SIMULATION OF PEDESTRIAN CIRCULATION IN DINNING HALLS

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ABSTRACT

The ability to test architectural design before it is built and to predict the performance of the building is important for the sustainability of the building. Simulation is used to model and test a design before it is built. A solution for testing designs for pedestrian circulation in busy self-service dinning halls is needed. WalkSim has the potential to fill this gap. WalkSim is a general pedestrian circulation simulation library that takes into account the level of comfort in architectural circulation elements. A study to explore the method of using WalkSim to check the design for pedestrian circulation (circulation of students during meals in particular) in the dinning halls building of an academic campus was proposed. A case study in an academic campus was 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), service time, waiting time, 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 pedestrian circulation in busy self-service dinning halls with WalkSim is thus demonstrated. This is also true in any case where there is some sort of queue for service. The method also proved valuable in assessing the magnitude of service points that should be provided to achieve appropriate service.

KEYWORDS: simulation, pedestrian, circulation, WalkSim, service, counter, restaurant, queuing, stairs, corridors, doors, computer, sustainable architecture, buildings

1. INTRODUCTION

Architects often face design situations where they have to rely on their judgment, which in its turn is not always right. A tool for testing designs from the movement-of-

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people[1] point of view[2] is needed. WalkSim fills this gap. WalkSim is a pedestrian simulation program developed by the author[3] and specialized in the simulation of architectural elements[4] in the form of an interconnected taxonomy representing the building (see the resulting model in Figure1) and through which simulated people are moved while comfort and quality of service are monitored.[5] Comfort and quality of service are represented by the Level-of-Service (LOS) concept, criteria and measures.[6]

1.1. Goal and Method

This study explores the use and value of WalkSim in the design and evaluation of service points and busy restaurants. Its is assumed that by producing better, more efficient and well tested design it is possible to enhance the sustainability of architecture.

The method of this study is to perform a case study to check the design for pedestrian circulation (circulation of students during meals in particular) in the dinning halls building of an academic campus. It is required to simulate the journey of the students from arrival until they exit the building. This journey goes as follows:

a- Students arrive to the building's approach with a certain stochastic distribution.

b- Each student enters the building through the main doors and heads towards a staircase that leads to the dining hall he is assigned to.

c- Each student walks up the stairs to his dining hall.

d- He gets a tray and queue infront of a service counter to be served.

e- Then he goes to a table where he sits down and has his meal

f- Upon finishing, each student returns his tray to a conveyor belt

g- He then may go to the lavatory to wash his hands

h- Then he leaves the building in the reverse of c, b and a.

Among the aims of the study is to limit the time this journey takes to less than 30 minutes for the total number of students.

