# Crowd Modeling in the Sun Life Building

**Michael Van Schyndel[1], Omar Hesham[1], Gabriel Wainer[1], Brandon Malleck[2]**

[1] Dept. of Systems and Computer Engineering
Carleton University, Ottawa, ON, Canada
{MichaelVanSchyndel,OmarHesham}@cmail.carleton.ca
gwainer@sce.carleton.ca

[2]Bentall Kennedy
Ottawa, ON, Canada
BMalleck@bentallkennedy.com

**Abstract**
Pedestrian movements are a critical component that must be taken into account when one is interested in planning and designing urban areas, buildings and large public spaces. Pedestrian and crowd modelling and simulation has become popular in order to provide information that can be incorporated into the design. This paper presents and discusses an advanced pedestrian model built using the Cellular Discrete Even Specification (Cell-DEVS) formalism. The new model allows the designer to provide an accurate representation of pedestrian behavior. The models presented here were applied to a real world scenario in the city of Ottawa, Canada. The case study focused on the effects of the construction of a new Light Rail Transit (LRT) System, and its influence on the flow of pedestrians into the Sun Life Financial building, located close to one of the main LRT stations. Further illustrated is how the pedestrian model was initialized and verified using data collected from the scene, resulting in accurate pedestrian behaviour. Finally, it's shown how these results were used to provide insights into possible problems and how to avoid them.

**Author Keywords**
Pedestrian dynamics; Crowds; Bi-directional flow; Discrete Event Simulation; DEVS; Cell-DEVS; Application.

**ACM Classification Keywords**
I.6.3 [Simulation and Modeling]: Applications; I.6.5; I.2.11 [Artificial Intelligence]: Distributed Artificial Intelligence.

## 1 INTRODUCTION

In the context of architectural and urban design, crowd simulation is often used as a demonstrative tool, providing an optimistic vision for the type of real-world utility of a given space. These virtual crowds could be used to guide the direction of development during the early design phases of a project, and are often considered to be an integral digital asset for any marketing effort down the line.

Beyond illustrative uses, crowd simulation is finding increased importance as part of the analytical tool chain that studies a given structure's safety and capacity concerns [1]. Typical uses include the simulation of emergency evacuation procedures, identifying traffic bottlenecks, and shaping pedestrian flow by manipulating access point allocations and doorway designs.

Modeling and Simulation (M&S) can also be useful in other aspects of Building Information Modeling (BIM). Throughout a buildings lifetime it will undergo many changes and renovations. These remodels can be to update the architecture or in response to a change in the environment. For large buildings, they can be a costly and lengthy undertaking. Therefore, it is very important that all aspects be taken into consideration during the designing phase. M&S can be used to help determine where problems might occur before construction has even begun, and it aide in shaping the new designs, potentially saving the developers both time and money.

Here, it'll be shown how M&S was used to help during the design phase of the remodel of the Sun Life Financial Building in Ottawa, ON, Canada, by simulating the effects of increased pedestrian traffic through the building and determining possible points that could cause problems in the future, so they could be addressed during the remodel of the building. The simulation is built on Cell-DEVS [10], a formalism based on the Discrete Event System Specification formalism (DEVS). Cell-DEVS combines an event-driven response with continuous timing. DEVS provides good means for coupling model components, hierarchical, modular construction [10]. Cell-DEVS combines the Cellular Automata (CA) theory with DEVS, dividing the model space is broken up into discrete cells, each with their state machine. Cell-DEVS has many benefits, chiefly, that cell state changes can be executed asynchronously. Additionally, unused cells can remain dormant until woken up by an external event or state change, reducing execution times by eliminating unnecessary burdens.

This research aimed to study the effect of the new Light Rail Transit (LRT) System on the Sun Life Financial building in Ottawa, Canada. There are fears that the increase in foot traffic through the building may negatively impact the daily routines. With construction under way, now is the time to make any changes to mitigate any future problems the LRT may cause. The paper shows how the model was designed and initialized using data collected from the scene, making it capable of modelling pedestrian behavior accurate to the specific conditions of the application environment. Finally, these results were used to provide insights into possible problems and measures that could be taken to avoid them.

