A SIMULATION MODEL
FOR GOLDEN WEST SHUTTLE SERVICE

by

Fines H. Munkonze

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Golden, Colorado

Date 4/9/92

Signed: [signature]

Fines H. Munkonze

Approved: [signature]

Dr. Ruth A. Maurer
Thesis Advisor

Golden, Colorado

Date 9 April 1992

[signature]

Dr. Ardel J. Boes
Professor and Head,
Department of Mathematical
and Computer Sciences

ABSTRACT

In this thesis, a simulation model was developed for Golden West Shuttle Service, in Colorado, to determine the utilization of the vans. Some sensitivity analysis was done on passenger volume to determine how changes in passenger volume affect the utilization of vans. Also, an attempt was made to determine the minimum number of vans for each route that minimize maximum passenger delay. This was done by varying the number of vans for each route and evaluating the performance of each resulting scenario on the basis of such measures of performance as the passenger delay and the queue length of passengers waiting for service. The option that minimized the risk of passenger delay involved using four (4) vans for each route. Hence, four vans were recommended for each route.

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CHAPTER 1

PROBLEM STATEMENT AND OBJECTIVES OF STUDY

1.0 Introduction

Air pollution and smog problems in the Denver region (in Colorado), coupled with congested highways and limited parking space, dictated the need for mass transportation that was tailored to the needs of the traveler.

Golden West Airport Shuttle Inc. was incorporated in 1980 with the express purpose of transporting travelers in the suburban areas of Golden, Lakewood and Wheatridge to and from the Stapleton International Airport. This company provides a high level of service by utilizing a shared ride door-to-door service concept as an alternative to taxicabs and private automobiles.

It was not until the introduction of gambling in Central City that the shuttle service was extended to include Central City. This inclusion of Central City in the service area meant a rise in passenger volume which dictated the need to add more vans to the fleet to handle this increase in demand for service.

There are currently two distinct routes that are serviced by Golden West Shuttle. These are :

(a) the **Stapleton Airport** route, providing service to and from Stapleton airport, and

(b) the **Central City** route that provides service to and from Central City.

Both routes serve the same area mentioned above.

The majority of the passengers going to and coming from Central City are employees, constituting about 66 % of the passengers, and players.

The shuttle service to both Central City and Stapleton Airport is, for the most part, based on reservations.

The trips from the airport are scheduled every thirty (30) minutes irrespective of the number of passengers. This way, there is almost always one van at each end of the airport route, thereby avoiding a situation in which all vans dedicated to the route are heaped in one location.

Trips from Central City, on the other hand, are usually triggered by the presence of passengers either at Central City who wish to go to other locations of the service area, or passengers at locations other than Central City who wish to go to Central City.

The minimum number of passengers required in order to release a van is one (passenger), a requirement by the Public Utilities Commission (PUC). This is essential to gaining passengers' confidence in the company in an effort to build business. The policy also gives the company a competitive edge over existing or prospective competitors.

Golden West Shuttle currently operates a fleet of thirteen (13) vans. Five vans are assigned to the Central City route, while the rest are dedicated to the airport route. Only four of the vans assigned to Central City are running at any given point in time, while the fifth one may be available for charter or for dealing with a sudden rise in demand for shuttle service. Similarly, only five of the vans assigned to the airport route are available while the rest are available to be chartered or to deal with sudden rise in demand for service.

This thesis was, for the most part, motivated by the need for Golden West to upgrade the existing fleet, an action that was necessitated by

(a) the inclusion of Central City in the service area to handle the gambling business, and

(b) the anticipated rise in passenger volume resulting from the planned extension of the service area to the suburbs of Arvada and South-West Lakewood, and the prospects of the new Denver International Airport which is currently under construction.

The issues that were to be addressed involved

(a) determining the appropriate number of vans to be added,

(b) investigating the impact of a rise in passenger volume on the fleet size, and

(c) estimating a near optimal fleet size to handle the anticipated rise in passenger volume subject to minimal passenger delay.

The number of passengers requiring transport to Central City or Stapleton Airport cannot be predicted with certainty, and in fact changes from time to time, and from one service point to the other. The same can be said about the time required to complete a trip. Trip times vary with the number of service points that a van goes through before reaching its final destination, and also depends on weather conditions. The stochastic nature of these components of the shuttle service renders the use of deterministic models inappropriate as a tool to tackle the issues mentioned above. A method to study and experiment with such a stochastic system, without requiring many simplifying assumptions, was required to solve this problem. Simulation methods meet the two criteria above, and can also be used to solve the problem even with sketchy input data. It was for this reason that simulation analysis was used to solve the problem.

1.1 Problem Statement

This thesis involves the simulation of the Golden West Shuttle Service, which transports travelers to and from the suburban areas of Golden, Lakewood, Wheatridge, and Central City, and to and from Stapleton International Airport, including major hotels and office parks in the service area.

