارية ومن ثم اختيار أفضل البدائل آداءاً في حالة الهروب الطاريء. أظهرت هذه الدراسة قيمة وأسلوب استخدام المحاكاة في تصميم واختبار المباني للهروب الطاريء.