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## 2 RELATED WORK

The Modeling and Simulation (M&S) of human behaviour is a complex endeavor [2]; and crowds are no exception. To this end, previous efforts have tackled the problem through varying levels of abstraction, depending on the application at hand. This section outlines those abstraction categories and their typical use cases. For a more detailed treatment, the reader is referred to the critical assessments in [1] and [3].

### 2.1 Modeling Pedestrian Flow

Pedestrian modeling can be divided into the following general categories, in order of increasing granularity: *flow-based*, *entity-based*, and *agent-based* methods.

*Flow-based* methods represent a macroscopic view of pedestrian dynamics. There are methods that treat the crowd as a continuum that behaves similarly to fluid flow [4], which is achieved by incorporating decision-making elements within existing fluid dynamics equations. Others tackle it from an operational research point view, using network optimization to solve a graph-based reduction of the crowd's environment [5]. This can be applied, for instance, to the modeling of building evacuation scenarios in which rooms are mapped to nodes on a graph whose edges represent the capacity-limited paths connecting them. The graph is solved for the shortest path to identify optimal exit routes. Computing the graph's maximum flow would identify potential bottlenecks around those nodes. These methods are computationally inexpensive making them suitable for large-scale projects that involve high crowd densities [6]. This level of abstraction is most appropriate when seeking a general sense of a crowd's orientation, density distribution, and collective rate of locomotion, without much concern for the specific actions of its individuals.

By contrast, *entity-based* methods simulate individual entities, which collectively result in the emergence of crowd dynamics. Each entity uses a global class of behaviors that dictate its interactions with the elements in its surrounding *local neighbourhood*. Typically, this results in highly homogenous entities and parallelization-friendly implementations of microscopic interactions [1]. Cellular Automata (CA) has become a popular entity-based method [7, 8]. In CA, a space is discretized into a uniform lattice of non-overlapping cells (i.e. *entities)*, typically based on any tileable shape with a consistent pattern (i.e., a square grid). A global clock periodically triggers a simultaneous update of all entities, where the next state of each cell is determined the by the state of all cells in its neighbourhood.

*Agent-based* abstractions view each pedestrian as an autonomous entity that encodes spatial interaction laws and has the capacity for goal-oriented decision-making. With this level of detail, minute variations to each pedestrian's goals, personality, kinematic properties, and the type of actions taken to reach such goals (e.g. leave work early vs. leave after rush hour, take elevator vs. take stairs, etc.) can produce near authentic representations of the real-life processes that lead to the emergent behaviour of crowds. However, this level of detail comes with a significant computational cost, making the use of agents prohibitive towards iterative development and composability with other models [9].

For the scope and practical considerations of this project, a cellular entity-based approach was chosen, as it delivered an adequate granularity with a computational efficiency suitable for repeated trials and rapid iteration.

### 2.2 Cell-DEVS Modeling of Pedestrian Flow

The Cellular Discrete Event System Specification (Cell-DEVS) [10] is a spatial modeling technique based on DEVS (Discrete Event System Specification) [10], which, much like CA, tessellates a space into a grid of cells. Each cell is an atomic model that connects with other cells in its local neighbourhood, effectively defining a coupled model for each entity and its environment. The modeler is able to define global properties of this coupling, and they are able to define the classes of behaviour that each cell could encode.

For this project, the pedestrian flow is modeled using Cell-DEVS, because it afforded several advantages compared to discrete-time CA, namely: event-dependent time stepping, asynchronous execution among entities, composability with DEVS and event-based architectural systems (e.g. [11]); and the ability to submit the model to formal verification, validation, and static analysis techniques [12].

Cell-DEVS was used for discrete-event pedestrian behaviour modelling in [13], where the authors showed how to integrate Building Information Modeling (BIM) to generate floor plans and exit flow maps for a multistory Cell-DEVS. The pedestrian entities shared a unified goal of exiting the building in the shortest path and time possible. Later developments included the ability to simulate bi-directional flow [9] using corrective sub steps to avoid oncoming traffic, and configurations for scalable execution on the RISE middleware [14], a cloud-based distributed simulation platform.

The proposed method improves upon the bi-directional flow models described in [9] by defining additional classes of goal-oriented pedestrians. This provides a mechanism for the necessary distinction between the building employees and the LRT passengers. Model complexity increases, as each class differs in their interactions with the environment, and in particular with an elevator system. Additionally, a run-time flow field remapping method was developed to automatically adjust the shortest path calculation based on the currently available destinations cells, enabling the integration of an explicitly dynamic elevator system.

