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HOW TO VALIDATE SOLUTIONS FROM SIMLUEX

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ABSTRACT

Simulex is a partial-behavioral egress model. While the ability of the software's computational functionality to accurately predict the duration of occupant pedal movements has been validated, the shortest-path methodology utilized by Simulex can result in an inefficient, inappropriate or even unreasonable evacuation scenario. In such cases, the user can apply techniques and methodologies to manipulate the building geometry and/or occupants in order to overcome these challenges.

Such application of engineering judgment in development of a performance-based design solution is prudent and essential to yield a reasonable conclusion. However, such manipulation of the modeled environment can lead to questions regarding validity of those results. This paper presents case studies with discussion of how an unmodified scenario could be deemed unreasonable and how application of engineering judgment to manipulate model conditions in Simulex yields valid solutions.

INTRODUCTION

In performance-based evacuation design, the principle that the Required Safe Egress Time (RSET) must be less than the Available Safe Egress Time (ASET) is well established. The RSET and ASET are comprised of multiple individual parameters, including movement time. If the movement time of the occupants can be accurately determined, a significant factor in the RSET versus ASET analysis is known.

To know that the movement time has been accurately determined, consideration should be given to the conditions of the evacuation being analyzed and the validity and applicability of the calculation tool or evacuation model being applied.

Simulex is a partial-behavioral evacuation model developed in mid-1990 at Edinburgh University which serves as a tool for predicting movement time. Version 6.0 of the software is currently commercially available through IES (Integrated Environmental Solutions), located in the United Kingdom.

As with any tool, the appropriateness of its application is the responsibility of the user. When employing Simulex for analysis of some scenarios, engineering judgment can be applied to enable the model to report a reasonable solution. Where this involves manipulation of the occupants or physical geometry of the space, the ability for solutions to remain valid can be observed through consideration of practical examples.

EVACUATION CONDITIONS

To ensure the validity of an evacuation model utilizing Simulex is maintained, consideration should be given to the conditions of the scenario. Such simulation parameters to be considered can involve the population to be accounted for, conditions of the modeled environment, and the state-of-mind of the occupants which influences their movement characteristics.

Population

The extent of the population to be addressed should be confirmed to be within the scope of the model. This should consider whether the evacuation involves a single room with a single exit or all occupants of a multistory building with multiple exits. Also, age and gender can be a factor; elementary school children may fit through a doorway side-by-side while two men would pass single file.

Environmental Conditions

Conditions to which occupants may be exposed during the evacuation should be considered when assessing the validity of the model. Occupants who are leaving class because the bell rang, or because the concert ended, may evacuate more lackadaisically than those who hear a fire alarm signal and sense cues of a fire burning in the building.

With a true fire emergency, occupants remote from the point of origin may initially only hear the alarm signals. For large voluminous spaces occupants may see the developing smoke layer, and eventually they may be exposed to conditions near the tenability threshold.

Occupant Attitude

Correlation exists between environmental conditions to which occupants are exposed during the evacuation and the effectiveness of their actions toward exiting the building. The SFPE Handbook, 5th Edition, suggests, "It is our challenge, as engineers, to ensure that [those who are in danger] become aware that a dangerous event is taking place, and that they perceive personal risk. If not, they are unlikely to take actions to protect themselves from harm. (Hurley, 2072)"

Accordingly, occupants who are unaware or who do not receive specific direction, such as from crowd management staff or voice messages, may evacuate inefficiently in the absence of exposure to physical fire cues. Where occupants are able to see the developing smoke layer, or are exposed to conditions near the tenability threshold, reasoned intentional movement toward an exit would be anticipated. Even among conditions at the tenability threshold, though occupants may be anxious or frightened, irrational panicked behavior would not be expected.

VALIDATION OF SOFTWARE

Simulex software incorporates research from observations of videos of people movement. The movement algorithm accounts for rates of body twist, acceleration/deceleration overtaking actions, speed fluctuations, inter-person distance, among others.

Tests validating Simulex have been carried out by staff at Edinburgh University, Lund University, Ove Arup (Australia) and University of Ulster. Tests were conducted on a variety of buildings, including department stores, office buildings, lecture theatres, sports stadiums, and others. Tests demonstrated that Simulex accurately models individual movement, and yields realistic results when analyzing groups. The simulated flow rates correspond well with real-life evacuation flow rates, including during fire drills, in the absence of fire cues.

Table 1: Summary of evacuation test results from University of Canterbury, Christchurch, New Zealand.

Building	Height (Stories)	Occupant load (Persons)	Duration (m:ss)	
			Test	Simulex
Lecture theatre	1	278	1:30	1:33
Law school	5	494	2:50	2:41
Business school	8	716	3:30	2:58

As apparent in Table 1, drawn from Olsson and Regan (2001), good correlation is observed between actual test results and the evacuation time predicted by Simulex. With this sample set, Simulex most closely predicts the evacuation time of the one-story building and the smallest population. For larger buildings and multiple stories, Simulex predictions were 5 to 19% shorter. Other, a 2005 study by Kuligowski and Milke found evacuation times forecast by Simulex to be as much as 70% longer than those predicted by EXIT89 in a multistory hotel building as indicated in Table 2 below.

Table 2: Excerpted evacuation model predictions for high-rise hotel by Kuligowski and Milke.

Population	Duration (s)	
	EXIT89	Simulex
Hotel simulation	445	698
Hotel (3% disabled)	633	1079
Minimum	384	447
Maximum	679	1079

SIMULEX ALGORITHM

Simulex program operates by evaluating user-input geometry of the building to create a distance map. Occupants are placed in the model environment by the user and assigned general characteristics. Occupants follow the shortest path along a distance map to reach an exit.

Distance Map

The domain is divided into a 0.2 m^2x0.2 m^2 grid with travel distance isoline bands illustrated at 1 m intervals from an exit, filling gaps and rooms in the building geometry. A representative illustration of a distance map as presented by Thompson et al is shown in Figure 1 below.

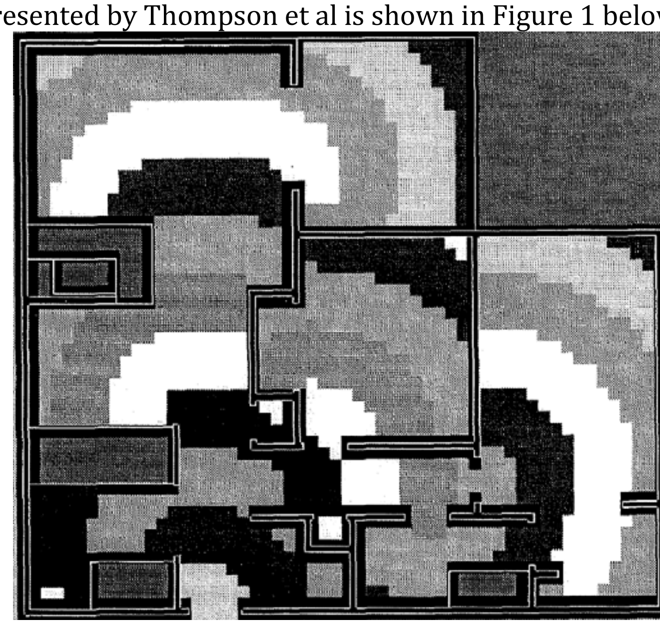

Figure 1: Illustration of Simulex distance map with exit doorway at bottom of figure.

Occupant Travel

Evacuation movements are generally perpendicular to the isolines of the distance map, though some side-stepping occurs when queuing conditions are encountered. As evacuees are driven to travel the shortest path, small gaps in geometry can cause occupants to become "stuck" in the domain as they attempt to travel the shortest egress path.

In a test with 50 subjects, Yanagisawa (2009) has proven that a column placed beside an exit where its position from the wall effectively blocks an occupant from accessing the exit from the side does not cause occupants to become stuck, but instead improves efficiency.

Overcoming this issue will be addressed further in a subsequent section below.

Population Characteristics

Simulex considers body size in its evacuation algorithm, and is a user-selected feature. Preset values attribute larger bodies to men down to smaller bodies for children. Walking speeds also differ between 0.8 to 1.7 m/s, with speeds reduced when traversing stairs.

While these parameters influence the analysis, the incorporation of body-positioning is a dominant factor as illustrated by Kuligowski and Milke (2005). Their study found that a model utilizing a continuous stair for the height of the building was more efficient than occupants transitioning to individual stair segments between each level.