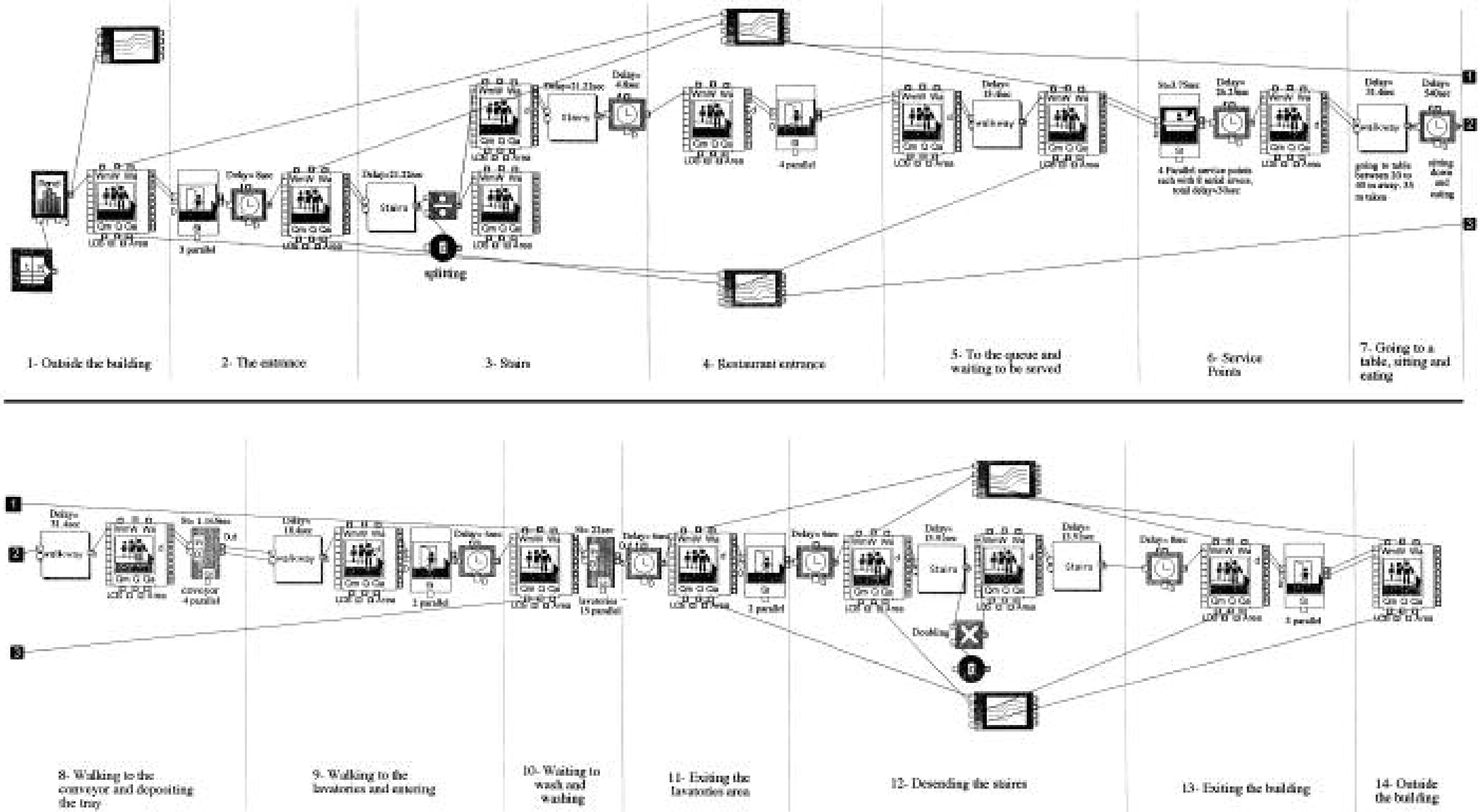


Figure 1. ***The Simulation Model***: A simulation model was built out of simulation blocks of WalkSim. Each simulation block represents a functional part of the building. Thus simulation blocks of stairs, doors, corridors, queues, self service counters, etc. were connected together to form a network that dynamically simulates the movement, queuing and service of students. Each block interacts dynamically with the other connected blocks of the system.

This study starts by testing two "Original Designs" using computer simulation to find the points of weakness and propose solutions, and go on performing what-if-analysis to enhance the design to reach a "Modified Design".

1.2. Simulation in the Design Process

The design process may be looked at as an iterative process[7] with the five steps of 1) analysis, 2) synthesis, 3) appraisal, 4) selection and 5) communication.[8]
Simulation as a dynamic analysis tool/design aid falls in the first and third steps. Simulation is defined[9] as the duplication of the essence of the system or activity without actually attaining reality itself. 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] 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.
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 [11] 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.

1.3. Scope

It is the scope of this study to investigate the path and performance of the building in reaction to the passage of students from entrance to exit in normal circumstances. It is not out to test the performance under emergency egress as this is beyond the scope of

this study. In addition, other factors, such as the economical impact of the design enhancements, are out of the scope of this study.

2. THE ORIGINAL DESIGN

The building being studied (Figure 2) is formed of a basement, a ground floor (with various functions) and two stories among which 16 dinning halls are distributed (8 dinning halls per floor). Each dinning hall is designed to handle 375 students (a total of 6000 students).

The study started with 2 initial designs. Debate occurred among the design teem about the validity of each. The main difference between the two designs was that the first design had 11 service points in each dinning hall, while the other had 6 service points only. It was among the goals of the design to reduce the number of service points.

