S16-6
A COMPUTER SIMULATION MODEL AS A MEANS OF EMERGENCY EVACUATION TRAINING FOR CONSTRUCTION PROJECTS

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ABSTRACT: Fire safety management on any construction site should start with recognizing fire risks in the workplace, understanding the extent of the risks, and proper assessment of the controls necessary to reduce the risks. However, the most important step to prevent fire-related accidents on jobsites is the constant review and monitoring of processes and controls by all individuals involved. This study was conducted to analyze the effectiveness of using computer simulation as an addition to maps or floor plans in safety training and management. Simulex was used on a real project to model various egress routes and to identify potential problem areas of the evacuation strategy. This study highlights the efficacy of simulated emergency evacuation as a training tool that visually shows constantly altering means of egress.

Keywords: Fire Safety; Fire Safety Management; Egress Routes; Evacuation Strategy; Emergency Evacuation

1. INTRODUCTION

The construction industry in the United States is a vast and far reaching industry that contributed $1.16 trillion to the US economy in 2007, comprising approximately 8.4 percent of the Gross Domestic Product, and employed nearly 7.8 million workers. The industry is inherently hazardous due to the activities and equipment involved. In 2007, more than 1,178 fatal injuries [1] and more than 420,000 non-fatal injuries [2] were reported in the construction industry.

The enhancement of safety within the commercial construction industry has far-reaching implications. This sector of the industry employs approximately 5.76 million workers, comprising 74 percent of total construction workers, and encounters 75 percent of non-fatal occupational injuries and 66 percent of fatal occupational injuries. Fire safety is imperative in commercial construction due to the labor intensity of the work, rapidly changing construction site conditions, intermingling of various trade laborers, and the presence of multiple subcontractors.

Structure fires in properties under construction, major renovation, or demolition, average 11,100 such fires in the United States each year, resulting in an average annual cost of 15 fatalities, 212 injuries and $331 million in direct property damage [3]. Fire can break out on most construction sites, and if not properly managed, can easily lead to tragic consequences that devastate those involved. Construction sites carry a high risk of fire as the nature of the work increases the hazards and risks which contribute to a fire starting [4].

Fire on a construction site often leads to tragic and devastating consequences for those involved. The Occupational Safety and Health Administration (OSHA) and the National Fire Protection Association (NFPA) publish minimum safeguards for fire prevention and safety on construction sites in an attempt to protect workers and property. These regulations and standards require measures to prevent fires and include specific requirements for fire safety as follows:

- prevention of risk from fire
- provision of emergency routes and exits
- preparation of emergency procedures in the event of fire
- provision of fire-fighting equipment, fire detectors and fire alarm systems
- instruction on actions to be taken in the event of a fire, including the use of fire-fighting equipment

The OSHA-required "Emergency Action Plan (EAP)", which encompasses most of specific safety requirements listed above, requires active involvement by the management which should ensure employees have a safe working environment. This study was conducted to provide a tool that management can utilize in meeting the OSHA requirements, especially in providing proper "Means of Egress" and appropriate training in case of emergencies related to fire at the work site.

This study was conducted under the research hypothesis that visual elements and media have a positive impact on learning improvement. Several studies [5], [6] have verified that visual elements promote cognitive processing of information that helps better integrate the material with prior knowledge. Using real project information, the 2D computer simulation model called Simulex was used to test the research hypothesis by modeling various egress routes and to identify potential problem areas of the evacuation strategy. This study highlights the efficacy of simulated emergency evacuation as a training tool that visually shows constantly altering means of egress.

2. PROJECT DESCRIPTION

The project used for this research is the construction of a new facility called Hospitality House located in Boone, North Carolina. Figure 1 below shows the main level (18,492 s.f. heated square footage) plan view of the facility with a total of eleven emergency exits as indicated in red numbers. Construction of the facility complied with the provisions of the North Carolina State Building Code, 2006 edition, and all work performed was based on the climatic and geographic design criteria as set forth in the state code.