Occupant Location

Positioning occupants within the computation domain necessitates a location sufficiently away from a boundary condition. The distance map appears to exist in areas which may be too narrow for occupants, such as in theater seating arrangements. An analysis involving occupants on a narrow row is presented with a case study below.

CONSTRUCTION OF GEOMETRY

Building geometry is entered into Simulex via 2-dimensional .dxf-format drawings. An iterative process is involved to develop a reasonable solution set, refining and altering the geometry in order to avoid conflicts within the simulation.

Refinement

Some line work can be automatically removed by Simulex, such as arcs of door swings which would otherwise be interpreted as a barrier. Other refinements are manual, such as removal of handrails or stair treads to facilitate space for installation of full-width Simulex "links" between the floor and a stair. Theater or stadium seats which are stowed folded can also be manually deleted to accurately represent the aisle width when the seats are not in use.

Alterations

Narrow gaps, such as between columns and the wall or individual furnishings, can cause occupants to become stuck. Where occupants would not pass between the objects, solid obstructions can be drawn to force occupants to travel around the obstruction, just occupants would realistically move.

Iterative Modifications

Some elements of the building geometry are revealed during the modelling process to require modification in order to facilitate a realistic evacuation scenario in Simulex. Case studies presented below address manipulation of aisle width and creation of barriers to modify the distance map in order to force some occupants within the domain to traverse a longer exit path.

Aisle width

With the body size assigned to occupants, the narrow aisle created by stadium benches or between seats in a theater can be insufficient for placement of occupants. If too narrow, the number of occupants to be accounted for in the row may not be physically accommodated in Simulex.

Similarly, where bleacher seating results in narrow aisle spaces, the front and sides of benches, or portions of rows in an arcing theater row, can be deleted to accommodate placement of the correct number of occupants to be accounted for in the scenario.

Generally, an increased aisle width would be thought to facilitate a faster evacuation scenario. How modification of the domain to increase aisle width can still be deemed to contribute to a valid conclusion will be discussed with the case studies below.

Modify distance map

In theater seating, though a distance map may fill the seating area, Simulex may interpret the gap between the armrests and seatbacks as too narrow a space for egress, trapping the occupants in their seats. The armrests can be deleted to remove the impediment to movement. However, this results in a substantially smoother aisle. With the case study below, clarification will be provided to support how a valid model can be maintained.

Where a bleacher is served by an aisle on both sides, occupants can be anticipated to generally utilize the aisle nearest them. However, as Simulex occupants are driven to travel the shortest path, occupants may wait in line to use the aisle at the other end of the bleachers rather than the vacant aisle right next to them. The case studies will illustrate how the stadium seating can be divided with an artificial barrier to modify the distance map and result in a valid solution.

Case studies also depict modifications to the distance maps involving channelization to direct occupant groups to a more remote exit while the entire population was assigned to a single distance map. Capabilities are now available within Simulex to assign select occupants to follow different distance maps. Whether manually creating channelization or selectively assigning portions of the population to different distance maps, there is a common purpose: to distribute occupants among exits which are more remote. With either technique, considerations with such manual manipulation and explicit direction of the occupants would be similar, as discussed further below.

Because Simulex commands the occupants to travel to the nearest exit, all occupants in an assembly space may travel to the rear exit, though the codes require the main entrance to be sized to handle 50% of the population. The case studies will present channelization to force a portion of occupants to use a secondary exit where initial model run revealed that occupants queued at one door while a second exit nearby was unused. This Simulex phenomena can even occur at a set of double doors, where occupants queue behind an obstruction and utilize a single leaf, rather than traveling around the obstruction and utilizing both doors.

When multiple exits are available, occupants travel to the nearest unobstructed exit. If there are double doors, occupants may utilize only a single leaf. If there is large queue of occupants gathered at the closest exit, while another exit has no occupants, occupants would remain in the back of the queue in order to reach the nearest exit rather than not enter the queue, or vacate the queue to more quickly exit via an available exit further away. In order to reduce the queue and balance the exits, channelization or distance map assignment can be employed to achieve a more efficient solution.

Where such a balanced egress arrangement approaches a more ideal evacuation scenario, care must be given to ensure that the solution is reasonable.

CASE STUDIES

Two case studies are presented to represent the application of Simulex and how the model domain was modified and the results interpreted in order to arrive at a valid conclusion. The first is a multi-purpose arena, the second is a theater. Screen shots of the Simulex model indicate occupants as red dots and obstructions as blue lines.

Multi-Purpose Arena

The intent of the analysis was to assist in the commissioning of the air-inflated multi-purpose arena. To ensure the availability of exits in the event of catastrophic failure of the air supply system, the building code prescribes a support structure to hold the membrane above the level of evacuating occupants. An alternate method was employed to demonstrate that the roof membrane would remain at a satisfactory elevation while exterior doors were manually opened and shut after the air supply was stopped, based on the duration of egress predicted by the Simulex model.

Three potential uses of the arena were analyzed:

1. Trade show
2. Sporting event
3. Stage performance

Discussion corresponding to each of these configurations is presented below.

Trade show

A portion of the arena floor plan is shown in Figure 2 as represented in Simulex to depict a trade show. Booths are arranged in a symmetrical pattern within the arena and 5,000 occupants are evenly distributed throughout the domain.

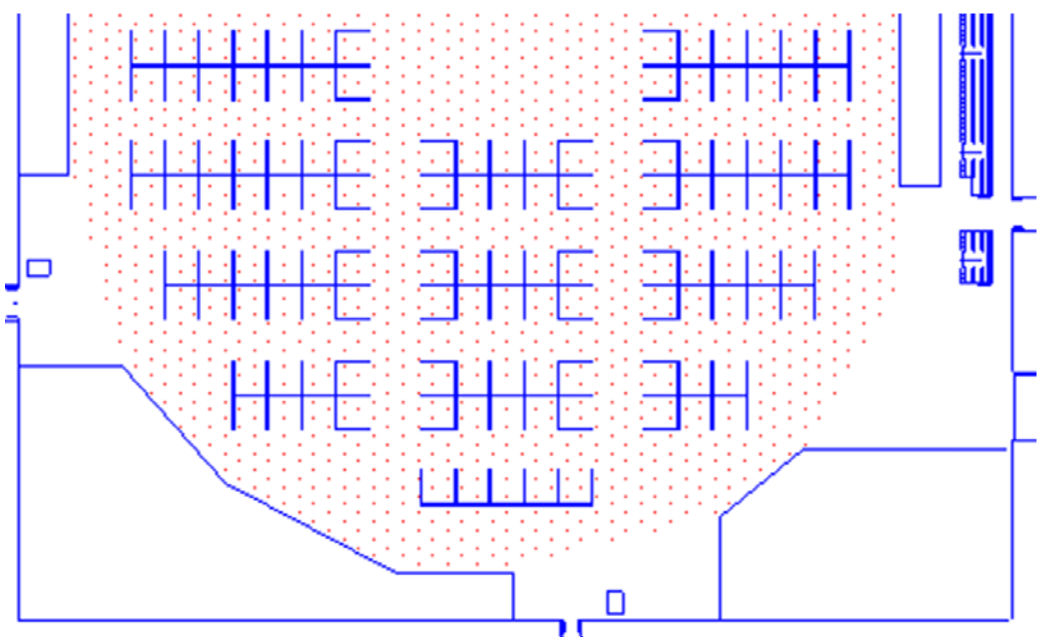

Figure 2: Simulex model image for portion of trade show scenario.

With the freedom of movement available to occupants, as availed by wide gaps between obstructions along the path of travel, together with the even distribution of occupants relative to the exits, Simulex was able to run automatically without modification of the imported building geometry, exiting all of the occupants in 6 minutes-4 seconds. Subsequent examples will illustrate the challenges encountered with more complex geometry.

Sporting event

The same region of the arena depicted in Figure 2 is shown below in Figure 3. In contrast to the previous example, occupants are generally absent from the arena floor, and instead closely clustered in bleachers. One hundred occupants were distributed around the perimeter of the playing field.

Spectator areas and bleachers were filled with 4,165 occupants in a far more concentrated arrangement with significantly restricted movement compared to the previous trade show scenario.