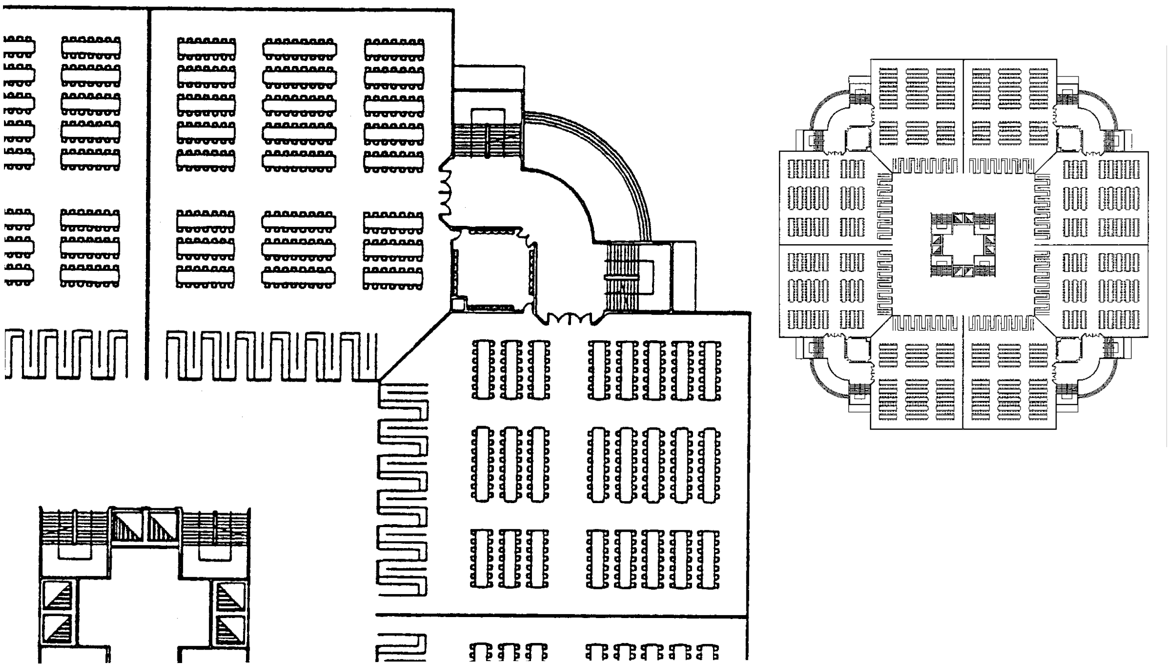


Figure 2. ***An Initial Design:*** This initial design had two floors each with eight dining halls, four large lavatories areas, eight main staircases, four secondary staircases and eight elevators. Each dining hall serves 375 students by 6 self-service counters (or 11 counters in another initial alternative). Checking this design was required and if necessary minimal changes to the initial design should be recommended in-order to keep the service duration for all 6000 students at or below 30 minutes.

3. THE MODEL

A model (Figure 1) was built to simulate each of the components of the building. The building components (and their internal components) were modeled using simulation blocks interconnected to represent the students' path from outside the building, till they end up outside once more. Due to the symmetric design of the building only about one eighth of the building floor plan was needed to be simulated. The following items were modeled and simulated:

a. Half of the external approach to the building
b. Half of an entrance hall of the building. (Since each entrance hall serves two staircases)
c. A single stair case leading to the second floor
d. A second floor dinning hall, which represents a "worse case" than the first floor one.
e. Half of the second floor lavatories area.

4. THE SIMULATION

The simulation process tries (within limits) to produce a real life situation. In our case this is done by passing simulated students (pedestrians) between the various interconnected blocks with controlled flow and service times, 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. Plotter modules were added to monitor and plot the performance of key areas of the building.

5. PARAMETERS USED IN THE STUDY

5.1. The Arrival Process

The arrival rate distribution is considered to be a Poisson distribution, since the probability of an arrival in one interval of time is proportional to its length, and the

probability tend to zero at a certain point of time.[12]

However according to observations of arrival patterns[13] the arrival process is considered to be time-variant. That is, the mean arrival rate varies on time basis. And the arrival pattern tends to take a bell shape. This was simulated in our model (see Figure 3) with a Poisson arrival rate distribution with a varying mean to allow for the 750 students (for one entrance) to arrive within a time interval of about 5 minutes.

