Implementation of a Simulation Model for Optimizing the Traffic Flow from Arafat to Muzdalifah

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Abstract

This project simulates the flow of pilgrims when they travel from Arafat to Muzdalifah. The system includes the roads network that connects Arafat to Muzdalifah, which is represented as a queuing system with different queue measurements that simulate reality. The system also includes different types of transportation, such as small and large buses and trains, all of which are represented as objects with different size and colors. All system objects carry specifications as their corresponding source system objects, and these specifications are based on data collected by the Ministry of Hajj. The primary objective of the system is to answer "what if" questions to support decision making to optimize Hajj traffic, which can be achieved by manipulating the system's variables and then by observing the key performance indicators of the system. The system presents the experimental results as visual feedback alongside written reports with statistics and illustrations.

Keywords: Simulation, Muzdalifah, Arafat, Traffic flow

Introduction

Due to the significant number of pilgrims arriving every year to the Hajj holy places, the crowds and traffic congestion have become significant. These crowds and traffic congestions can cause serious problems, such as the late arrival of pilgrims to the holy places. In addition, there is time inefficiency in providing essential services, such as medical care in cases of emergencies (Shafi et al., 2016).

In this paper, we develop a simulation model for a non-Arab and African shuttle-trip system to support the decision-making process in working toward a more optimized system performance.

Literature Review

Three research papers have been reviewed related to our project. For each paper, included is a summary of the paper and a conclusion that shows all the results and findings obtained from the paper. These papers are as follows:

Modeling and Simulation of Transportation Systems: A Scenario Planning Approach (Papageoriou, Damianou, & Pitsilides, 2009)

This paper suggests that instead of building more and bigger roads to increase road capacity, effort should be made to determine ways to enhance the level of service of public transport modes, especially with the use of advanced technologies, such as intelligent transportation systems (ITSs). It proposes the traffic modeling and simulation method shown in Figure 1.

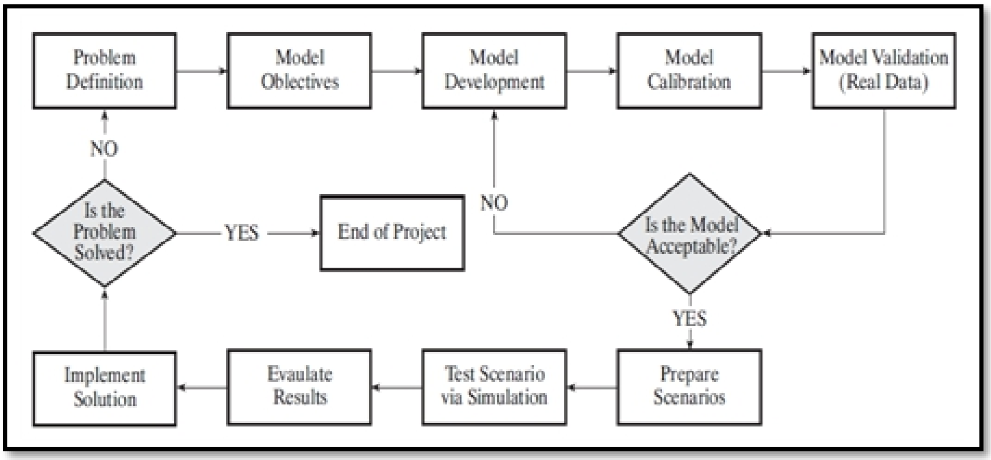


Figure 1. The proposed traffic modeling and simulation method
Source: Papageoriou, Damianou, and Pitsilides (2009)

This paper points to the increasing number of vehicles as the main cause of the traffic congestion problem. Therefore, the long-term solution is to decrease the number of vehicles and increase public transportation occupancy.

The parameters that have been considered include traffic control signals, priority rules, routing decisions, pedestrian crossings, signalized and non-signalized intersections, and so on. The traffic data are classified as static data, which represent the roadway infrastructure, and dynamic data, which include traffic volume and vehicle mix for all links entering the network.

Based on the validated microscopic simulation model alternative, bus priority strategy scenarios involving dedicated bus lanes, signal preemption, and bus advance areas are evaluated. Via computer simulation experimentation, it was possible to develop a scenario solution that reduces the total travel time by 27%, increases the average speed by 45%, and reduces delays by 28% for the bus transport mode, with almost no negative effects on the rest of the traffic.