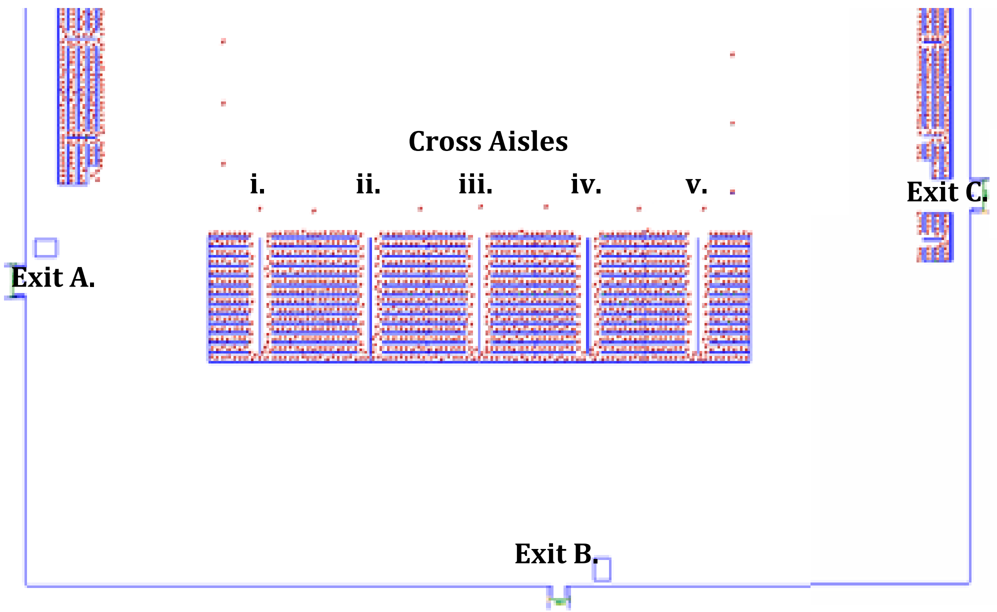

Figure 3: Simulex model image for portion of sporting event scenario with exit elements labeled.

Looking closely at the image reveals that the benches of the grandstands are represented by single lines, rather than the rectangular seat. This is to afford sufficient space for insertion of occupants and enable Simulex to determine aisles available for egress use.

Though this results in wider aisles than exist in reality, the validity of the Simulex analysis is maintained with this modification. This is because the movement of occupants evacuating from the benches are constrained by the handrail and cross-aisle, which is unmodified. Further, the retained portion of benches still causes occupants to enter the cross-aisle single file.

When the distance map is applied, based on the position of Exits A and C on the ends of the grandstands, the occupants travel along the benches and toward the nearest exit. This results in a condition where occupants do not utilize Cross Aisle iii. As it is unreasonable for occupants to remain in front of their bench waiting to exit the grand stands via a cross-aisle at the opposite end of the bench while they are standing next to a cross aisle, the benches were manually modified with a barrier to divide them in half, forcing the Simulex distance map to draw occupants to their nearest cross-aisle. These barriers are highlighted green in Figure 4.

Another issue arises with the small gap present between building equipment and the wall in the vicinity of Exit A. When a large queue forms, occupants on the periphery of the queue sidestep in attempt to avoid the congestion and arrive a location where the shortest path along the distance map is through the small gap. As the width of the gap is insufficient to pass an occupant, after the queue dissipates and Exit A is available, a queue of occupants remain stuck trying to traverse the shortest path through the narrow gap. This is easily solved by inserting a barrier to eliminate the gap, circled red in Figure 4.

Eliminating the small gap maintains the validity of the Simulex simulation as it is unrealistic for occupants to not traverse the longer route around the obstruction to the available exit. Further, with the well-accepted absence of panic during an evacuation and the location of the gap to the side of the primary egress route, the stuck occupants are not considered representative of a crowd-crushing condition.

Additional modifications were made to add channelization to the distance map. In the absence of channelization, large queues formed at Exits A and C, while Exit B remained unused despite it being readily apparent and visible to occupants at the back of the queue. Red arrows in Figure 4 point to the added channelization.

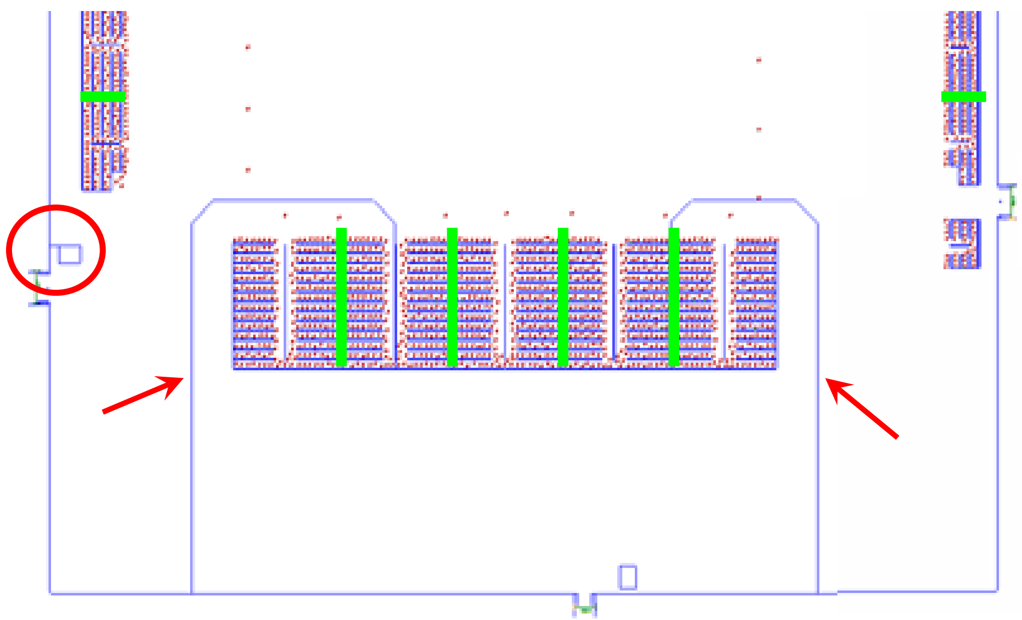

Figure 4: Simulex model image of sporting event with modifications identified.

Further explanation is warranted regarding the manipulation of the distance map with this channelization. It is reasonable to expect that occupants utilizing Cross-Aisles i and v would be evacuate via Exits A and C, respectively, and that occupants from the center cross-aisles would choose whether to wait in the queue or travel the distance to Exit B.

Channelization was added through an iterative analysis of the evacuation scenario based upon observation of queuing which occurred. Exits A and C receive occupants from grandstands along the sides of the arena as well. Therefore, it was determined that the number of occupants attributed to evacuating via Exit B could be represented by one-half of the main grandstand population. Though the occupants represented are the inverse of the population anticipated to egress via Exit B, as the elevation of the roof membrane is related to the open doors, the duration the egress doors would open during an evacuation is reasonably represented by this analysis, a total of 5 minutes-40 seconds.

Stage performance

The final scenario contemplated is a stage performance, such as a concert, with a seated audience of 4,158 persons plus 110 more scattered around to account for performers and facility staff. Similar to the sporting event, seating rows are divided by a barrier to force occupants to the nearest cross-aisle. Channelization is also present to force some occupants back to the main entrance, rather than the nearest side exits. It is contemplated that ushers would assist with crowd management to assist occupants' wayfinding by identifying locations of side exits. Figure 5 depicts the concert layout with black arrows identifying some added barrier elements. Small gaps at the perimeter were also manually obstructed.

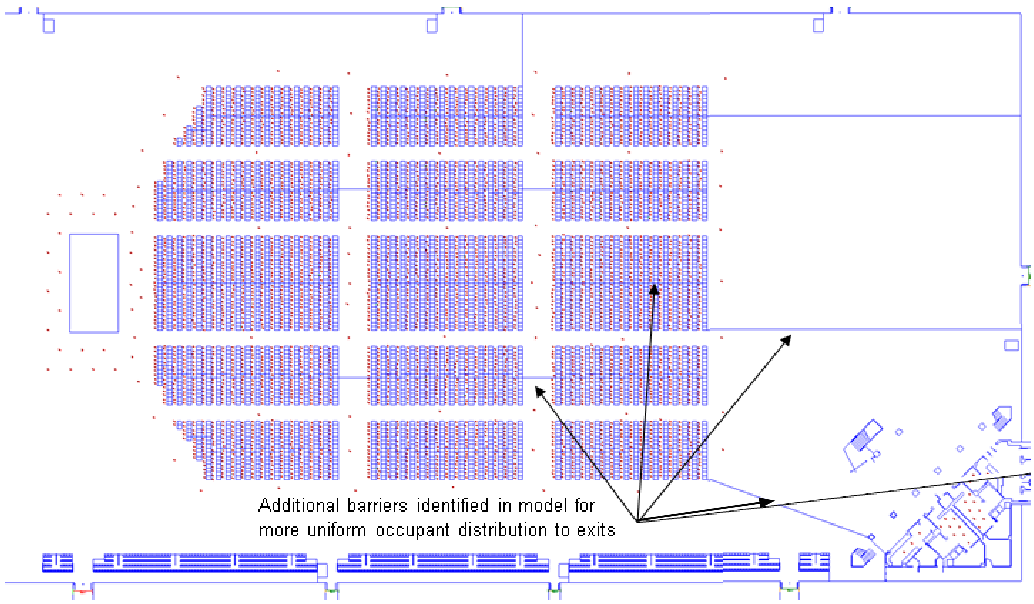

Figure 5: Simulex model image of arena stage performance identifying some modifications.