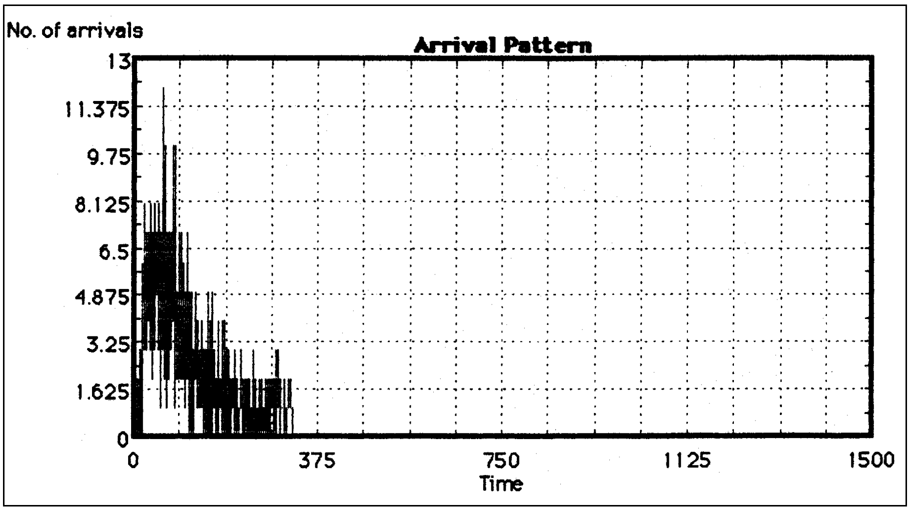


Figure 3. ***The Arrival Pattern:*** Each of the four ground floor entrances receives (within five minutes duration) about 1500 students. A Poisson arrival-rate distribution with a varying mean was used to simulate the arrival pattern

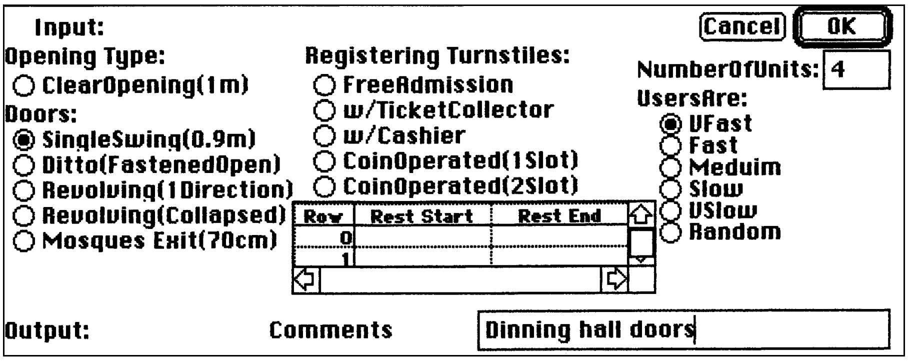


Figure 4. ***Parameters of a Doors Module:***. Sample parameters and inputs to the doors computer simulation block. As the users are young, agile, and expected to be very fast, the upper range of the flow rate is used.

5.2. Doors

Swing doors (0.9m) were used. A 90cm swing door gives a flow rate of about 40-60 ped/min .[14] Since the users are young, strong and non-carriers, the upper range was

used. Figure 4 represent the parameters and inputs to the doors computer simulation block.

5.3. Queues

Queues formed before the external entrance doors, before the stairs in the ground floor, before the food service points and before the lavatories.

All queuing areas were designed with the level-of-service C[15]. The only exception was the queue before the lavatories, since this is a bulk queue where much cross circulation is expected. The simulation program was given the opportunity to change the area according to the accumulation of students. Figures 5 show the inputs and outputs of a sample queue block.

5.4. Staircases

Level-of-service E was assumed in staircases. Although this level-of-service is not particularly comfortable, it was assumed since the very fast rate of arrival of students will lead to this LOS anyway. Volume is the number of pedestrians passing through each meter (or foot) of the width per minute of time. LOS E gives a volume range of 42.65 to 55.77 pedestrians per meter width (of the flight) per minute which is equivalent to 13-17 pedestrians per foot width (of the flight) per minute (PFM). A moderate volume of 15 PFM was chosen. This is equivalent to 49.21 pedestrian per minute per meter width (ped/min/m) which is equivalent to 0.8 ped/sec/m. This gives a service time of 1.22 sec/ped for each meter width. This time was used in all staircases.

While ascending, the delay at stair was adjusted to 0.6 sec/riser. Though slow, this delay is expected under crowded conditions. While descending, the delay was adjusted to 0.383 sec/riser.

5.5. Corridors

In the walkways, level-of-service D was used, which gives a volume range between 49.21 to 32.81 ped/minute/m. A volume of 42.64 ped/min/m. (0.711 ped/sec/m) was chosen. This accounts for a 1.407 sec/ped./m service time. Since the users are young and agile the upper range of the speed (1.22 m/sec) was chosen.
On this basis all walking delays were calculated. The delays are shown in the network diagram of the model. It should be noted that these are the minimum delays that a pedestrian will experience as a result of walking through these walkways assuming they were empty. Of coarse, a pedestrian will be delayed more as a result of crowding in the queuing area (queue module).