Overall, this paper does a good job of identifying the main cause of the congestion problem as the increasing number of vehicles and not road capacity. It introduces different scenarios that will help improve the level of optimization of the targeted system, and these scenarios could be adapted to the Hajj environment. However, the proposed traffic modeling and simulation method is not quite beneficial, as it does not explain the model development process. It suggests we go back and redefine our problem in case the suggested solutions do not work, rather than trying to find alternative solutions.

A Dynamic Highway Flow Control Simulation Model for Solving the Congestion Problem

The authors of this paper (Yang & Wen, 2007) developed a simulation model coded in Arena to help design a dynamically automatic traffic flow control simulation model. As shown in Figure 2, the model simulates the section of the Chung-Sam highway between Taipei and TaoYuan, the distance of which is 31.9 km. They adopt dynamic speed limits and practical measures to simulate the number of cars arriving and the number of cars leaving within a time interval. First, they set each lane with a speed limit of 100 or 125 km/hr. Next, they determined that controlling the departure speed of the junction leads to a better result, enlarging the maximum flow. The simulation model with a dynamic speed limit is able to guide traffic dynamically during rush hours. However, in the framework for the simulation model, the authors assume that the highway has only three junctions, consisting of a starting junction (junction 1), an exit junction (junction 2), and an end junction (junction 3), and they assume there is a stop-and-go traffic light at the starting junction (junction 1). To understand performance, the authors designed various cases with different speed limits and different red light durations to improve the traffic problem on the highway and to compare the current number of cars with the average speed in each lane.

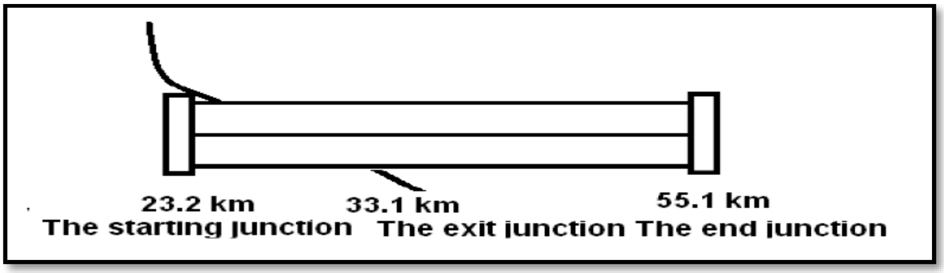


Figure 2: A framework for the dynamic highway traffic control simulation model

Overall, this paper shows that if cars are being made to wait on the entrance ramp by a controlled mechanism, the highway traffic will have a good performance. The simulation results physically prove that setting a dynamic speed limit signal during rush hours will increase the speed and improve the performance of the highway. Although this paper presents and analyzes a dynamic highway flow control simulation model, several aspects should still be further considered to make the proposal more realistic. For example, it can be extended to include additional exit junctions or distances to understand the interrelationship between junctions and speed limit. In conclusion, the suggestion of setting a stop-and-go traffic light could be adopted to control the flow of vehicles to Muzdalifah and to decrease overall traffic congestion.

Dynamic Traffic Simulation for Traffic Congestion Problem Using an Enhanced Algorithm

In this paper (Lee, Osman, & Talib, 2008), a dynamic traffic simulation model for traffic congestion has been developed for the purpose of forecasting the traffic congestion level at a merging point on Penang Bridge in Malaysia. As shown in Figure 3, traffic congestion can be characterized by three factors: the slower speed of vehicles, longer travel times, and increased queuing. To suit this special environment, two algorithms, the fluid-dynamic algorithm and the kinematic wave theory, are combined to create an enhanced algorithm, which provides a better solution for reducing traffic congestion while maintaining traffic flow. This enhanced algorithm is shown in the below formula.

(Traffic flow/mean velocity) + V(1+e) = 0

The enhanced algorithm presents a suitable speed limit for cars to reduce the traffic congestion level at a merging point. The methodology of this simulation is based on the following:

- The first step is the study of the traffic parameters of road merges.
- After the parameters are studied, an observation of the traffic activity at a road merge is carried out to accumulate data on the travel time based on a certain distance, vehicle type, and speed limit.
- When the observation is complete, the enhanced algorithm is applied.
- Then, a dynamic simulation tool for visualizing lane merging is developed. The outputs from the tool include the time duration, travel time of each vehicle, traffic queue length, and the total number of vehicles that passes through the merging point.
- The final step of the methodology includes experiments using the dynamic simulation tool.