## 3 THE SUN LIFE FINANCIAL BUILDING

The Sun Life Financial Building (SLF) located at 99 Bank Street, Ottawa, Canada (as seen in figure 1) provided a unique chance to demonstrate the proposed methodology.

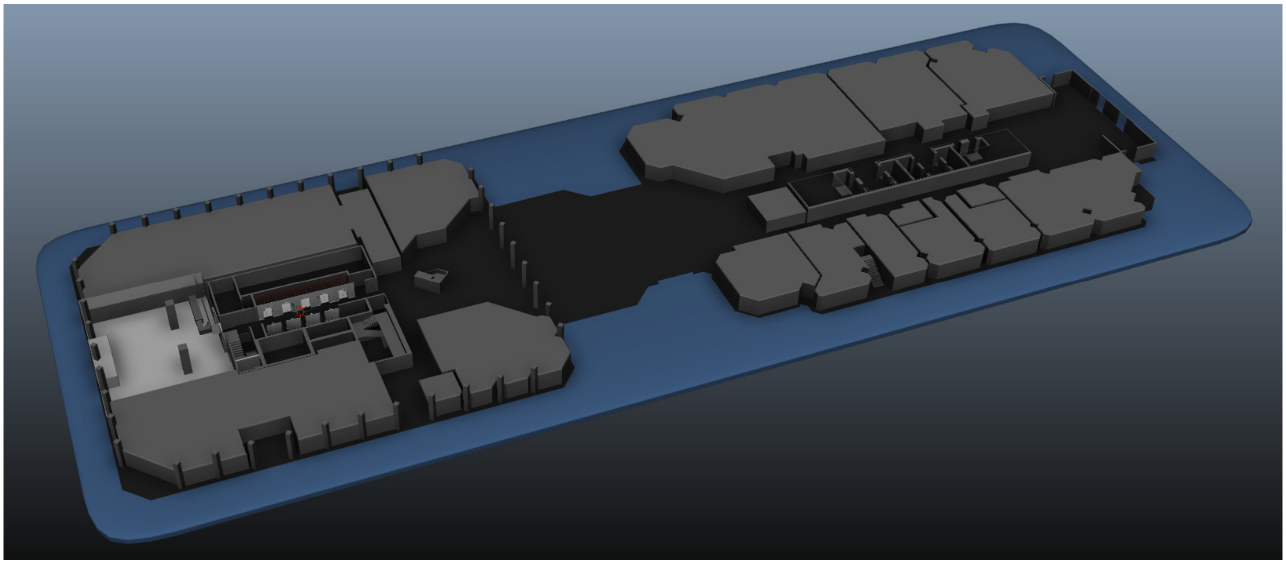

**Figure 1** Sun Life Financial Building

The SLF consists of two building separated by a mezzanine (as seen in figure 2). The City of Ottawa is in the process of expanding their light rail transit system to extend into the downtown core. Once the LRT is operational, it will be used to transport commuters to the downtown core. One of the LRT terminals will be located adjacent to the SLF building, and commuters will exit near the building's mezzanine.

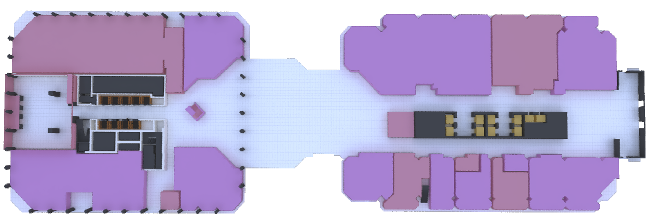

**Figure 2.** Building plan for 50 O'Connor and 99 Bank

With the new LRT terminal will come a large increase in the pedestrian traffic through both buildings and the mezzanine. The impact of an increased number of pedestrians through the building at 50 O'Connor will have very little impact on it as there are wide hallways and the elevators banks are located off the main hallways. The building at 99 Bank however, has one very narrow hallway that is rarely used, as seen in figure 3. To compound the problem further, along this narrow hallway are the 10 elevators that service the building. These elevators are used by the hundreds of employees that work at 99 Bank as well as patrons of the Rideau Club located at the penthouse suites.