5.6. The Food Service Points

The food service points (Figure 6) were assumed to serve 8 types of food (and beverage) in series with total delay of about 30 seconds. The student passes and may be served from each. Thus a single counter serves 8 students concurrently and is capable of receiving a new student every about 3.75 second. The number of service points was finally set to 4 service points per hall after trying 11 and 6 and finding them to be extravagant. The width of a service point's lanes was set to 0.85m to allow for circulation of tray carriers. Guide rails were provided at 85 cm to allow for tray carriers to return safely.[16]

5.7. Having the Meal

A student then moves to a table, sits down and stars having his meal. A reasonable amount of time (9 minutes) is given to this process. However, no time was initially allowed for social interaction with comrades.

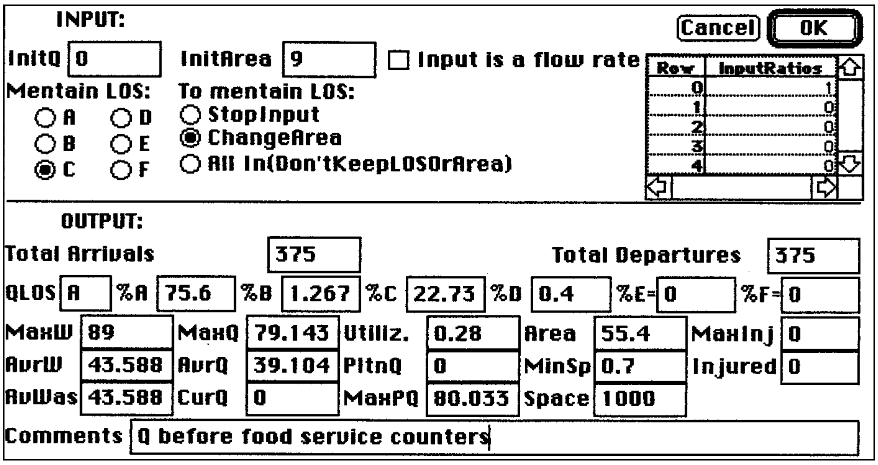


Figure 5 ***Parameters and Results of a Queue Module:*** Sample parameters and inputs to a queue computer simulation block are shown in the upper half. The lower half shows the results of that simulation block in that simulation run. Results include accumulations, waiting times, LOS, area, injuries, etc..

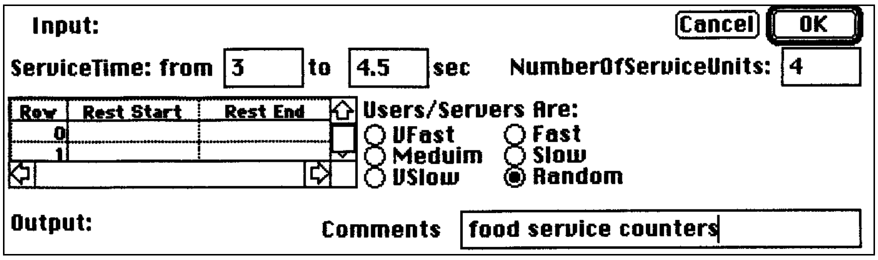


Figure 6 ***Parameters of a Food Service Counter Module***

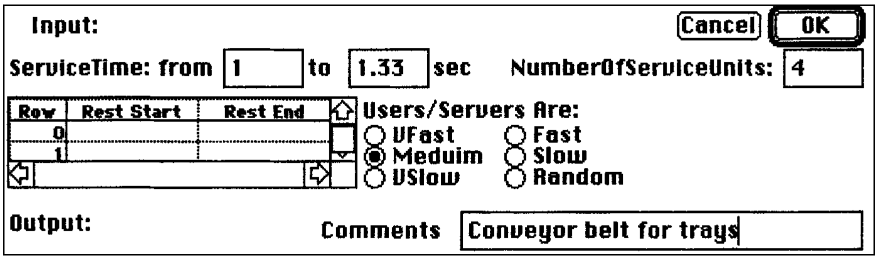


Figure 7 ***Parameters of a Conveyor Belt for Trays Module:***. This conveyor is used in returning the trays to the kitchen.

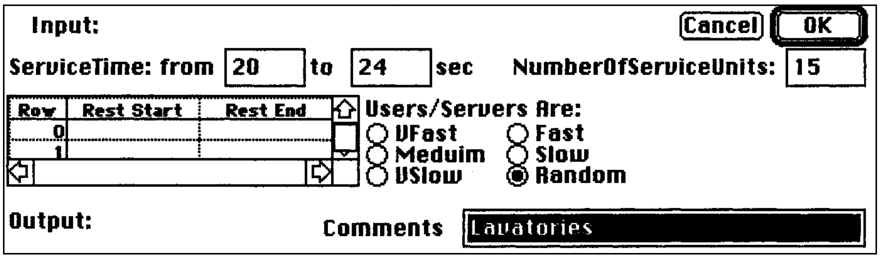


Figure 8 ***Parameters of a Lavatory Module:***. This module represents the lavatory where students wash their hands.