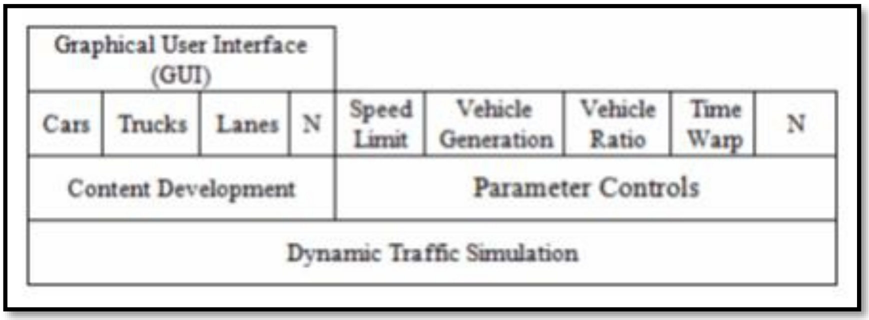


Figure 3: Dynamic traffic simulation framework

Based on the results produced by the dynamic traffic simulation tool with the integration of the enhanced algorithm, 87 km/h is the suggested speed for Penang Bridge traffic. The disadvantage of this enhanced algorithm is that it did not consider road obstacles and road conditions, these may also affect the vehicle traffic flow on the road.

Methodology

Traffic flow models can be grouped into three main categories depending on the level of detail (Adams, 1936; Mearivoet & Moor, 2005): microscopic, mesoscopic, and macroscopic.

At the macroscopic level, we use the analogy of fluid dynamics models, where we have a system of partial differential equations that involves variables, such as density, speed, and the flow rate of the traffic stream with respect to time and space. Macroscopic models can be applied when detailed information about the behavior of a single vehicle is not required, but they offer only a general evaluation of traffic flows in a network. These models are often used for regional transportation planning (Maciejewski, 2010; Papageoriou, Damianou, & Pitsilides, 2009). Therefore, the author believes a macroscopic model is best suited for the project.

Using Google Earth, we determined the road lengths between holy sites (Arafat and Muzdalifah) with the aid of the data collected by the Ministry of Hajj. We found that the camps of the African pilgrims are distributed into three sections, with three connecting roads to each. The following are the road lengths we measured using the Google Earth map:

- From parking to Arafat Camps: 3.749 km
- AF3 Road: 0.711 km
- AF4 Road: 1.076 km
- AF5 Road: 2.325 km
- Roundabout: 0.634 km
- From Arafat to Muzdalifah: 11.626 km

The loading stations are distributed as follows: Road AF3 has seven stations, Road AF4 has nine stations, and Road AF5 has 16 stations.

Figure 4 shows the roads' division. This division or sectioning is done by us, because after each marked point, a decision must be made, as follows:

- At exit/entrance point: enter road AF3 or Section A.
- At the end of Section B: enter road AF4 or Section C.
- At the end of Section D: enter road AF5 or the roundabout.

Below are descriptions of each section of these roads:

- Section A: starts from the Arafat exit point to the AF3 intersection, at a length of 83.132 m.
- Section B: starts from the intersection of road AF3 to the road AF4 entrance, at a length of 286.508 m.
- Section C: starts from the road AF4 entrance to intersection AF4, at a length of 64.324 m.
- Section D: starts from the intersection of road AF4 to the road AF5 entrance, at a length of 179.494 m.
- Roundabout: The roundabout consists of two adjacent line roads. The first one will gather the buses coming from roads AF3 and AF4, while the second will gather the buses coming from road AF5. At a particular point at the end of the roundabout, the two adjacent roundabout lines will combine into one road; this point is marked as intersection F.

