# EVALUATING TRAFFIC STREAM MODELS FOR NAFRAH USING SIMULATION

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## ABSTRACT

*Moving millions of pilgrims from Arafat to Muzdalifah in six hours presents a unique and extraordinary challenge in terms of management of the traffic. Traffic simulation models are widely used in planning, design, and operations of transportation systems. These simulation models require an adequate traffic stream model that relates traffic speed, traffic density, and traffic flow. In the literature there are several traffic stream models that can be embedded within simulation models. Traffic at Nafrah is unique in its characteristics. The purpose of this paper is to test several traffic stream models and select the most appropriate one to use in the simulation of traffic flow at Nafrah period. The selection is based on the validity of the traffic stream model in representing the real traffic flow at Nafrah. The results indicated that the piecewise linear model is the most appropriate model to use in the simulation model.*

**Keywords:** *Traffic stream models, simulation, shuttle bus, Hajj, Nafrah.*

## الملخص

تمثل مسألة نقل ملايين الحجاج خلال النفرة من عرفات إلى مزدلفة تحدياً فريداً فيما يتعلق بإدارة النقل. تستخدم نماذج المحاكاة في تخطيط وتصميم أنظمة النقل. تحتاج هذه النماذج إلى تعريف علاقة رياضية تربط بين عناصر الحركة والتي هي السرعة والكثافة المرورية والحجم المروري. يهدف هذا البحث لاختبار عدة نماذج رياضية لتمثيل عناصر الحركة. ومن ثم اختيار النموذج الرياضي الأنسب لمسالة النقل خلال النفرة حيث تم الاختيار بناءً على مقدرة وصحة النموذج على تمثيل الانسياب المروري خلال النفرة ودلت النتائج أن نموذج العلاقة الخطية المعرف مقطعياً هو الأفضل في تمثيل انسياب المرور خلال النفرة.

## 1. INTRODUCTION

Hajj involves one of the world's largest mass movements. Over two million pilgrims converge every year at the same time to perform this religious duty. The result is a crowded event of extraordinary magnitude leading to uniquely challenging problems. One of the challenging problems during Hajj is the management of the traffic during Nafrah period. Nafrah is defined as the movement of pilgrims from Arafat to Mina through Muzdalifah from sunset of the ninth day of the tenth month of the lunar year till the dawn of the tenth day. It is required to safely evacuate all pilgrims from Arafat to Mina in minimum amount of time which should not exceed the Nafrah period. This problem has important religious, spatial, and time constraints. Traffic simulation models are widely used in planning, design, and operations of transportation systems. [AlGdhi, 1999] developed a microscopic simulation model to assess the impact of dedicating some of the Nafrah highways to the shuttle bus system.[Ramadhan and Abdah, 2002] used Arena simulation software to assess the use of shuttle train to transport pilgrims between Arafat and Muzdalifah. [Andijani et al., 2002] developed a simulation model for bus scheduling and routing during Nafrah period. [Andijani et al., 2001] developed a simulation model for the shuttle bus traffic during Nafrah. In the developed simulation model the authors used a linear traffic stream model to determine the number of bus stops and fleet size to be used. The purpose of this paper is to test several traffic stream models and select the most appropriate one to be used in the simulation model. Next section of describes the Nafrah traffic problem and the use of shuttle bus. Third section presents the development of the simulation model using Promodel and testing three traffic stream models. A sample application of the simulation model to determine the bus management policy that can achieve the best performance measures values for the shuttle bus is presented in the forth section. Finally, conclusions are outlined in section five.

## 2. NAFRAH TRANSPORT PROBLEM

The problem of moving the pilgrims during Nafrah period has time and space constraints. The Nafrah time constraint requires that all pilgrims start to move from Arafat at the sunset of the ninth day of the twelfth month of the Islamic lunar year, and must be in Muzdalifah before the dawn of the tenth day. The space constraint consists of Arafat, Muzdalifah, and the road network. The holy sites of Arafat, Muzdalifah are geographically limited. Arafat is connected to Muzdalifah (8 km to the west) by 9 highways. The problem under consideration is to transport the pilgrims during Nafrah period within the required time and in a safe manner with minimum congestion by utilizing the exiting road and parking network under the above constraints.