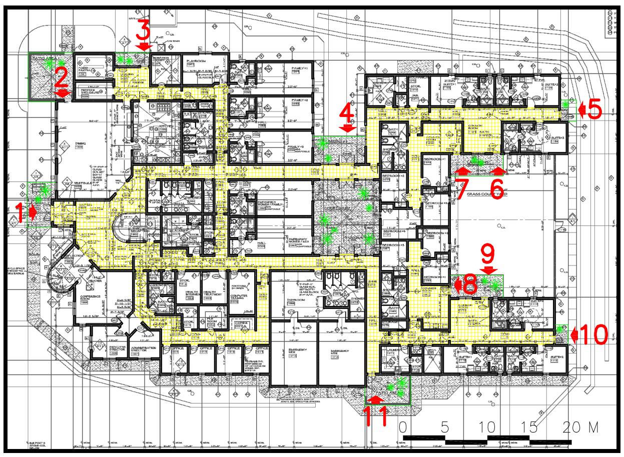

Figure 1. Main Level Floor Plan with Emergency Exits

Although the emergency exits are provided in proper arrangements for quick and safe egress, if the emergency escape routes leading to the exits are not readily visible and the construction workers are not trained for proper emergency evacuation, fire hazards can easily turn into a detrimental consequence during the construction phase.

Entrance doors and emergency exits differ in size and shape as shown in the Table 1 Door Schedule. The work condition applied in this simulation model was that a total of 100 construction laborers were spread out and working on various areas on the main level.

Table 1. Main Level Door Schedule

		Size	Note
Laborer		100	Predominantly male
Door	1, 4	1.8 m (w)	Main entrance, double
	2, 3, 5 - 11	1.0 m (w)	Emergency exit, single

3. PROBLEM STATEMENT

Proper employee training accompanied by well-prepared emergency plans will result in fewer and less severe employee injuries and less structural damage to the facility during emergencies. Conversely, a poorly prepared plan can lead to a disorganized evacuation or emergency response, resulting in confusion, injury, and property damage [7]. Lack of proper training can further increase the damage as the human factor can create difficulties in the evacuation process. Without proper training, employees may only be familiar with the exit route they are used to and will follow their instinct in locating the exit that they habitually use.

Because the dynamic project environment is in constant change, evacuation models and procedures should be updated accordingly and shared with the employees frequently. Without these frequent updates, employees can easily miss the near exits but rather follow lengthy routes to the exit guided by their instinct, and delay the evacuation process. After all, it is the responsibility of each employee to ensure that they are familiar with the most current emergency evacuation plan, including the posted exits and evacuation routes.

4. SIMULATION ANALYSIS

In order to model and evaluate the evacuation process using Simulex, several scenarios were created that considered various factors that affect evacuation procedures. Normal evacuation occurs when all exits are available for use and all evacuees are provided with proper training so that they can quickly identify the nearest exits. However, under emergent situations such as fire, timely evacuation of all evacuees may be difficult to achieve, especially if they make unreasonable decisions due to panic or unfamiliarity with the escape route. Distinguishing this situation as an abnormal evacuation, simulation models were created and compared with the effectiveness of the evacuation [8].

4.1 SIMULEX

Simulex was used to create a simulation model for the study because of its simplicity as well as its popularity. Simulex (IES Ltd, 2007) is an evacuation simulation tool that can accurately model the physical aspects of evacuation movement. This software can model the movement each individual, acceleration/deceleration, speed fluctuations in evacuation and the effect that the invasion of personal space has upon the velocity and direction of each individual in the building population. Simulex not only simulates occupant behavior in the event of a building evacuation, but also identifies potential problem areas and enables users to evaluate solutions.

4.1 SIMULATING NORMAL EVACUATION

Figure 2 models the escape routes and the movement of evacuees as shown by numerous red dots and Figure 3 shows graphical displays of various distance "contours" obtained by calculating the distance to the nearest exit for every point on the spatial mesh. Using this distance map, users can explore different evacuation strategies depending on the progress of the construction.