The purpose of this research was to examine the impact an increased number of pedestrians through 99 Bank will have on the daily operations. More importantly, that during the cold months or the days that have adverse weather conditions, commuters using the LRT will choose to cut through the SLF instead of walking around the building outside, resulting in a drastic increase in traffic through the building. This already happens at a smaller scale, but during peak hour (8-9 am), as many 2686 commuters arriving from the LRT may benefit by passing through the building.

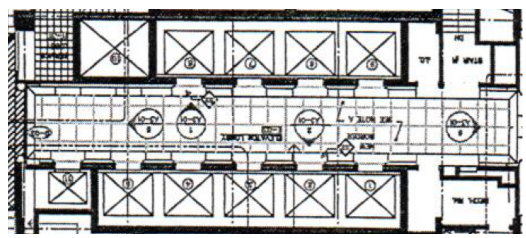

**Figure 3.** 99 Bank Street Elevator hallway

A model was generated to simulate the pedestrian traffic in the hallway in question to determine what impacts the increased number of pedestrians may cause and possible solutions to rectify the problems.

## 4 MODEL DEFINITION

The goal of this model is to portray the physical and sociological behaviors of the pedestrians as they move through the building accurately. These behaviors are created from a set of rules, which can be organized into three categories: *mapping*, *movement* and *elevators*. For each type of pedestrian, these rules will vary to reflect their specific goals. There are three types of pedestrians modeled. The first are the people using the elevators, who enter from either the lobby or the mezzanine and head to an elevator. The second are people passing through the building, heading from the lobby to the mezzanine. The final type is the people who pass from the mezzanine to the lobby. In the following sections discuss the different rules which were implemented in the CD++ toolkit [15]. The reader can find the simulator in http://cell-devs.sce.carleton.ca, and obtain the models from http://www.sce.carleton.ca/faculty/wainer/wbgraf .

### 4.1 Mapping

The mapping rules focuses on building a shortest path diagram from any cell to a desired destination. To do so, we store a direction vector in each cell, which is used during the movement phase to determine which move(s) will get the person closer to their goal.

The mapping process begins in the cell adjacent to the exit. The model computes how many cells away it is from the exit iteratively. A cell's value is determined by taking the value of an adjacent cell that has a value, as seen in figure 4. The process continues until all cells have a value.

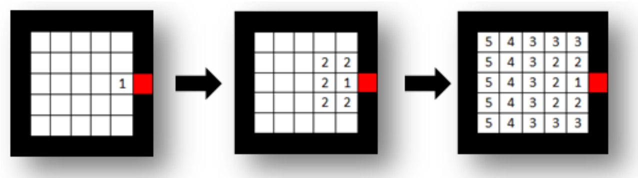


**Figure 4 Mapping**

The direction vectors are created by a simple rule. If the adjacent cell value is less than the current value than it is a valid direction (furthermore, additional rules can be easily created to add more complexity).

Several maps needed to be created for the different types of pedestrians (as each of them had a different destination). This was an easy fix as Cell-DEVS allows each cell to contain several state variables. This method was used in [15], in which the map was created at the very beginning of the simulation (and once created, cannot change). However, when the destinations location is dynamic, as in the case of elevators, the map needs to be updated regularly. The remapping process starts when a destination (elevator) becomes unavailable. A ping is propagated throughout the map, erasing all values. This ping that is created is akin to the bell that sounds when an elevator arrives. It notifies the people of a new destination and they react by recalculating the closest destinations.

### 4.2 Movement

The rules dictating the movement of pedestrians during the simulation were based on a variation of the method presented in [15], called the handshake method. This method reduces the neighborhood to simply the eight surrounding cells, as seen in figure 5. This is important aspect because the cell's state is determined by the cells that are located in its neighborhood, and, in order to define complex rules, the neighborhood can become quite large. This can cause the rules to become too complex or result inefficient.