Subsequent figures depict the progression of the evacuation at identified time steps. Figure 6 illustrates occupants streaming toward the nearest exit at 15 seconds into the simulation.

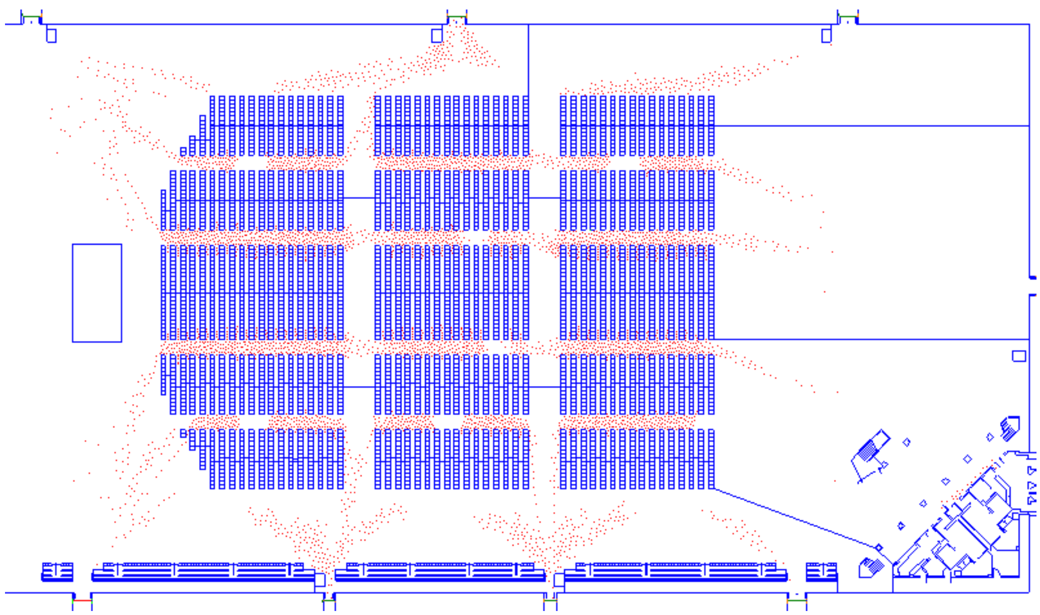

Figure 6: Simulex model image of arena stage performance at time step 0:15 seconds.

At 30 seconds into the analysis, Figure 7 illustrates occupant queuing beginning to occur at the bottom of the page. The bulbous shape is formed by the stream of occupants sidestepping in an attempt to navigate around the person in front of them while continuing along the distance map to the nearest exit.

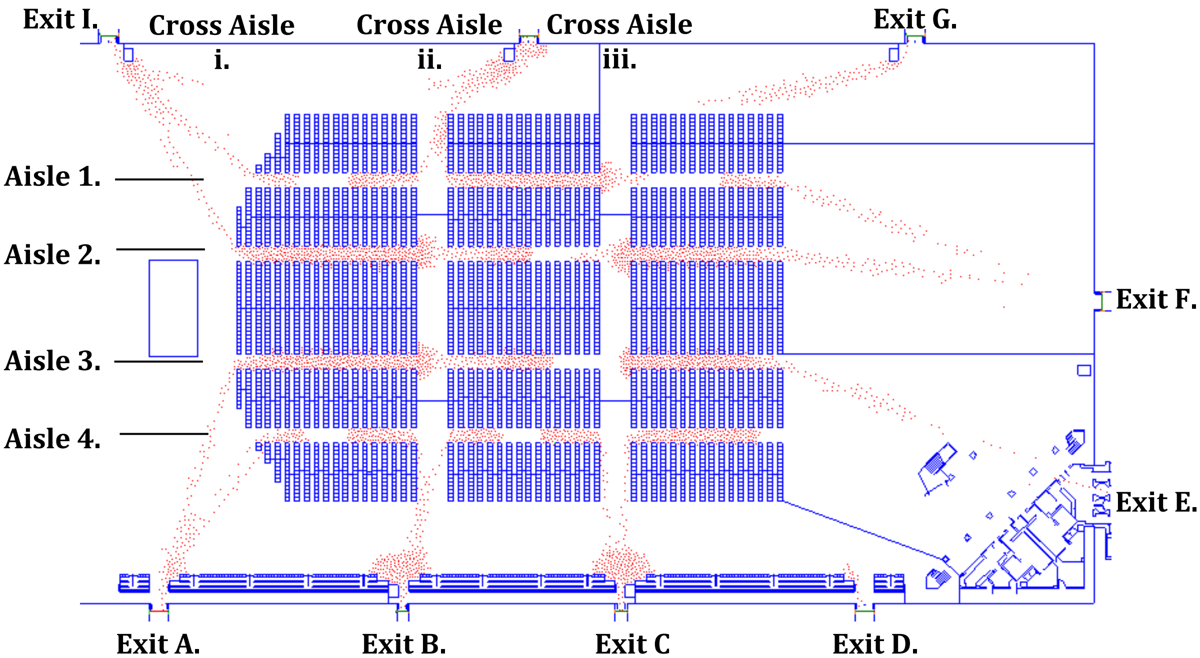

Figure 7: Simulex model image of arena stage performance at time step 0:30 seconds.

Occupants in Aisle 1 at Cross Aisle iii. are queued to exit toward Cross Aisle ii. though no impediment to egress via Exit G is present. This illustrates an example of how the simulation results can appear illogical when occupants are simply adhering to the shortest path. As the exit doors are the same size, and the purpose of this model was to determine how long the exit doors would be held open, the results are sufficient for the intended purpose and the absence of further refinement of the distance map by channelization is justified.

It is apparent that occupants in Aisles 2 and 3 are prevented from traveling to Exit B via Cross Aisle ii. While it may be unrealistic for occupants to travel within Aisles 2 and 3 toward Cross-Aisle i., it is reasonable for these occupants to evacuate via Exit A. This is because no queue exists at Exit A, which these occupants would realize if they travelled within Cross-Aisle ii. toward Exit B. for these reasons, the egress arrangement observed is deemed to be valid.

At Exits G and I, an obstruction near the exit is not yielding the benefits reported by Yanagisawa (2005). Rather, we see that the obstruction situated beside the exit and along the shortest path of the distance map to be an impediment to more efficient egress. Instead, the stream of occupants who could enjoy the double doors are reduced to a single-file line through one door leaf. This condition appears unrealistic, though perhaps conservative to the extent that it extends the egress time.

In Figure 8, at 2-minutes-45 seconds into the simulation, occupants can be seen streaming toward Exits E and F. The channelization separation these exits represents the occupants from the center aisles who may be seeking to exit via the main entrance (Exit E), but upon seeing it is in use the occupants opt for Exit F instead.