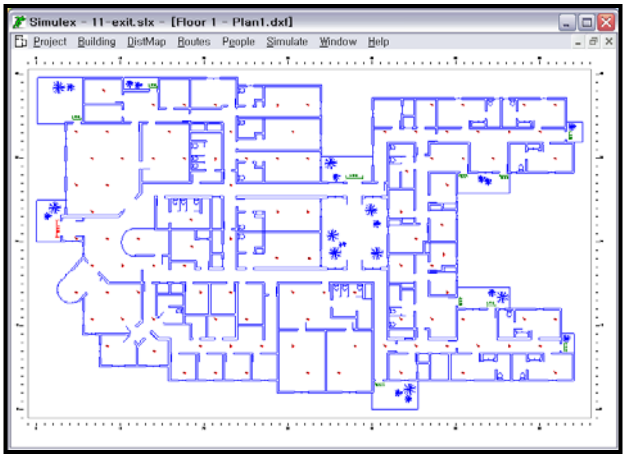

Figure 2. Simulation Model Under Normal Evacuation

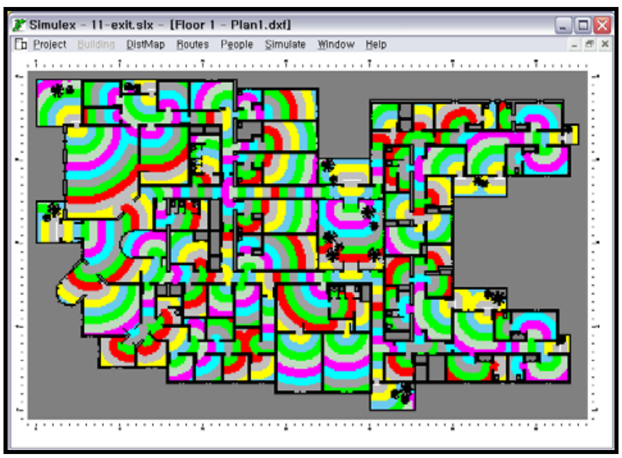

Figure 3. "Distance Map" Showing Total Distance to Exit

Each individual on the main level is indicated as a red dot on Figure 2. Because the figure has been reduced in size, identifying these dots is difficult since the size of each red dot is proportionate to the actual building. However, the on-screen display provides much easier illustration of these dots; hence the evacuees, in every 0.1 seconds of movement on their evacuation paths. The zoom in/out function further facilitates evacuation modeling and its analysis. All individuals in the evacuation model are assumed to be adult males with a normal evacuation walking speed of 1.3 meter per second.

Figure 4 shows the still screen-shot of simulation modeling in progress 10 seconds after evacuation has started. Safe and swift evacuation was possible under this normal scenario as evacuations evenly occurred on all eleven exits that were available (hence, no notable signs of congestion on any particular exits). Training provided to the employees further enhanced the efficiency of the evacuation process as evacuees spent less time locating exits that were nearby.

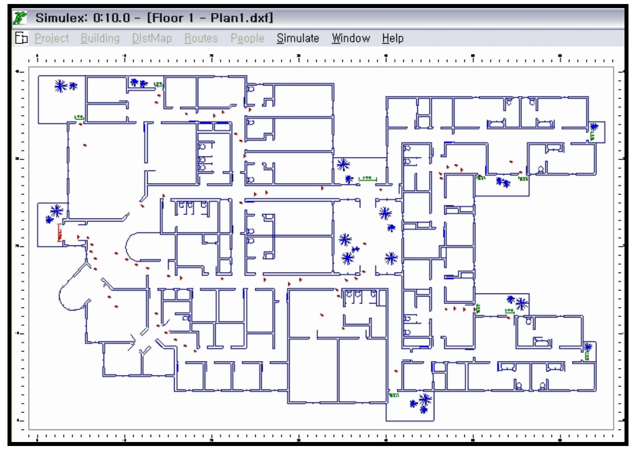

Figure 4. Normal Evacuation in Progress After 10 Seconds

Thirty seconds into the evacuation, as shown in Figure 5, the evacuation process neared its completion with final approach to safety being made at Exits 1 and 4. Under this scenario, the entire evacuation took 35 seconds to complete, as measured at Exit 1.

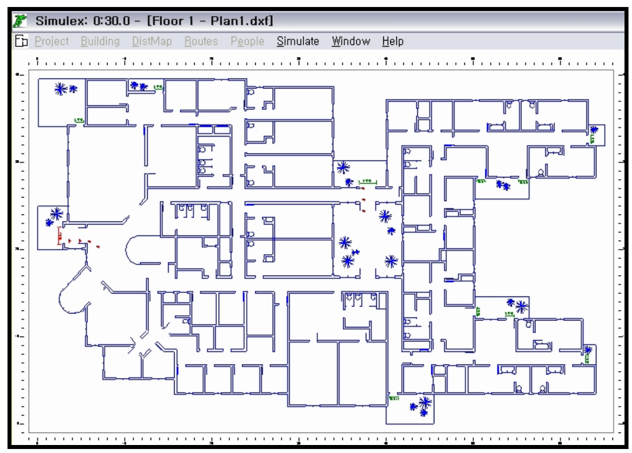

Figure 5. Normal Evacuation in Progress After 30 Seconds

4.2 SIMULATING ABNORMAL EVACUATION

As shown in Figure 6, most evacuation conditions on the abnormal model are similar to those of the normal evacuation model except that Exits 1 and 4 are the only available means of egress. Exits leading to the courtyard in the center of the building are not operational. Figure 7 graphically displays various distance 'contours' to the nearest exit for every point on the spatial mesh under the abnormal evacuation model. Unlike the distance map shown on Figure 3, the distance map under the abnormal condition shows the wide spread of equally-spaced contour lines formed around Exits 1 and 4.