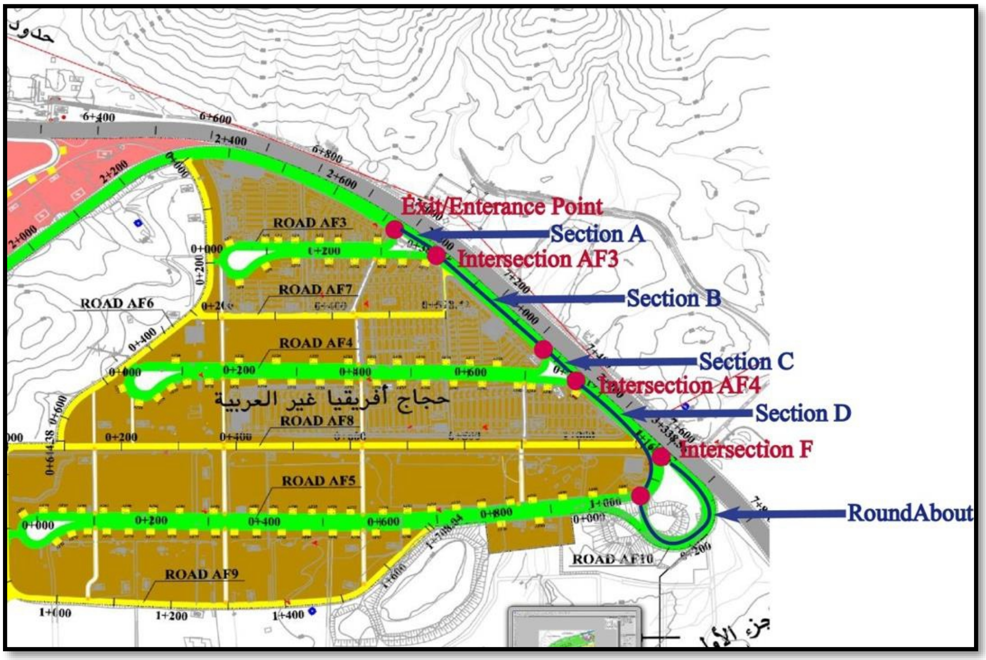


Figure 4: Road divisions at African camps

Shuttle-trip Flowchart

The below flowchart presents the pre-simulation phase, and it shows how the simulator will work in detail.

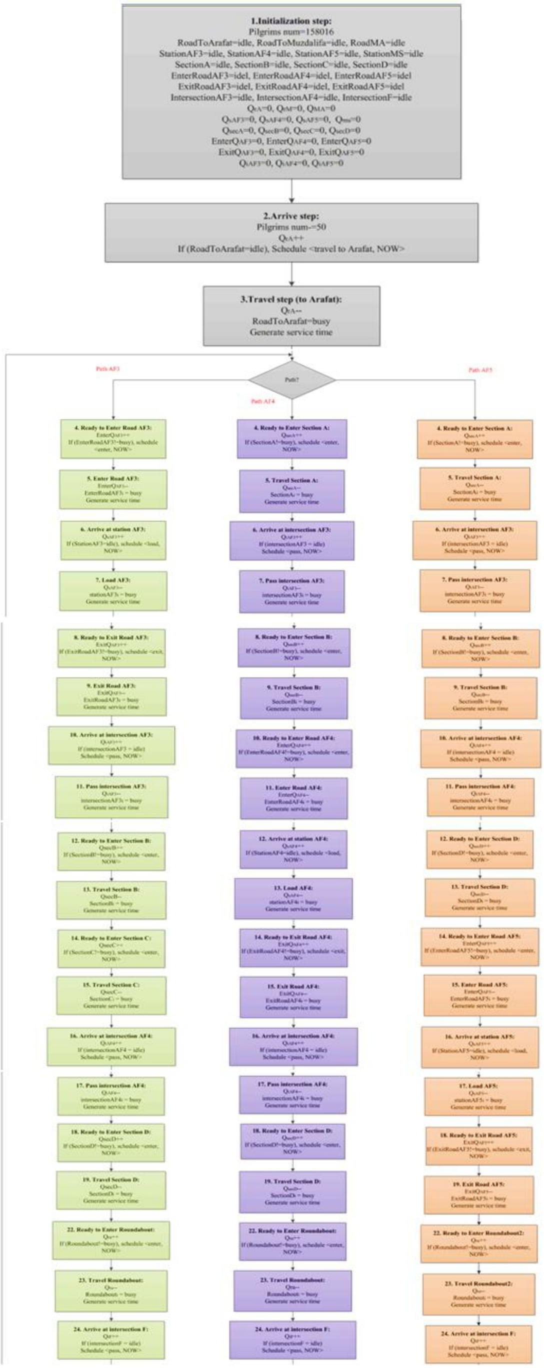
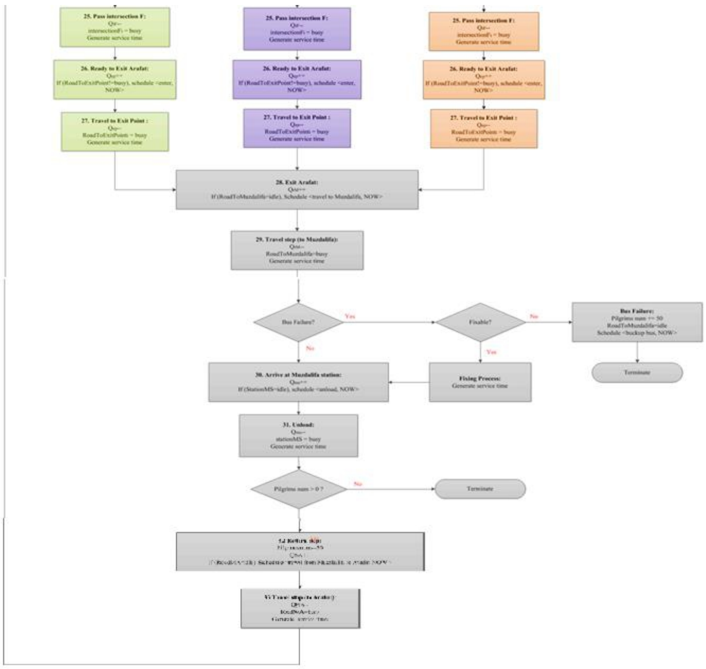