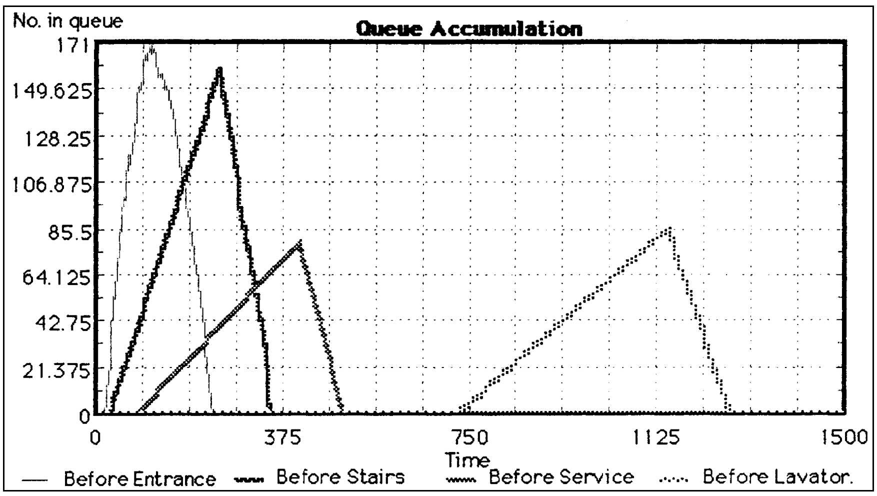


Figure 9 ***Queue Accumulations:***. Sample output from a plotter module showing the queue accumulation in several spaces over time.

5.8. The Conveyor

A student then moves to the conveyor (Figure 7) to deposit his tray. Assume 1m/s conveyor speed and tray with about 50 cm thus each second 2 trays are deposited. If double depth conveyers are used, thus, each second 4 trays are deposited. It is safer to calculate for 3 trays/sec and to set the conveyor module accordingly.

5.9. The Lavatories

A student then moves to the lavatories area (Figure 8) where he washes his hands. A reasonable service time of around 22 seconds for washing hands and mouth is assumed. No drying or toweling allowance was given. The student then continues his way until he ends out of the building.

6. WHAT-IF-ANALYSIS & DESIGN RECOMMENDATIONS

After the model was built and the parameters were fed into each simulation block, several simulation runs were performed. During each run several performance measures are plotted (Figures 9,10,11). Building the model and the simulation-runs helped in acquiring a better understanding of the system. Simulation aided in performing what-if-analysis which is useful in testing variations of the design (an example of which is shown in Figure 12) and exploring their impact on the performance of the building in order to reach suitable conditions in all parts of the building. Following are some examples of cases that were tested (simulated).

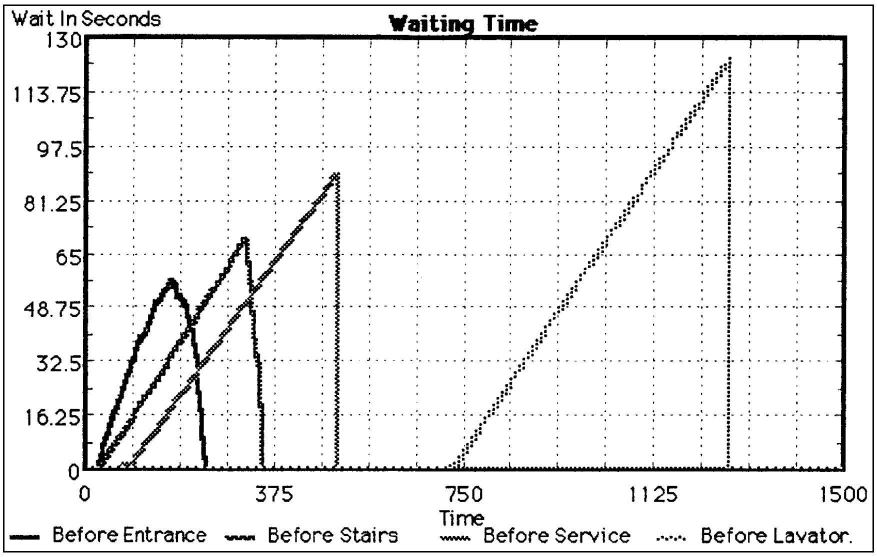


Figure 10 ***Waiting Time:*** Sample chart output of a plotter module which monitors the conditions of the system through out each simulation run. Here the chart represents the waiting time in several queue modules.