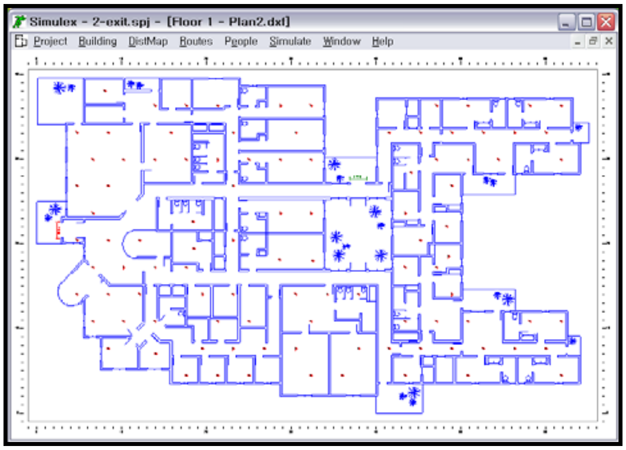

Figure 6. Simulation Model Under Abnormal Evacuation

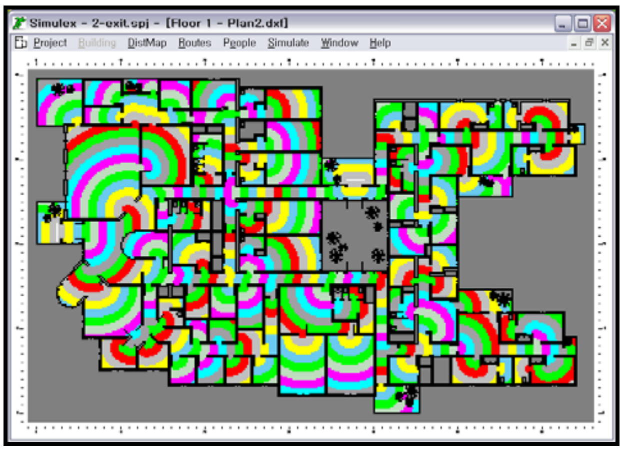

Figure 7. Distance Map for Abnormal Model

Figures 8, 9, and 10 are captured screen-shots of the simulation model of evacuation under the abnormal condition at intervals of 10, 30 and 60 seconds, respectively, from the start of the evacuation. Note that the majority of evacuees spotted on the lower right corner took the long route to Exit 1 as their means of egress. This was because exits to the central courtyard were unavailable and the evacuees missed the closer exits (i.e., Exits 8 to 11). Compared to the normal evacuation process, the overall evacuation was significantly delayed with the completion time at Exit 1 measured was 77 seconds.