Figure 5: Shuttle-trip flowchart

The following are variable abbreviations, including what they stand for in Figure 5.3:

- RoadMA: Road from Muzdalifah to Arafat.



- StationAF3: The set of load stations of road AF3. A single bus seizes StationAF3$_i$, where "i" is a number between 1 and the maximum capacity of the set (same for the AF4, AF5 stations).
- IntersectionAF3: The intersection at road AF3. A single bus seizes IntersectionAF3$_i$, where "i" is a number between 1 and the maximum capacity of the intersection (same for the AF4, AF5 intersections).
- IntersectionF: The intersection that joins roundabouts 1 and 2. A single bus seizes IntersectionF$_i$, where "i" is a number between 1 and the maximum capacity of the intersection.
- Q_{rA}: Queue of the road from parking to Arafat.
- Q_{rM}: Queue of the road to Muzdalifah.
- Q_{MA}: Queue of the return road from Muzdalifah to Arafat.
- EnterQ_{AF3}: Queue of the road AF3 entrance.
- ExitQ_{AF3}: Queue of the road AF3 exit.
- Qs_{AF3}: Queue of the road AF3 stations.
- Qs_{AF4}: Queue of the road AF4 stations.
- Qs_{AF5}: Queue of the road AF5 stations.
- Q_{ms}: Queue of the Muzdalifah stations.
- Qi_{AF3}: Queue of the road AF3 intersections.
- Qi_{AF4}: Queue of the road AF4 intersections.

- Qi_{AF5}: Queue of the road AF5 intersections.
- Q_{secA}: Queue of section A.
- Q_{secB}: Queue of section B.
- Q_{secC}: Queue of section C.
- Q_{secD}: Queue of section D.
- Q_{ra}: Queue of the roundabouts.
- Q_{iF}: Queue of intersection F.
- Q_{ep}: Queue of the exit point.

Implementation

Here, we describe the steps of implementation in Arena, starting with the non-Arabic African system. The creation process establishes one entity at time zero. The entity then reads from a notepad file that contains the actual arrival times of the entities using the read/write process (found in the advanced processes panel). Next, the bus entity is delayed until the actual arrival time using the "Delay" process. After the delay, the entity is sent to a "Separate" process that duplicates the single created entity; it releases this duplicate entity to the rest of model, while the original entity returns to the read/write process to be duplicated again.