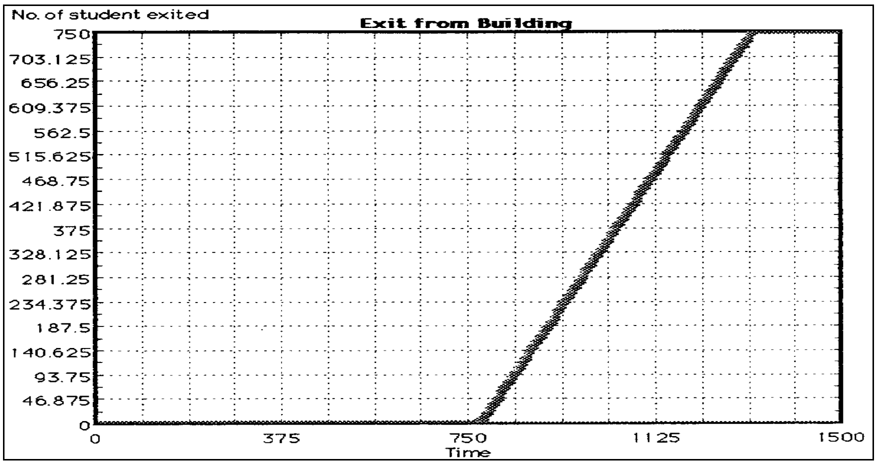
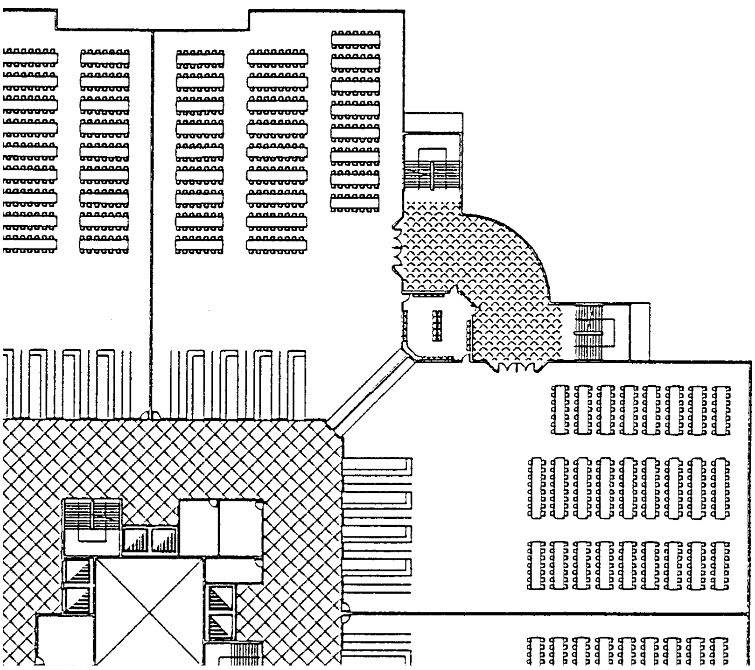


Figure 11 ***Exiting the Building:*** In this run the first student to exit the building exited at about the 13th minute while the last at the 22nd minute.



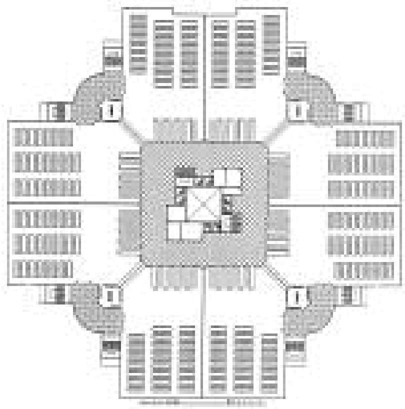


Figure 12. ***A Modified Design:*** After comparing the initial designs and doing What-if-analysis, several modified and more efficient designs emerged. Modifications were done to dining halls, service counters, lavatories areas and staircases holding areas. Service duration for all 6000 students was maintained below 30 minutes.

6.1. The Queuing Area before Food Service Points:

a. If number of service-point unites is 5 unites, then:

Queuing area =26 sq. m (for 5 servers)

Maximum queue accumulation = 37 ped (for 5 servers)

Maximum waiting time = 34 sec.

Average waiting time = 17 see.