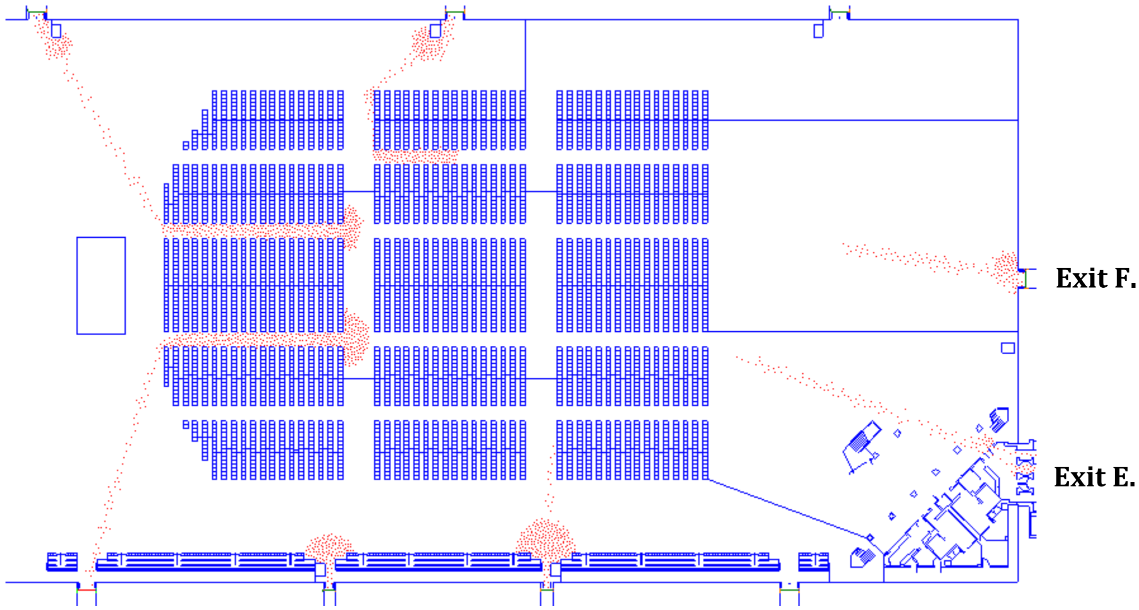

Figure 8: Simulex model image of arena stage performance at time step 2:45 (mm:ss).

Due to the distance map resulting from the channelization shown, occupants from Aisle 3 continue to queue in the aisle in order to evacuate via Exit A as shown at 3 minutes-30 seconds in Figure 9. Since the aisle is vacant behind them, in reality we would expect the queueing occupants to travel the other direction toward Exit E, the main entrance. Thus, consideration is given to the purpose of the analysis in order to justify absence of further refinement of the channelization and distance map.

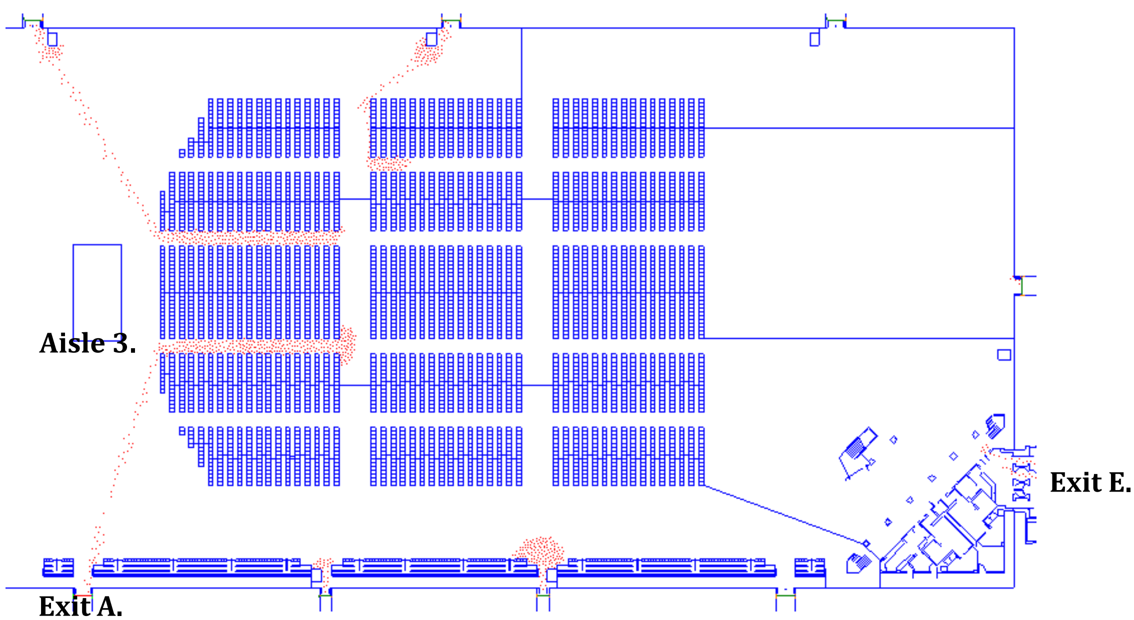

Figure 9: Simulex model image of arena stage performance at time step 3:30 (mm:ss).

While the venue is nearly clear at 4 minutes-30 seconds, Figure 10 illustrates how Exits H and I continue to be used inefficiently. As stated above, this condition appears unrealistic, though perhaps conservative to the extent that it extends the egress time, and is acceptable for the purposes of the analysis.

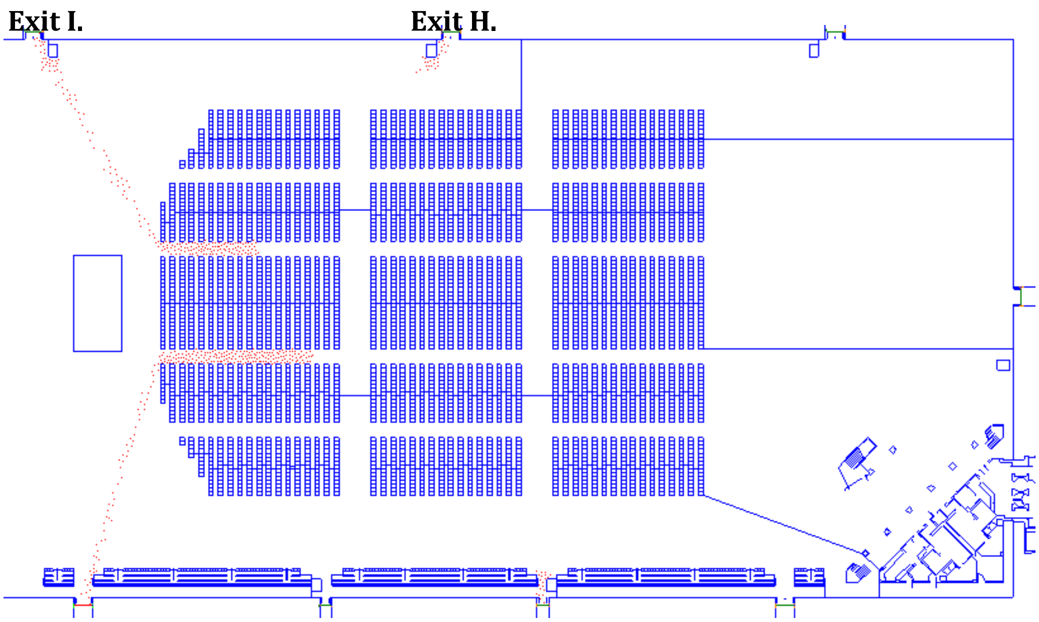

Figure 10: Simulex model image of arena stage performance at time step 4:30 (mm:ss).

The final occupants were observed to have evacuated the arena after 7 minutes-18 seconds.

Theatre

In the configuration of a theatre, the incorporation of stair elements to connect the tiered seating area to the main floor below adds further complexity to that described above. Figure 11 below presents a screenshot of the Simulex model at time 0 with the tiered seating highlighted in red, yellow and green to corresponding positions relative to the main level below.

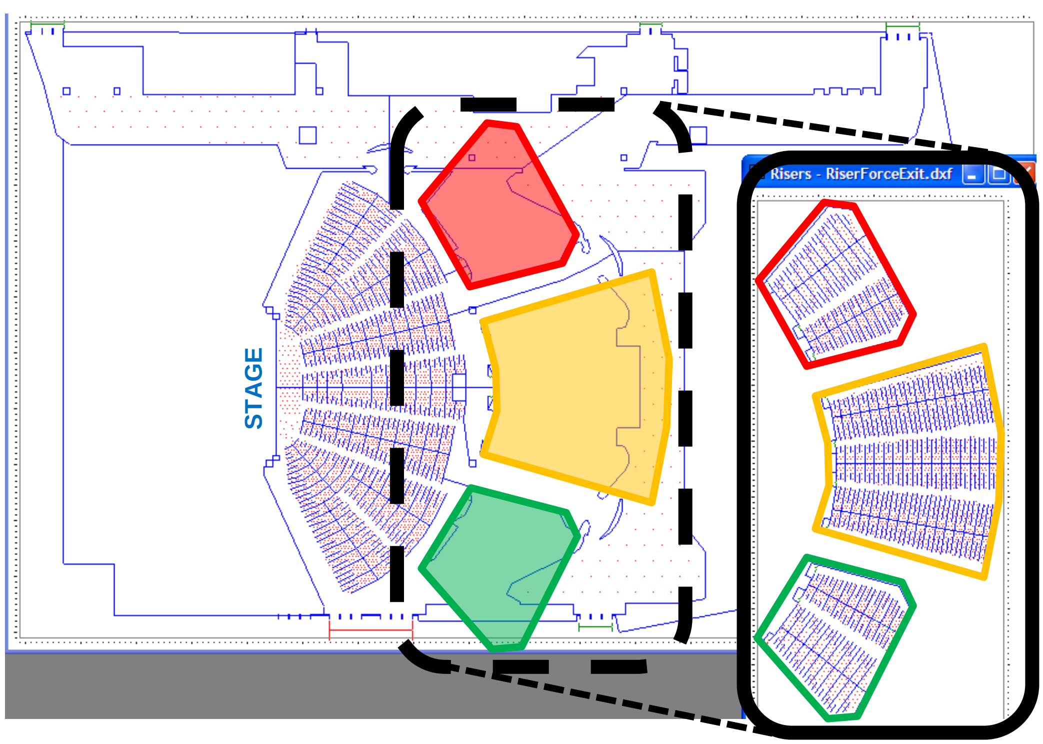

Figure 11: Simulex model image of theater with color-coded tiered seating overlay.