With each entity duplication process, the number of pilgrims is decreased by 50 (the bus capacity). This is implemented in Arena using the "Assign" process.

The normal speed of the buses is 40–60 km/h on the main roads (from parking to Arafat, from Arafat to Muzdalifah, and on the return route to Arafat). For the inner roads in Arafat, the speed limit is normally between 30–50 km/h. Based on the above-mentioned data (speeds and distances), we calculated the transportation time by dividing the distance by speed. We used the triangular distribution to vary the speed on each road. As indicated, the transportation time from Arafat to Muzdalifah, for example, varies from 3.7 min to 5.6 min. The rest of the road transfer time is calculated in the same manner.

After the "Create" process, which is the buses' movement from the parking area, the buses will arrive to the camps in Arafat (at the exit/entrance point). Then, a bus will decide whether to go to the first road (AF3), to the second road (AF4), or to the third road (AF5). We created a two-dimensional array that indicates the path for each entity.

We used two variable indices, "i" and "y," to control the path of each bus. Initially, their values are 0, and because we have only three inner main roads, their values must be between 1 and 3. The "Modulo" function is used when increasing the i or y values using the expression builder. Figures 6 and 7 show the formula used.

The two-dimensional array indices in Arena start from 1 instead of 0. Therefore, we use a condition that converts i or y to 1 if it equals 0.

To simulate the bus choice at each decision-making point, we use the “Decide” process in Arena, which can be either by condition (with an entered expression) or by chance (with an entered percentage). In our case, we implemented the decision by condition according to the buses’ distribution array values.

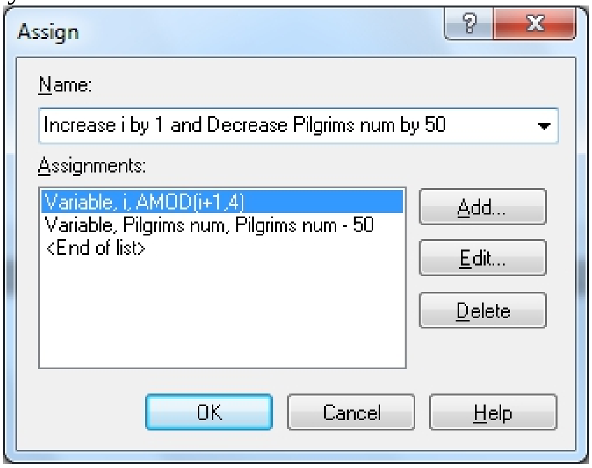


Figure 6: Assign the “i” update function

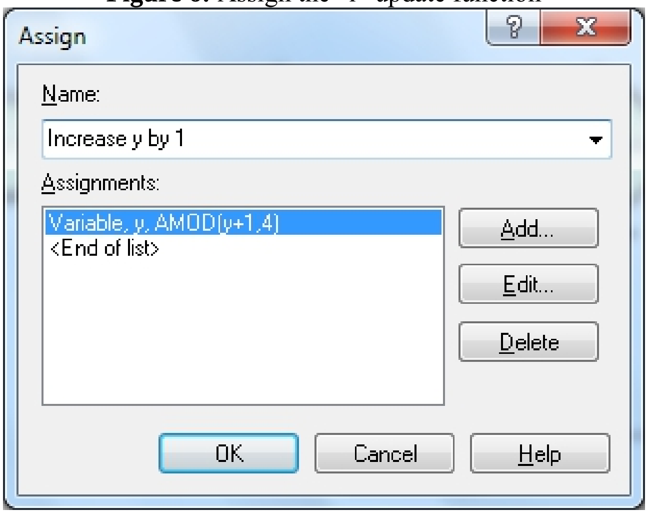


Figure 7: Assign the “y” update function

The process of using the array values is as follows: if the value of variable “Buses_Distribution[i][1]” equals 1, the evaluation check for the condition at the exit/entrance point is true; therefore, the bus will enter road

AF3. Otherwise, if the evaluation is false (the value is not equal to 1), the entity will enter section A.

In the second decision, if the value of the variable "Buses_Distribution[y][2]" equals 1, the evaluation check for the condition at the end of section B is true; therefore, the bus will enter road AF4. Otherwise, if the evaluation is false (the value is not equal to 1), the entity will enter section C, and from there, it will go to road AF5.