The handshake method implemented in this model consists of 3 phases as seen in figure 6. The first phase is when an agent in occupied cell announces its intended destination (which is determined by the mapping; priority is given to movements in the four cardinal directions).

| | | |
|---|---|---|
| (-1,-1) | (-1,0) | (-1,1) |
| (0,-1) | (0,0) | (0,1) |
| (1,-1) | (1,0) | (1,1) |

**Figure 5** Neighbourhood Definition

In phase II, the unoccupied cells check their neighborhood for any cells indicating they want to enter. There are three possible outcomes: there is a person that wants to enter that location, there are more than one people desiring to enter that cell, or there is no one wanting to enter the cell. If only one person wants to enter the cell, its state is updated to create a link between the source and the destination cells. If more than one person is attempting to enter the cell, one is chosen and a link created. If no one wants to enter the cell, it remains available. Once a pair is linked, they will remain so until the end of the final phase. If a link is not created, an occupied cell will repeat phase I until either one of two things happen, 1) a link is eventually created, or 2) there are no empty cells available (the person must remain there).

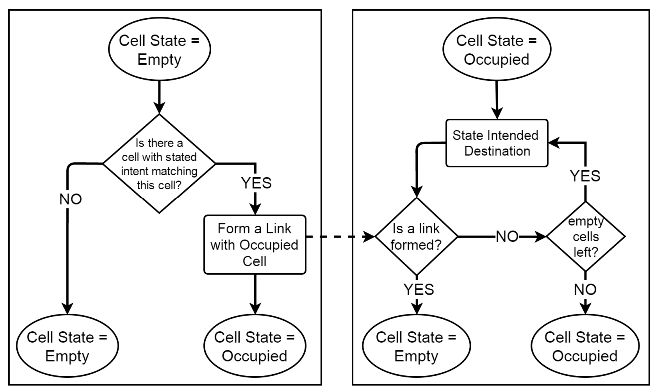


**Figure 6** State Diagram for movement [15]

Once phase I and II are complete, phase III makes occupied cells that are linked become empty. Empty cells that where linked will receive the person and occupied cells that were unable to form a link will remain occupied.

This method is beneficial for several reasons. First, by linking the source and destination cells it ensures that no errors will occur. In other methods, it is difficult to deal with collisions when two occupied cells try to enter the same cell, which sometimes results in errors. Another benefit is, as previously mentioned, a smaller neighborhood. This is because only the destination cell must lie in the neighborhood, whereas with other methods would require being able to "see" further to avoid collisions.

### 4.3 Elevator

The elevator model introduces new complexities compared to the cases when the destinations (doorways) remain static. An elevator however, is a dynamic destination, its cell state is constantly changing between open and closed. The rules governing the elevators behavior are straightforward.

1) Upon opening a door, a ping is generated to update the map, as previously discussed.
2) The elevator will remain open until a person enters said elevator
3) Once a passenger has boarded the elevator, it will remain open until one of two things has occurred
    a. The elevators maximum capacity has been reached
    b. The time since the first person has entered has exceeded a set time
4) The elevator will remain closed for a period of time, the length of which is normally distributed about a mean wait time that is chosen

## 5 EXPERIMENTAL SETUP

Before simulating the impact of the LRT, it was important to re-create the current activity in the SLF, later referred to as baseline data. The collection of actual data from the building was critical to generating accurate models specific to the conditions at the scene.

### 5.1 Baseline Data Collected

The data used to develop the model was collected by examining security camera footage from the month of January. There were several reasons for this. First, a winter month was desired, as it would see the largest number of days in which it would be preferable to remain indoors for the longest time possible. For average Canadian winters, this would fall between December and March. December was not used, as around the holiday season traffic patterns would be too sporadic. To narrow the parameters further, data was collected between the hours of 8 am to 9 am as this represented the highest volume of traffic through the building from both employees and people passing through. Additionally, the projected data was provided for the peak hour of 8-9 AM. Table 1 shows the average breakdown of the three types of pedestrians during this one-hour period.

| Time Period | Employees | Lobby | Mezzanine |
|---|---|---|---|
| 8:00 – 8:10 | 45 | 18 | 18 |
| 8:10 – 8:20 | 65 | 40 | 30 |
| 8:20 – 8:30 | 70 | 40 | 25 |
| 8:30 – 8:40 | 75 | 38 | 29 |
| 8:40 – 8:50 | 77 | 36 | 27 |
| 8:50 – 9:00 | 66 | 40 | 38 |
| Total | 398 | 194 | 149 |

**Table 1.** Data Collected

With employees referring to people who used the elevators, lobby referring to pedestrians that are passing through that entered from the lobby and mezzanine referring to the pedestrians that are passing through who originated from the mezzanine. Only the number of employees seemed to have any real pattern, which was a peak between 8:30 and 8:50 after which traffic for the elevator slowed.