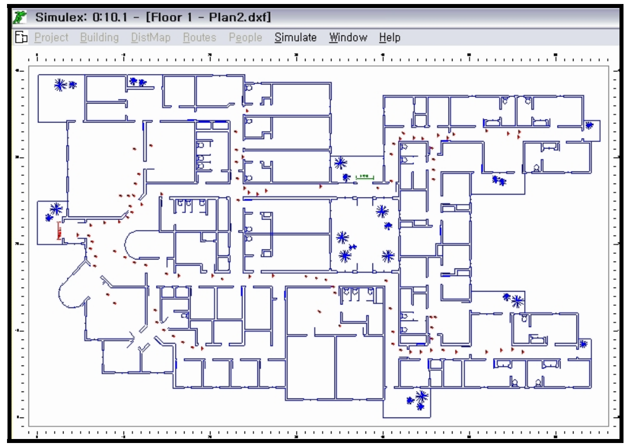

Figure 8. Abnormal Evacuation in Progress at 10 Seconds

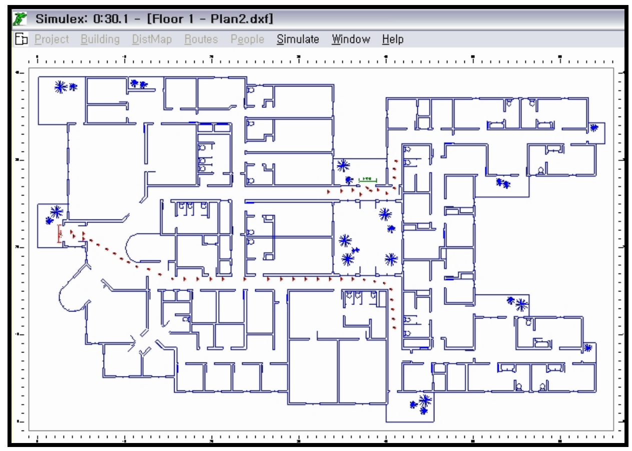

Figure 9. Abnormal Evacuation in Progress at 30 Seconds

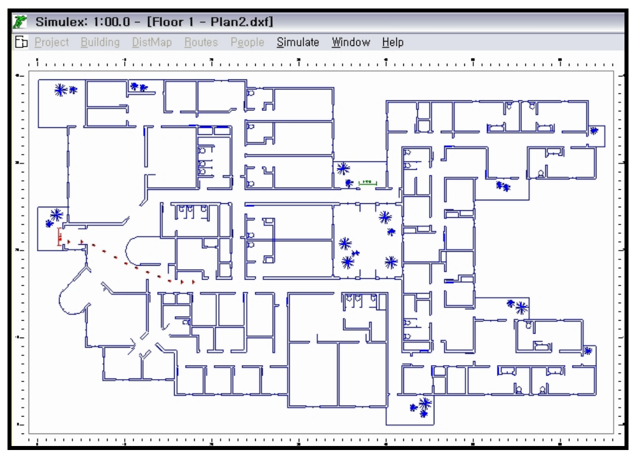

Figure 10. Abnormal Evacuation in Progress at 60 Seconds

4.3 EVACUATION MODELS COMPARISON

Graph provided on Figure 11 clearly shows the impact evacuation conditions have on the time it takes to safely complete the evacuation. Under normal conditions, most evacuees readily identified the shortest exit route and made the quick exit as the evacuation process began. This is explained by the stiff slope shown between the time frame of 5 to 15 seconds on the normal evacuation model.

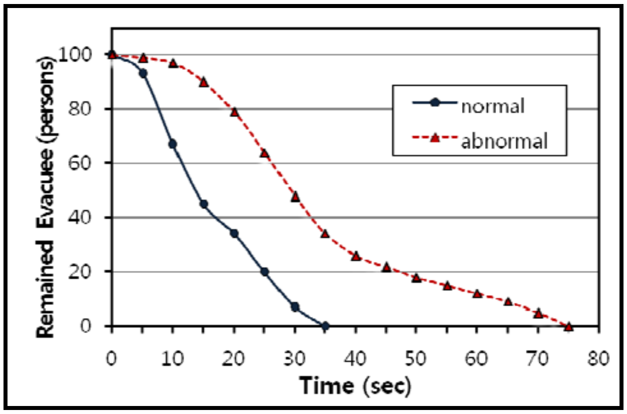

Figure 11. Time vs. Remaining Evacuees for Normal and Abnormal Evacuation Conditions

Under the abnormal condition, the evacuation process shows a similar pattern during the early stage as indicated by the curve inclination which is similar to that of the normal condition. However, once the evacuation was completed at Exit 4, which took 35 seconds, significant delay occurred as most evacuees took the route to Exit 1. The graph clearly shows this pattern by its gentle slope between the 40-to-80 second frame.

5. CONCLUSIONS

This study was conducted to analyze the effectiveness of using computer simulation in addition to maps or floor plans in safety training and management. Simulex was used on a real project to model various egress routes and to identify potential problem areas of the evacuation strategy. Particular findings of this study using the different evacuation models are:

- Time required to complete the evacuation under the normal condition (35 seconds) and abnormal condition (1 minute 17 seconds) is still faster than the national criteria of 2 minutes and 30 seconds for similar type buildings. This can be attributed to the fact that the model area used in the study was on the first floor and ample exits are provided in various facets of the building.
- This study's approach in analyzing the evacuation model based on different scenarios can be effective and beneficial in analyzing the safety of the occupants in an emergency situation.
- The simulation shows the number of people left in the building at any given time and predicts how long it will take for all of them to reach the exits safely. These features not only provide an effective training tool, but also serve as a check for completeness of the emergency action plan OSHA requires.
- By altering the conditions of evacuation, this simulation model can capture the effect that a constantly changing project environment may have on the alteration of means of egress.

This research is an on-going effort to further verify the effect of simulation as a visual medium that enhances a higher learning curve. The research approach outlined in this paper will contribute to providing a safer work environment as a tool that safety managers can easily adopt and use.

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