A total of 5,302 occupants were represented in the model, with 2,155 located on the elevated tiered seating. The purpose of this theater model was for design of smoke-protected seating. In order to assess the adequacy of the smoke control system, it was necessary to determine the duration that the top tier of seating was occupied, and ensure that the occupants were able to descend before being exposed to untenable conditions.

Similar to the arena sporting event and stage performance scenarios, added elements to divide the audience seating areas are present, as well as barriers for channelization. Further, due to the curvature of the seating rows and narrow space between rows, Simulex software parameters were unable to accommodate the entire occupant load when each row was strictly defined.

To overcome this challenge, middle segments of some rows were removed in order to populate the space with the correct number of occupants. The ends of every row were retained in order to continue to limit occupants' entry into the aisles.

With this, the egress time of the last row in the grouping would be reduced and the egress time of the first row in the group would be longer. However, with regard to the group as a whole, the egress time would be unchanged.

Figure 12 presents the Simulex conditions at 1-minute into the analysis, showing the seating areas generally empty and the aisles full, and some queueing or congestion. Some areas of queuing are predictable, such as approaching the narrow space between the stage and ends of the front row.

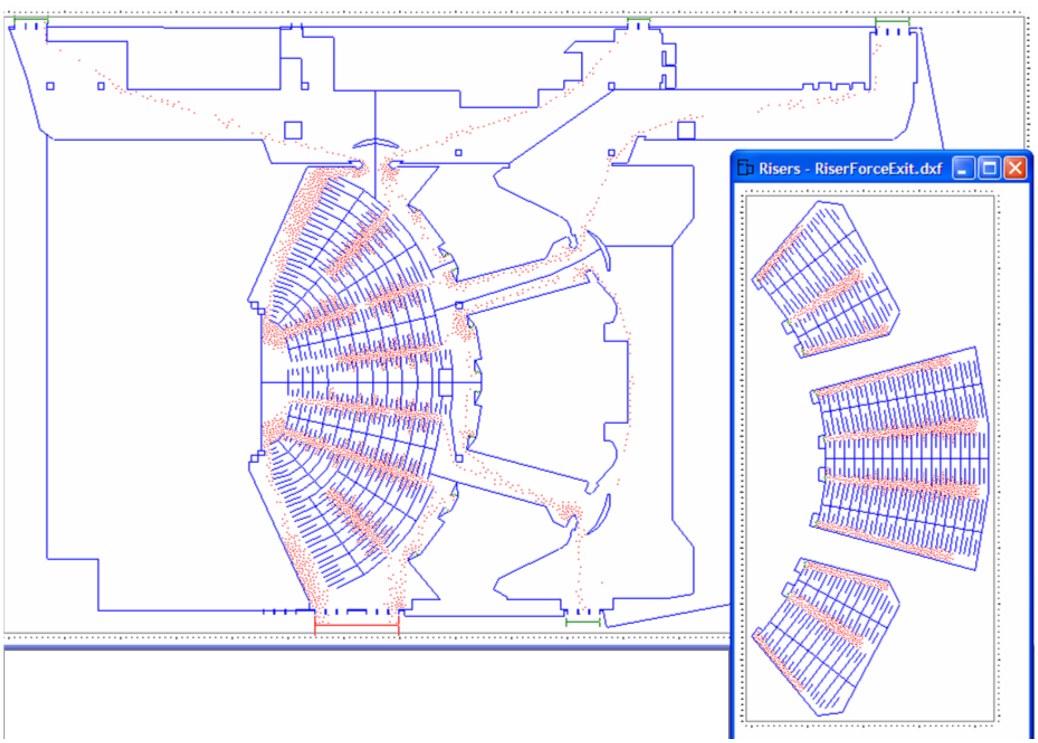

Figure 12: Simulex model image of theater at time step 1:00 (mm:ss).

While there would not be channelizing barriers in reality, a similar result could be achieved with facility staff and ushers directing occupants toward an exit as they entered the pre-function space outside the seating area.

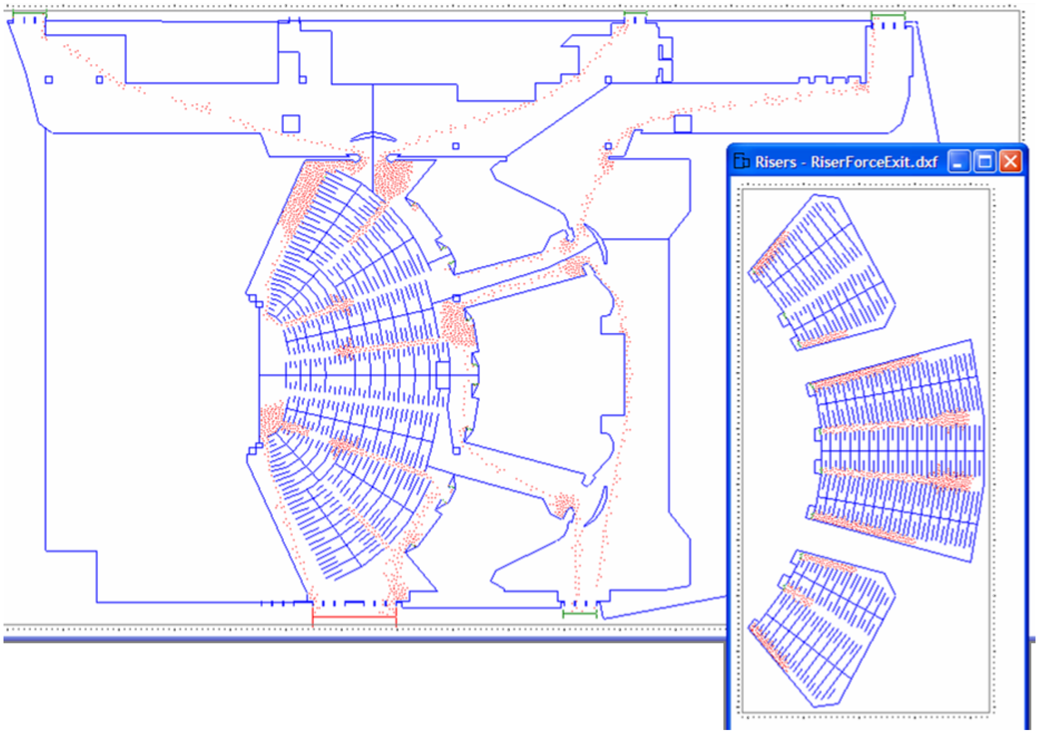

Figure 13: Simulex model image of theater at time step 3:30 (mm:ss).

At 3 minutes-30 seconds in Figure 13, the barriers added for channelization appear to be contributing to queuing which is preventing occupants from one aisle of the central tiered seating section from reaching the main floor level. To the extent that this prolongs the egress time, conservatism is added to the analysis such that the resulting egress time should ensure a safer condition. Other tiered seating areas should continue to evacuate with unimpeded access to the main floor.