Other observations that where important to take into consideration are as follows:

- Elevator round trips ranged from 0:45 to 4:30 with a mean of 2:00
- Elevator wait times ranged from 0:00 to 0:45 with a mean of 0:10
- Elevator occupancy ranged from 1 to 8 with a median of 2
- Elevator queues (more than 2 people) occurred between 3 and 5 times per 10 minute interval

### 5.2 Baseline Simulation

The first step to setting up the model parameters was to determine a cell size. For the purpose of this model, a cell's dimensions were defined as 0.75 meters by 0.75 meters. There were several reasons for choosing these dimensions. First, the width of the elevator doors works out to be about 2 cells wide. Secondly, the dimensions represent the area a pedestrian can occupy without becoming uncomfortable. As this is an office building and not a busy sidewalk or a subway, a reasonable amount of space is expected. Finally, this cell size is widely used in crowd simulations using CA.

Furthermore, each frame in the simulation represents 0.5 seconds or a rate of 2 frames/second. As a pedestrian has a maximum speed of 1 cell per frame, this means that the average velocity of the pedestrians is 1.5 m/s [16]. Figure 7 shows the comparison between the floor plan and the cell space used in the model as well as the cell states.

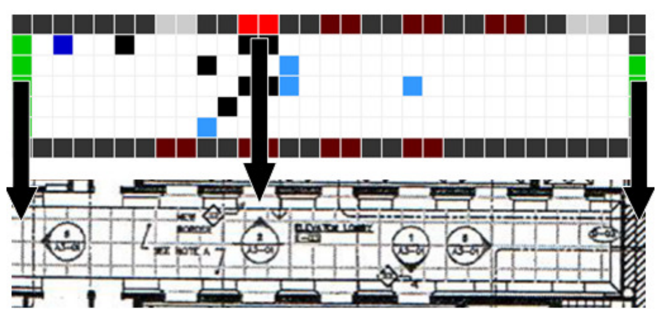

**Figure 7.** Comparing Floor Plan to Model

Table 2 outlines the results of a baseline trial. Once a baseline had been achieved that was able to recreate the real world scenario it was possible to modify the parameters to test the hypothesis. It was desired to examine the impact that an increased number of pedestrians passing through the SLF building would have. As previously stated the LRT would bring approximately 6400 additional commuters during the peak hour, every day. As many as 2686 of whom might benefit by passing through the building at 99 Bank St. While it would be reasonable to assume that people would be favorable to cut through the building it would be unreasonable to assume all the people exiting at the mezzanine would do so.

| Observations | |
|---|---|
| Employees | 66 |
| Lobby | 34 |
| Mezzanine | 24 |
| Number of Queues Formed | 3 |
| Queue Lengths | Min = 2 Max = 8 |
| Elevator Wait Times | 0:00 to 0:55 |
| Elevator Occupancy | Min = 1 Max = 8 |

**Table 2.** Observed Baseline Data

The simulations run would produce results for 10-minute periods. Therefore, the maximum number of additional people passing through would be 447. To best see the impact increasing the traffic would have, the simulation was started with 5% or approximately 22 additional people passing through over the 10 minute period, followed by 25% and 35% or, 111 and 156 people respectively.

Since the number of employees should remain within the same range as the baseline, the elevator parameters would remain the same.

## 6 SIMULATION RESULTS

This section shows the simulations results for different sets of parameters. Videos of the results can be found on at the following link www.youtube.com/user/ARSLab . Furthermore, the model and simulation log files are available at http://vs1.sce.carleton.ca:8080/cdpp/sim/workspaces/test/lopez/BK .

To determine the effects of the increased traffic, the number of queues formed and their lengths are examined. The maximum wait time for an elevator and the number of collisions (in this case, it's considered a collision when a person in the simulation becomes stuck) are also studied. In most cases a person is able to avoid any obstacle, however when traffic is particularly heavy a person may not be able to move around the obstacle and become stuck for a period. Such incidences were rare when testing the baseline model, and were rarely observed from the security footage. However, such incidence became more frequent during tests with increased traffic.