The shuttle bus operational strategy was experimented in Hajj transportation system, for the first time in 1416H. In that year a total of 117000 pilgrims were transported along an exclusive 2-lane bus way (road number nine) using only 520 buses shuttling between Arafat and Muzdalifah. Compared to the conventional Hajj transportation system, the shuttle bus system resulted in much less average travel times (20 min vs. 195 min) and smaller bus fleet size (520 buses vs. 1270 buses) [Elbar et al., 1999]. In addition, the use of shuttle bus reduces the transport cost and air pollution [Elbar et al., 1999]. Being encouraged by the success of this experiment, the shuttle bus operational strategy was used in the following years to transport Turkish pilgrims along the road number nine.

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## 3. NAFRAH SHUTTLE BUS TRAFFIC MODELING

We develop a conceptual model to present the shuttle bus system as implemented in 1416H. The conceptual model is a traffic model that represents the flow of buses shuttling between Arafat and Muzdalifah. The shuttling buses are responsible of transporting the pilgrims from Arafat to Muzdalifah. All the buses are under the control of ministry of Hajj and the service organization (Moesssasat Attwafah). The pilgrims are located at Arafat according to the ministry of Hajj plan. Enough space is assigned outside legal boundaries of Arafat to be used as a center and store for the buses. Bus stops (with suitable gates) are constructed on the roads' shoulders, at Arafat and Muzdalifah. The main elements of the conceptual model are bus management in Arafat, road traffic modelling, and bus management in Muzdalifah. The most important performance measures that can be used to assess any different alternatives for Nafrah transport system are evacuation time, average travel time, and congestion level. The evacuation time is defined as elapsed time between start of Nafrah and the time by which the last pilgrim reaches Muzdalifah. This measure will reflect the success in evacuating the pilgrims within the required time.

### 3.1 Traffic Stream Models

Traffic flow theory seeks to describe in precise way the relations among traffic stream characteristics. The traffic stream characteristics include speed, traffic density, and traffic flow. Several mathematical models describing the speed-flow-density are found in the literature [Roess et al., 1998]. In this work we used and tested three different stream models. Each of the tested models is briefly presented below.

**1. Greenshield's model**

Greenshields proposed the linear model

$$u = u_f - \left(\frac{u_f}{k_f}\right)k$$

Where u is speed, $u_f$ is free flow speed (maximum speed), k is density, $k_f$ is jam density.

**2. Edies two-regime model**

Edies two-regime model is a hypothesized model that uses Greenberg's logarithmic model for high densities and Underwood's exponential model for low densities [Roess et al., 1998]. Edies two-regime model is of the following form:

$$u = \begin{cases} 54.9e^{-k/163.9} & (k \le 50) \\ 26.8\ln\left(\dfrac{162.5}{k}\right) & (k \ge 50) \end{cases}$$

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## 3. Piecewise linear model

The simulation group at KFUPM proposed a piecewise linear model to approximately depict the non-linear relationships between the traffic stream characteristics using simple equations [Andijani et al., 2002]. The proposed model takes the form:

$$u = \begin{cases} 70 - k & (k \le 10) \\ 60 - 0.5(k - 10) & (10 < k \le 20) \\ 55 - 0.38(k - 20) & (20 < k \le 33) \\ 50 - 0.59(k - 33) & (33 < k \le 50) \\ 40 - 0.9(k - 50) & (50 < k) \end{cases}$$

## 3.2 Simulation Model

The conceptual model is developed into a simulation model and implementation using logistics features of ProModel simulator. Since ProModel assumes a simple type of traffic, additional user defined logic elements are introduced to the simulator to satisfy the specific requirements of a traffic model. Each road is assumed to have two lanes, each lane has some bus stops in Arafat and Muzdalifah. Each bus is assumed to be 12 meters long, 2.75 meters wide, and with 50 passengers occupancy. The simulation model is basically based on the shuttle bus operational strategy experienced in 1416 H.

Road nine is represented in ProModel as a set of path segments and nodes. Path segments and nodes are used to make up a particular path network. Each path segment is assigned a distance in order to measure the vehicles travel time on the path network. Path nodes mark the end points of the path segments. They also mark the points along a path network where resources (buses) can interface with a location. Nodes are also used to control the bus traffic through the use of node logic or search routines such as work and park searches. Path nodes have a limit on the number of resources in route to the node. This determines the road capacity. Multiple segments may share the same path node to represent intersections. In order to represent the road capacity each lane is broken into several subsections. The node limits for each subsection is used to define the capacity of that subsection. Service offices and bus stops are represented as locations and assigned capacities that determine the number of pilgrims that the location can hold at any one time. Pilgrims arriving at each service office are routed to three bus stops. Bus sops are located on both sides of the road connected to the road nodes via interface elements. Buses are represented as dynamic resources. In ProModel dynamic resources are elements that move along an assigned path network. Dynamic resources may escort or transport entities between locations, such as a bus moving pilgrims from Arafat to Muzdalifah.