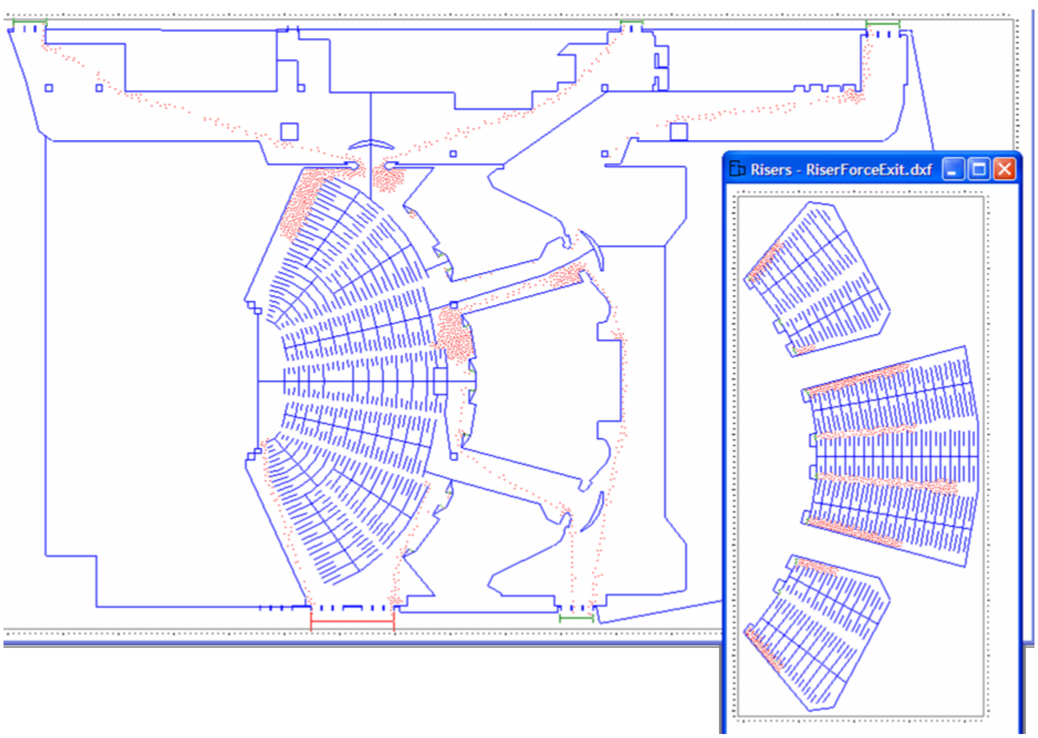

Figure 14: Simulex model image of theater at time step 5:00 (mm:ss).

At 5 minutes into the simulation, as shown in Figure 14, queuing is evident near the center of the image due to a channelization barrier which is forcing occupants to exit via the main entrance rather than availing the nearer secondary exit. This configuration contributes to a longer egress time, and is accounts for the preference of occupants to exit via the route by which they entered the building.

Also in Figure 14, the extent to which Simulex depicts occupants remaining in some of the tiered seating appears to be a "log-jam" condition. This is where due to the body shapes and behaviors assigned to the occupants, and/or misalignment of geometry with Simulex grid, occupants simultaneously reaching an exit may have conflicting movements and form a blockage in the scenario, despite the availability of an exit. Also, due to adherence of the distance map created by Simulex, the potential for occupants to travel across a row to access a vacant aisle in order to avoid congestion is not accounted for.

A minute later, as shown in Figure 15, some of the tiered seating aisles appear to have made no progress, supporting the conclusion that a log-jam is present.

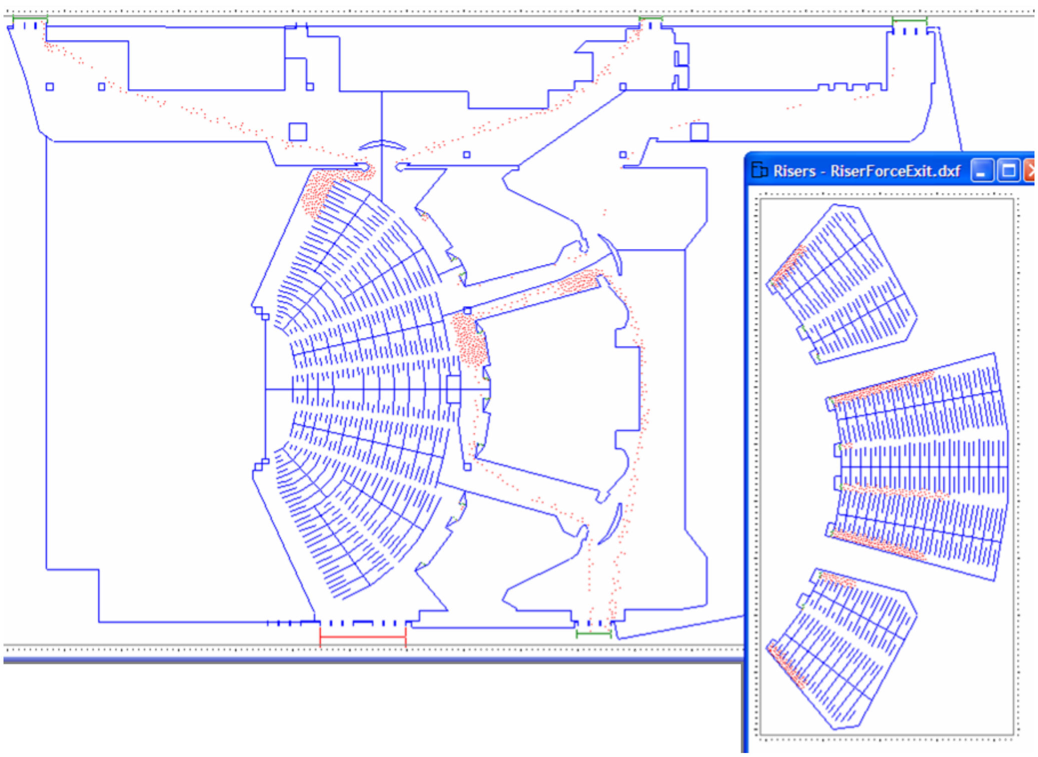

Figure 15: Simulex model image of theater at time step 6:00 (mm:ss).

The extent of the log-jams are apparent in Figure 16, where conditions at 8 minutes into the scenario indicate that egress routes are available, so occupants from these risers should be evacuating.

Due to the similarity and symmetry of the tiered seating areas, it is unclear why the Simulex output is inconsistent. Nonetheless, it is this similarity and symmetry that enables a conclusion to be reached in order to determine the time that these tiered seating areas would have been vacated had a log-jam not been present.

To account for these occupants with regard to the evacuation time of the ground floor, rather than simply considering the average walking speed along the route, the queuing within the vomitory contributes to the attributed time.

Figure 16 shows the last occupant from the central tiered seating area entering the vomitory at simulation time step 8 minutes, and moving toward the queue. The queue has dissipated and the last occupant is leaving the vomitory 1 minute-30 seconds later, as shown in the following Figure 17.

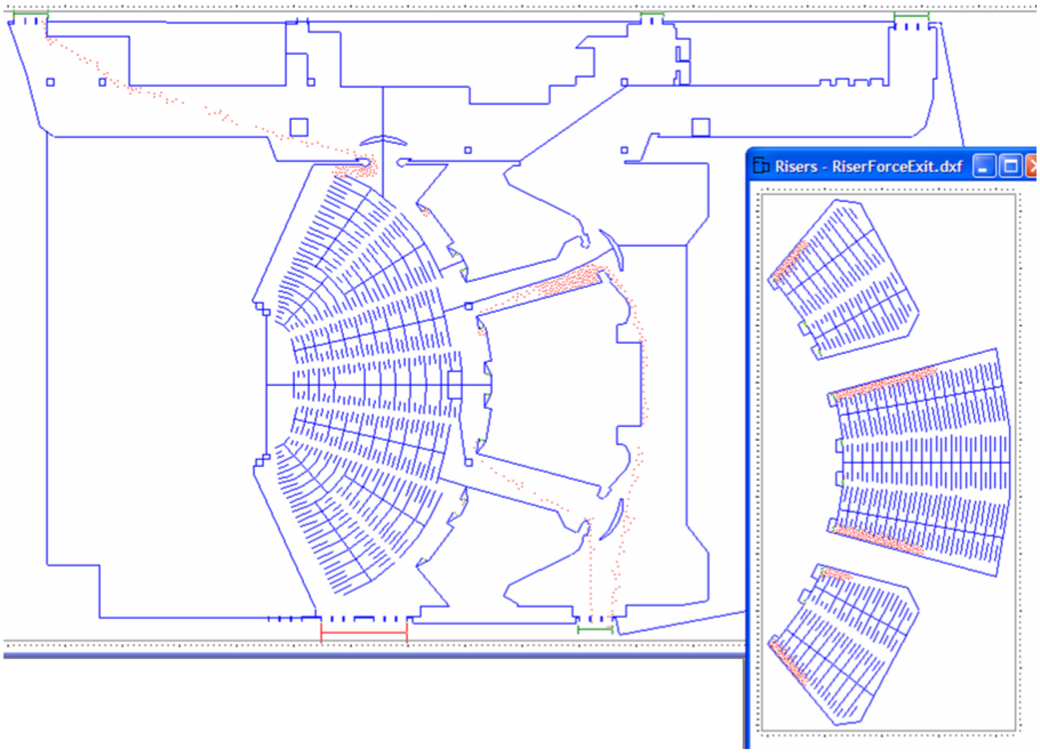

Figure 16: Simulex model image of theater at time step 8:00 (mm:ss).