### 6.1 Low increase of possible commuters scenario

The first test case was to increase the number of pedestrians entering from the mezzanine by approximately 5% of the total possible commuters arriving via the LRT. As previously stated, this indicates that it's expected to see an additional 22 people enter the hallway from the mezzanine over a 10 minute frame. As the creating of people is random, the numbers for the employees and people entering from the lobby will vary but will remain within the ranges found in table 1.

The simulation results showed 56 employees entering the hallway, 34 people passing through from the lobby and 56 passing through from the mezzanine. The number of people passing through from the mezzanine has increased by approximately 7% of the 2686 commuters that would arrive via the LRT. The simulations results showed eight queues form while waiting for an elevator with a maximum length of six. The maximum wait time for an elevator was approximately 52 seconds. Finally, there were four instances of minor collisions and four major collisions.

### 6.2 Medium increase of possible commuters

The second simulation tests were built to try to demonstrate the impact of increasing the number of people entering from the mezzanine by 25% of the LRT commuters. This corresponds to an increase of approximately 111 people over a 10-minute period.

The results of the simulation show that over a 10 minute period 74 employees used the elevators, 36 people entered the hallway from the lobby and exited into the mezzanine and 132 people passed through via the mezzanine. This represents an increase of approximately 102 people, which is close to 25% of the LRT commuters. The results show that over a 10-minute period six queues formed with the longest containing seven people. The longest wait for an elevator was 33s. During the simulation period, there were 22 minor collisions and 4 major collisions.

### 6.3 High increase of possible commuters

The last simulation tests study the effects of increasing the number of people entering from the mezzanine by approximately 35% or 156 people over a 10-minute period.

The simulation results shows that over a 10-minute period 70 employees used the elevators, 26 people passed through from the lobby and 184 passed through originating from the mezzanine. This corresponds to an increase of approximately 152 people or close to the 35% desired. There were 10 queues formed during this period with the largest having five. The longest wait for an elevator lasted 34s. During the simulation there were 24 minor collisions as well as four major collisions.

## 7 VISUALIZING

One of the barriers to widespread adoption of M&S formalisms in real-world applications is the difficulty of reproducing the results in a consistent manner across platforms and work environments. This problem is particularly accentuated when dealing with clients and domain experts. The simulation modeler is left with little choice but to use annotated images or video to illustrate and share the results. Video is a non-interactive medium that limits exploration, feedback, and collaboration on new ideas with third parties, since a new video had to be created for every iteration of the discussion. To address these concerns, a new visualization platform built on web technologies (HTML, CSS, and JavaScript) was developed in parallel to, and based on what've was learned from, the crowd simulation project. To visualize the results, an internally developed Cell-DEVS visualization engine written entirely using web technologies (HTML, CSS, and JavaScript) was used. This provided us with a high degree of platform independence, which was important in such a collaborative and application-oriented simulation project, involving simulation developers and domain experts alike. The platform is designed with a data core optimized for DEVS and can be interfaced with using a flexible set of programming APIs.

For instance, it's possible to visualize the simulation directly on a webpage using the hardware-accelerated Web Graphics Library (WebGL), encode the results into a compressed video file, or export the scene to an Alembic 3D file. Since the visualization is computed on the client side, multiple visualization clients can query a single simulation source, such as the distributed DEVS simulation service RISE [14].

The key motivation here is allowing users to share and modify the visualization parameters (e.g. color-coding, sprite-coding, statistical graphs, etc.) without requiring expert knowledge of the underlying simulation model or having to install specialized software on their devices. The engine operates on any HTML5-capable web browser or mobile platform.

**Figure 8.** Rendered Model of Hallway

Rendering the Cell-DEVS grid data directly on the page using WebGL was sufficient for the early development phases of the project, which demanded the rapid iteration and prototyping of pedestrian dynamics. Later efforts aimed at contextualizing the pedestrian simulation results within their target environment required us to export the kinematic information of the pedestrian entities into an Alembic 3D file.