Queue length = 2.8 to 3.7 m.

b. If the number of stair cases is doubled (16 stairs):

Although it would solve the queuing problem at the building entrance, it would have the following impact on the queuing area before the food service points and:

Queuing area =93 sq. m (for 5 servers)

Maximum waiting time = 120 sec

Maximum queue accumulation = 133 ped (for 5 servers)

Average waiting time = 70 sec.

Queue length = 10 to 13.3 m (per server)

c. If number of food service points is reduced to 4 and the number of stairs is 8 (which is the chosen design) then:

Queuing area = 55.4 sq. m (for 4 servers)

Maximum queue accumulation = 79 ped (for 4 servers)

Maximum waiting time = 89 sec.

Average queue accumulation = 39 ped.

Average waiting time = 44 sec.

Maximum queue length = 8.3 to 11 m.

6.2. In The Queuing Area Before Lavatories:

a. If 15 lavatories (per hall) are used (which is the chosen design) then:

Queuing area =76 sq. m (for 15 lavatories)

Maximum queue accumulation = 85 ped (for 15 lavatories)

Maximum waiting time = 124 sec.

Average queue accumulation = 42 ped.

Average waiting time = 61 sec.

Queue length per lavatory =2.13 to 2.8 m.

b. If 20 lavatories (per hall) are used

then:

Queuing area =58 sq. m (for 20 lavatories)

Maximum queue accumulation = 64 ped (for 20 lavatories)

Maximum waiting time = 71 sec.

Average waiting time = 34 sec.

Queue length per lavatory=1.2 to 1.6 m.

6.3. The Entrance Hall

a. If 10 doors are used then:

The area of the entrance = 310 to 400 sq. m. This space will be used as a hold area for both stairs.

Maximum waiting time = 96 sec

Average waiting time = 57 sec

b. If 6 doors are used (which is the chosen design) then:

The area of the entrance = 221 sq. m. This space will be used as a hold area for both stairs.

Maximum queue accumulation = 158 pedestrians per stair (316 pedestrians for 4 halls)

Maximum waiting time = 70 sec.

Average queue accumulation = 80 ped (per stair)

Average waiting time = 35 sec.

In this case, the external area of the building approach should be used to hold much of the incoming flow. Results may reach:

The area of the entrance = 238 sq. m. This space will be used as a hold area.

Maximum queue accumulation = 342 pedestrians (for 4 halls)

Maximum waiting time = 57 sec.

Average queue accumulation = 204 pedestrians (for 4 halls)

Average waiting time = 30 sec.

7. THE RESULTS

Among the results that this study has reached are the following:

1- Among the two initial designs, the one with 11 servers was extravagant, and the design with 6 servers was the one to develop upon. This design ended up as a 4-

server solution.

2- The length of the service counter was increased to be about 7 meters to allow for 8 students with their trays to circulate, with an additional allowance of 0.85m to get out of the service point.

3- It was recommended to allow for 6m of exposed conveyor in order to give way for four in-out queues/lanes to form.

4- After several experiments, 15 lavatories per hall were reached.

5- The stairs were set back to allow for more queuing area before them.

6- The whole cycle from entering of the first student to the building until the last student leaves the building takes around 22 minutes. It should be noted, however that nothing but the minimal social interaction has been allowed. Assuming 30 minutes for the whole cycle should be realistic. This should allow for some social interaction.

8. CONCLUSIONS AND RECOMMENDATIONS

1- This study demonstrated how simulation could aid in better understanding of how the system of a certain building works. The study also investigated the use and value of WalkSim simulation modules in simulating buildings with service counters in general and dinning halls in particular.

2- What-if-analysis was possible using WalkSim, which allowed the testing of various ideas and seeing their impact on the performance of the building. Further, it aided in the choice between different alternatives based on the performance of each alternative.

3- WalkSim's ability to assign flexible boundaries to a space and thus change its area according to the accumulation of users in this space albeit while maintaining a constant level-of-service and comfort proved valuable. It allowed the assessment of the suitable area for certain spaces to accommodate the maximum accumulation of pedestrians that my happen during the simulation.

4- WalkSim seems to be a valuable tool in improving the sustainability of architecture by allowing the architect to chose the best alternative, thoroughly test his design and even enhance it. Thus improving design quality.

5- It is recommended to perform a post occupancy study to find ways of further extending the use of WalkSim in the design process

6- A method of linking to other systems like CAD systems may be a useful addition. Using such a method, it may be possible to automatically generate the model from floor plans and thus the system may form a part of a comprehensive design environment.

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