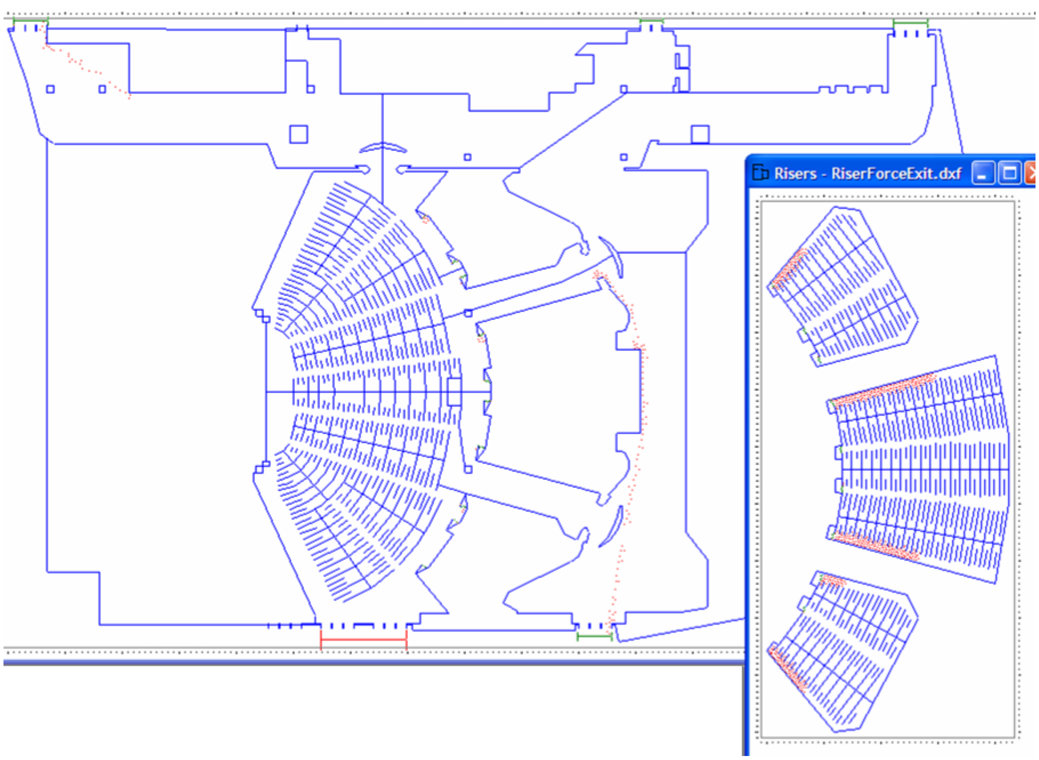

Figure 17: Simulex model image of theater at time step 9:30 (mm:ss).

At 11 minutes, occupants have evacuated from the main floor, as shown in Figure 18. Accordingly, the Simulex model's depiction of occupants on the tiered seating is unrealistic and therefore invalid.

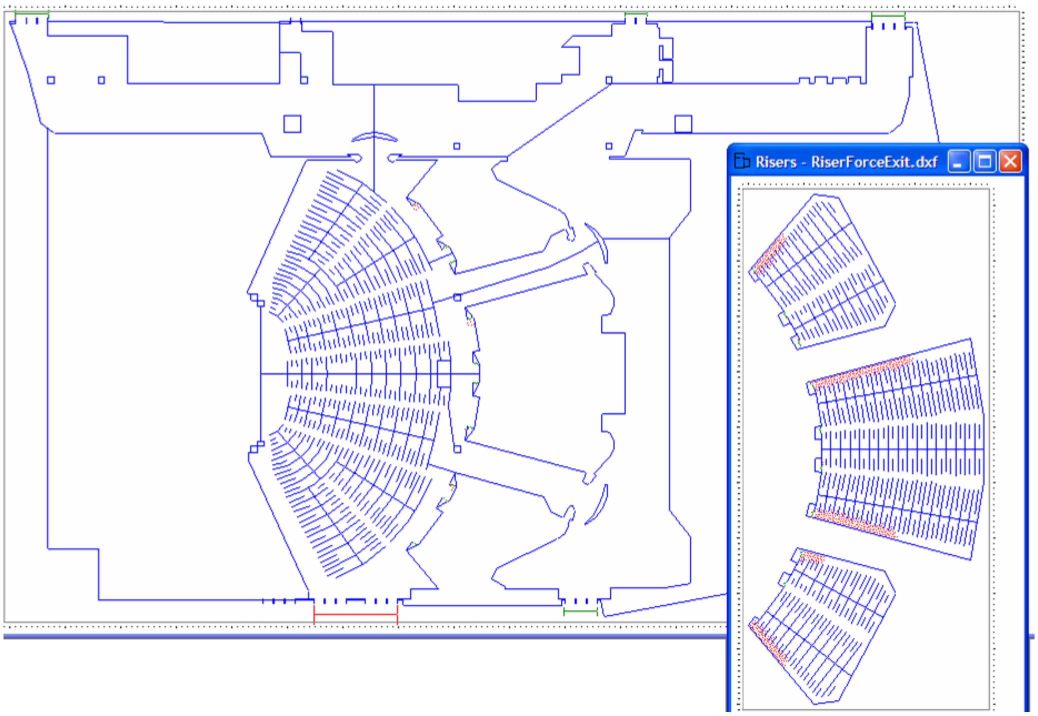

Figure 18: Simulex model image of theater at time step 11:00 (mm:ss).

Though the results displayed in the model are unreasonable, a valid conclusion can still be drawn from the Simulex results. Adding the durations as discussed above for similar occupant movements to account for evacuation of the occupants shown to be remaining on the tiered seating levels adds another 3 minutes for a total evacuation time of 14 minutes.

At the conclusion of the first sold-out concert in this venue, the local fire authority shared that they timed the audience leaving the venue. They stated that by 14 minutes the exits were clear and the occupants who were remaining in the gift shop could have evacuated.

This report from the fire authority supports the conclusion that modification of the modeled domain to channel occupants in a reasonable and thoughtful manner, together with the behavioral elements of the Simulex algorithm, can work together to provide for valid results.

SUMMARY

To ensure a Simulex solution is valid, the scenario being assessed should be comparable to test data by which the software itself was validated. One such factor is the absence of environmental conditions which would cause the occupants to panic.

Some modification of the geometry of the space, such as enlarging rows in assembly seating areas, can be required in order for Simulex to accept the occupants and conduct a simulation. Where the aisles by which the rows are accessed are unchanged, the results for evacuation of the seating section remain valid.

Unmodified, following the shortest path can cause a Simulex scenario to result in available exits being unused with excessive queuing at the nearest exit. This can be resolved with rational manipulation of the distance map by creating channelization to cause occupants to travel to a difference exit. As such manual intervention does create opportunity for a more idealized solution, any modifications must be defensible with engineering judgment.

Potential Refinement

With the log jams apparently associated with the stairs in the tiered seating model, and the variation in egress times observed by Kuligowski and Milke with differing high-rise stair configurations, Simulex improvements to the algorithm for stair travel may address these issues.

While Yanagisawa has observed that an obstruction near the exit can improve egress, a larger queue appears in Simulex. Adjustments to the Simulex algorithm for navigation around an obstruction may contribute to more efficient simulations.

Use of a single general movement speed may be an over-simplification. Occupants leaving a concert likely move more slowly than occupants who are exposed to fire cues. Accommodation in Simulex to account for these differences in movement speed could contribute to an improved solution.

CONCLUSION

While creation of Simulex simulations is a relatively simple process, the user must have sufficient knowledge and expertise to assess when and how manipulation of the scenario is warranted by applying engineering judgment. It is insufficient to simply accept that because the software program has been validated that every solution set it produces is therefore necessarily valid. Similarly, it is incorrect to presume that the solution from a manipulated Simulex model is necessarily invalid.

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