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## 4. TESTING THE TRAFFIC STREAM MODEL

To test the traffic stream models presented in section 3.1 we run the simulation using data from the season of 1416 H. The simulation run is replicated 100 times to generate reliable estimate for the average evacuation time in hours for the different traffic stream models. The results are summarised in Table 1 below. Figures 1 through 3 depict the traffic diagrams generated by the simulation model when we use the piecewise traffic stream model. From Table 1 it can be seen that both Greenshield's model and piecewise linear model are resulting in acceptable deviation of simulated evacuation times from the observed one. Therefore both stream models can be considered valid for the shuttle bus traffic simulation model. However piecewise linear model is the most appropriate since it resulted in less deviation from the observed value for the evacuation time.

**Table 1**. Nafrah evacuation times resulting from use of the three stream models

| The model | Average evacuation time in hrs. | Standard deviation. | %Deviation from the observed value |
|---|---|---|---|
| Greenshield's model | 5.71 | 0.16 | 0.98 |
| Two-regime model | 4.61 | - | 18.84 |
| Piecewise linear model | 5.686 | 0.02 | 0.005 |

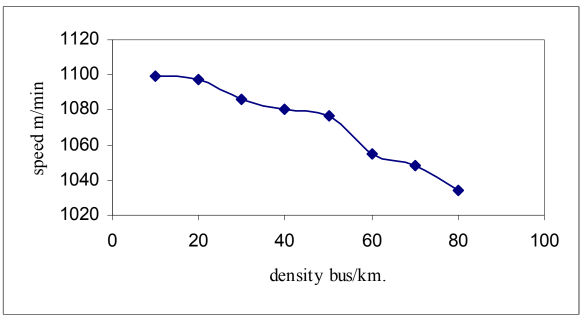


**Figure 1**. The traffic density –speed relation as generated using the piecewise traffic stream model.

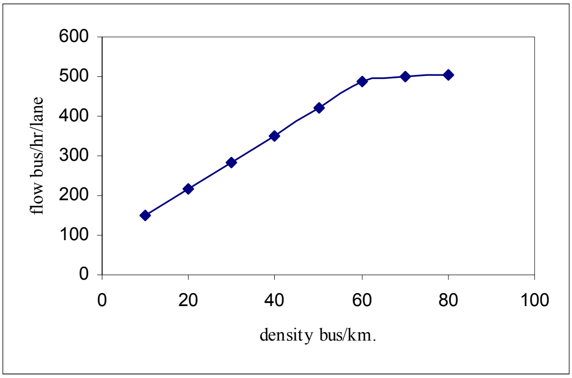


**Figure 2**. The traffic density–flow relation as generated using the piecewise traffic stream model.

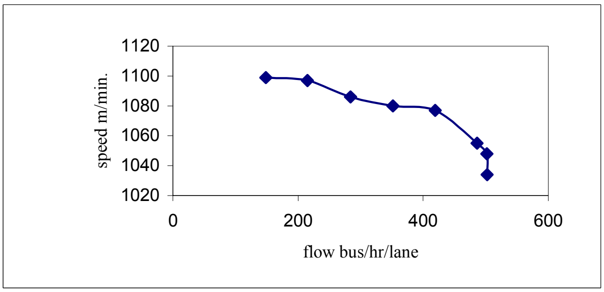


**Figure 3**. The fundamental traffic flow–speed relation as generated using the piecewise traffic stream model.

## 5. CONCLUSIONS

In the recent years, traffic simulation has become one of the most widely used and powerful tools for the analysis and assessment of the transportation systems. These traffic simulation models require an adequate traffic stream model that relates traffic speed, traffic density, and traffic flow. This study is focused on the selection of the traffic stream model to be used in a simulation for the traffic flow at Nafrah. The results indicated that the piecewise linear model is the most appropriate traffic stream model that can be used in the simulation model.

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