1.2 Objectives Of Study

The objectives of the study are :

(a) to determine the average utilization of the current fleet of vans,

(b) to investigate the impact of a rise in passenger volume by 10 % on the current fleet of vans.

(c) to determine the minimum fleet size that maximizes van utilization subject to minimal passenger delays.

1.3 Overview

This thesis consists of four chapters and the rest of it is organized in the following manner.

Chapter 2 gives a review of related work that exists in literature. For each paper reviewed, a brief outline is given, laying more emphasis on the problem definition, objectives of study, and the methods used to solve the problem. Brief comments are given on the methods used to solve the given problems.

Chapter 3 discusses the simulation model that was developed to solve the problem. Entities, attributes, and events of the system being modeled are described. Data input and its analysis, parameter estimation of probability distributions to model number of passengers per hour and service time, goodness of fit tests, and design of experiments are also given in this chapter.

Chapter 4 presents the results, recommendations, and topics for further study. An outline of a typical summary report is given with specific focus on such statistics as the average van utilization, average time in system for a passenger, and the average number of passengers in the system. The percentage utilization of the vans is obtained by dividing the average van utilization by the total number of vans available, and then multiplying the quotient by 100.

The appendix contains the data for all the scenarios that were simulated. A graphical representation of the model is also given in the appendix.

CHAPTER 2

LITERATURE REVIEW

Simulation analysis is becoming one of the most widely used and acceptable tools in operations research and systems analysis (Jerry Banks & John S. Carson, II 1984). This trend may be attributed to the availability of

(a) special-purpose simulation languages, and

(b) the ever more powerful computers.

In addition, many of the well known simulation languages now run on the microcomputers, and have very elaborate graphics and animation capabilities. These capabilities have greatly increased the popularity of the PC-based simulation languages (Bernard J. Schroer 1989).

The advantages of simulation analysis lie in its versatility as a tool of analysis as it permits :

(a) the evaluation of operating performance prior to the implementation of the system,

(b) the comparison of various operational alternatives without perturbing the real system, and

(c) time compression so that timely policy decisions can be made.

Thus, simulation modeling can be used both as an analytical tool for predicting the effect of changes to the existing systems and as a design tool to predict the performance of new systems under varying sets of circumstances. This explains, at least in part, why simulation has been used successfully in modeling manufacturing, inventory and transport systems, nuclear facilities and even sports events such as the Bolder-Boulder race (Interfaces, Mar-Apr 1989).

A considerable amount of related work has been done and given below is a review of some of the work that has already been done. For each paper reviewed, a comment is made on how it relates to the problem being solved in this thesis.

William W. Williams and Oscar S. Fowler (1980), tackled the problem of determining minimum cost fleet size for the University of Tennesse motor pool using simulation analysis. The two authors investigated the cost effectiveness of the motor pool's operations, with a specific focus on the size and composition of the dispatch fleet. The model that was developed consisted of a fleet simulator, the output of which was used as input to the analytical cost model. A total of fifteen (15) years of simulated experience was generated for each alternative fleet size, with each simulation run comprising one year of system activity.

Identical streams of random numbers were employed between runs of each fleet configuration in order to minimize the introduction of random variance. Structural validity of the model was assessed via regression analysis of simulated outputs on actual data and testing for statistically significant differences. The simulation-generated output was found to be consistent with the actual data.

The common issue being tackled is that of determining the appropriate fleet size. The problem being addressed in this thesis forms only a part of the problem discussed by the two authors in the sense that they take a further step of determining the composition of the dispatch fleet, and evaluating its cost effectiveness. The analytical cost model was used to accomplish this additional step.

S. C. Parikh (1977) described a quick, approximate method for solving a fleet sizing and allocation problem for a company that had a large number of transport vehicle units

(TVUs) nationwide, divided up into self-contained units, each unit servicing its own group of customers. The fleet sizing problem involved determining the number of transport vehicle units that a particular fleet should have when the arrival pattern and shipping times of the customer orders were known in probabilistic terms, in order that no more than a fraction, α, of the arriving orders faced any delay. In the TVU allocation problem, the model for analyzing the fleet sizing problem for each fleet was employed to determine the allocations of the total available TVUs to various fleets so that a uniform level of service was provided by all fleets.

Historical data was tested and arrivals were found to be approximately Poisson distributed, but the service times were significantly different from the exponential distribution. This meant that the standard M/M/C model, for which a direct algebraic formula is available for calculating the delay probability, could not be used.