The bus that goes to the AF3 stations will first load the pilgrims and then pass intersections AF3 and AF4. The bus that goes to the AF4 stations will first pass intersection AF3, then load the pilgrims, and then pass intersection AF4. The bus that goes to the AF5 stations will pass the AF3 and AF4 intersections, and then it will load the pilgrims.

In each road path figure in our model, there is an indicator (shown in green) that shows whether the resource is idle (green) or busy (red). A counter is also located next to the indicator that tallies the number of passing entities.

As discussed, each road has a different number of stations, and each station has a capacity of two buses. In our model, we created one station on each road with a capacity of 2 time the actual number of stations on that particular road.

After a bus exits Arafat, it will go to Muzdalifah, and the bus will unload the 50 pilgrims (the unload stations are treated as the load stations at Arafat). After the bus is unloaded, the model will check the total number of pilgrims. If it reaches "0," then the entity will terminate. If it is greater than "0," the bus will return to Arafat.

According to the data collected from the Ministry of Hajj, there is a 6% chance that the buses could fail. The probability of the failure being fixable is 50%. If a bus failure occurs and the problem is fixable, then the bus will be delayed for 5–10 minutes. On the other hand, if the bus failure is not fixable, then the number of pilgrims will be increased by 50, and the bus will return to the beginning of its journey to act as a backup bus.

Because the Iranian shuttle-trip system uses the same roads network, we considered the Iranian shuttle in the model by using separate create and dispose models. Between the two, the buses are sent to the "From Parking to Arafat" process, sharing the same resources of the African buses. After arriving in Arafat, the buses are separated by a decide model; the African buses go through the previously explained process, and the Iranian buses go to a single process that includes the expected time of arrival at the load stations, both loading and exiting Arafat. Then, the African and Iranian buses meet at the "Travel to Muzdalifah" process. Next, they break apart during the unloading process to meet again at the "Return to Arafat" process. Figure 8 shows the fully created Arena model.

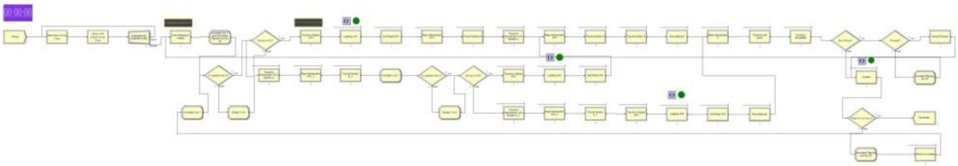


Figure 8: Arena model

Results

From the first run of the model, the following results were identified:

- Run time is 7.66 hours.
- Entity average wait time is 0.057 hours (3.42 minutes).
- The wait time at the road AF3 stations is the longest.
- The instantaneous utilization of the load stations is the largest comparing to other processes.

For a more optimized system, we should focus on increasing the level of utilization at the load/unload stations and the intersections. This is because they have the lowest capacity among the system's resources. If we try to maximize the use of the highways, it will lead to congestion on the inner roads of Arafat. We tested multiple combinations of speed limits to try to figure out the best, taking into consideration the safety of passengers. A speed limit on the highways between 55 and 65 km/h is better. It is still safe, and it improves the system's performance by 6%, which translates to almost half an hour decrease in run time. The updated findings are as follows:

- Run time is 7.27 hours.
- Average entity wait time is 0.048 hours (0.5 minutes less than before).
- Resources are more instantaneously utilized.

Other scenarios tested include changing the distribution policy. Instead of distributing the buses equally among the three roads (AF3, AF4, and AF5), we tried a 1-2-2 method, where the first bus enters AF3, the second and third enter AF4, and the fourth and fifth enter AF5, and this repeat. This policy decreased the waiting time at AF3 stations by 9%.

Conclusion

This paper produces fully functional software that simulates the non-Arabic African shuttle-trip system from Arafat to Muzdalifah to optimize the current system's performance.

We tested the model's validity, and we measured the error rate, which was 4.5%. Then, we tested different scenarios and from the run results, we can recommend the following:

- The upper speed limit should be 65 km/h and the lower limit 55 km/h.
- AF3 stations is the busiest resource; therefore, bus scheduling should consider widening the time gap between the arriving buses to avoid crowding.

Acknowledgment

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