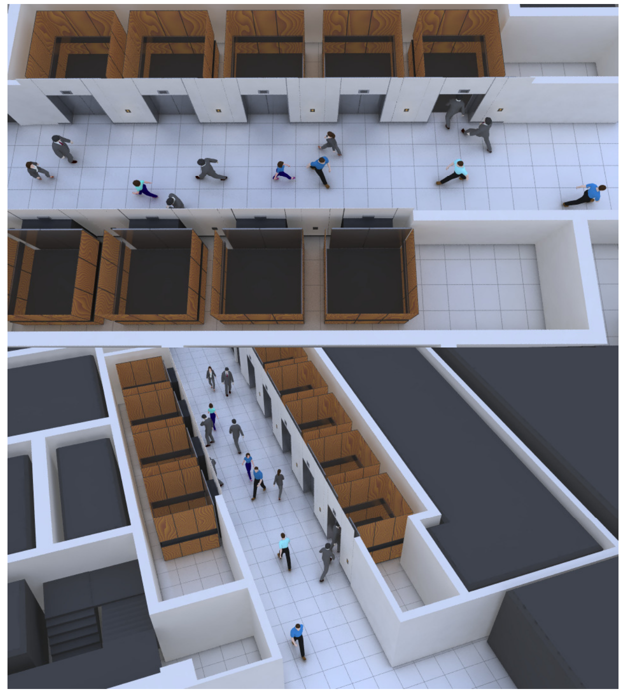

**Figure 9.** Rendered Visualization of Simulation Results

This was then imported into a 3D content creation package, such as Autodesk Maya, to be used as destination guides for color-coded and pre-animated 3D sprites, which represented the different pedestrian classes in the scene. The pedestrians are integrated into a representative 3D model of the environment, and links are formed between the dynamic elements to their respective events (e.g. elevator availability triggers door control). Figure 9 was created from the model's simulation results using the aforementioned visualization tools.

## 8 DISCUSSION

The results from the simulations provided several important insights regarding the effect an increase in foot traffic may have on the daily operations of the building at 99 Bank St.

The hypothesis was that the increased traffic would cause delays and serious congestion in the elevator hallway. The results showed an increased number of queues formed. However the length of the queues where significantly shorter and the maximum wait times remained unchanged.

Another fear was that long queues would create significant barriers that, with an increase in foot traffic, would cause chokepoints. As previously mentioned the results showed more frequent but shorter queues. In the simulation, the people were able to remain along the walls and leave the middle of the hallway free.

Finally, even though there was no detrimental effects to how quickly employees entered the elevators, there was a significant increase in the number of collisions, especially with a 35% increase. While observing the simulation results it became apparent that the hallway began to resemble a busy sidewalk than an office hallway, something employees working there may not appreciate.

The benefits of M&S became apparent when running the tests for several reasons. Not only was it possible to test the presented hypothesis but also possible to observe things not previously thought of. For example, while the east side of the hallway, as seen in figure 9, is wide open the west side contains three glass doors. During the simulation, there were several occasions with bottlenecks. As the doors would not operate as efficiently as they did in the model, this would likely be a significant problem that would need addressing. Overall, it proved beneficial for the building planners and architects to be able to visualize the impact the LRT would have on their building.

## 9 CONCLUSION

The goal of this project was to determine what impact, if any, an increased number of pedestrians would have on the daily operation of the Sun Life Financial Building. Through the work presented here, it was possible to determine the theoretical impact of such a scenario as well as discover other unforeseen consequences. It was also shown how M&S could be integrated into the design process.

To improve the quality of the results generated by the model there are several areas that can be improved upon. One benefit to DEVS is the ability to link many smaller models together to represent a larger more complex system. For example, a DEVS model could be created to simulate an elevator, where the inputs would be number of people and floors and the output would be how long until it was free. Linking this model to the current model would improve the overall quality. Similarly, other DEVS models could be created to increase the functionality of the model. Having models for sliding doors, revolving doors, escalators, horizontal escalators, would help improve the functionality of the Cell-DEVS toolkit for use in building simulations.

Lastly, in order to accommodate more freeform and non-axis-aligned structures, one is motivated to consider a Lagrangian approach to computing the relevant physical quantities -i.e. position, orientation, and vision assessment being computed at the vector location of each entity as it moves continuously through space- instead of the current Eulerian fixed grid approach.


## ACKNOWLEDGMENTS

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