Analysis at several fleet locations showed that the service times could be reasonably be modeled by a member of the k-Erlang family of distributions with the shape parameter k ranging from 6 to 12, so that the appropriate model was $M/E_k/C$. The behavior of the $M/E_k/C$ model can be bounded by the behavior of some other models, notably, the M/D/C and M/M/C models. We, thus, have

$$CD < CE_k < CM \qquad (2.1)$$

where CD, CE_k, and CM are the optimal service facility sizes for a given threshold delay probability α, and for the assumed queueing models of M/D/C, $M/E_k/C$, and M/M/C, respectively. The actual choice of the number of servers would depend on how close the service time distribution is to the exponential distribution. Thus, a value closer to CM would be chosen if the parameter k of service time distributions were small (or close to 1), and a value closer to CG would be chosen if the parameter k were large.

The common problem in this case is that of determining fleet size. Parikh solves the problem by bounding the behavior of the $M/E_k/C$ model by the behavior of the M/D/C and M/M/C models, which are mathematically more tractable than the $M/E_k/C$ model. On the other hand, the system being modeled in this thesis can be viewed as a D/T/C model, the behavior of which may not be bounded by the behavior of the M/D/C and M/M/C models. (T denotes triangularly distributed service times). The main difference in the formulation emanates from the fact that a delay is allowed, with the restriction that no more than a fraction, α, of the arriving orders are delayed, whereas no delay is allowed in the case of the Golden West problem (a van is released as long as there is at least one passenger waiting to be picked up).

A. Lavindran, B. L. Foote, A. B. Badiru, L. M. Leemis, and Larry Williams (1989), developed a large simulation model (in SLAM) that facilitated the analysis and efficient design of the modular repair center (MRC) layout which replaced the previous machine-based layout in the engine overhaul facility. A prime use of the simulation model was to determine the appropriate number of machines of a particular type needed in each repair center. The objective was to have 95 % availability for each machine. To determine the smallest number of machines needed to provide 95 % availability, they first ran the simulation assuming ample machine capacity so that there was no queueing at the repair center. The resulting utilization statistics for the case of ample capacity were used to determine the minimum number of machines necessary for the 95 percent availability.

The common problem consists in determining the appropriate number of machines, which is analogous to determining the appropriate number of vans for the efficient operation of the shuttle service. It should be noted that Lavindran, et al, do not describe how they used these utilization statistics (for the case of ample capacity) to determine the minimum number of machines needed in a repair center nor is there is a mention of how many runs were conducted for the ample capacity scenario. The latter implies that a reader will not have an idea of how reliable the utilization statistics were for use in determining the appropriate number of machines required for a repair center. (Interfaces, Jan-Feb 1989).

Deepak Bammi (1990) developed a simulation model (in GPSS) to determine whether pipe for the Northern Border Pipeline could be delivered within the planned nine months. The project also considered the arrival of pipe from abroad, construction of pipe in domestic factories, train transportation including breakdowns, barge transportation, unloading pipe, inspection, and subsequent welding. By varying the number of trains in the model, and calculating (and comparing) the number of days it would take to complete the project in each case, the author found that using 1,358 cars took 260 days to complete the project. This analysis led to a 20 % reduction in rail cars needed to transport the pipe which in turn resulted in savings of over $4m in rail car hiring costs.

The common problem lies in determining the number of rail cars required to complete the project within nine months, which corresponds to determining the fleet size of the vans required for the shuttle service. Bammi does not mention how many runs were made for each scenario corresponding to the number of rail cars employed in the model nor does he say anything about having made any efforts to validate the model. (Interfaces, May-June 1990).

CHAPTER 3

SIMULATION MODEL

3.0 Introduction

The simulation model for Golden West was built in SLAM, and consists of two sub-models: one for each route. It is based on a time unit of one hour. The entities are the groups of passengers waiting for service at various service points, and the servers are the vans that are used to ferry passengers to their respective destinations. There are basically two types of events: passenger arrivals to the system, and passenger departures from the system. SLAM uses a vector scheme to keep track of the various characteristics, called attributes, of the entities. Attribute 1 is stored in the first column of the vector. The attributes are the characteristics of the passengers that we would like to keep track of. These include the time of creation (stored in attribute 1), the number of passengers during the given hour (stored in attribute 2), and the duration of the service activity (stored in attribute 3). Of these attributes, the last two cannot be predicted with certainty. The number of passengers at any given service point varies from time to time, depending on need to travel. Also, the time it takes a van to get from one point to the other is stochastic in nature. Weather conditions (e.g. snow on highways), heavy traffic, and traffic lights are only some of the factors that induce this variability in travel time. In addition, not all passengers make reservations before they travel and this renders the system even more stochastic.

3.1 The Network Model

The SLAM graphical representation of the model is as given on page 18. The nodes and the characteristics of the system that they model are discussed below.

3.1.1 Modeling Trips Using the CREATE node.

The CREATE node is used to generate entities and route them into the system over activities that emanate from the CREATE node. The time at which an entity is created may be assigned to some attribute of the entity.

The ASSIGN node is used to prescribe appropriate values to the attributes of an entity passing through the ASSIGN node.

The portion of the network that is meant to model the arrival of passengers for each trip is given below.

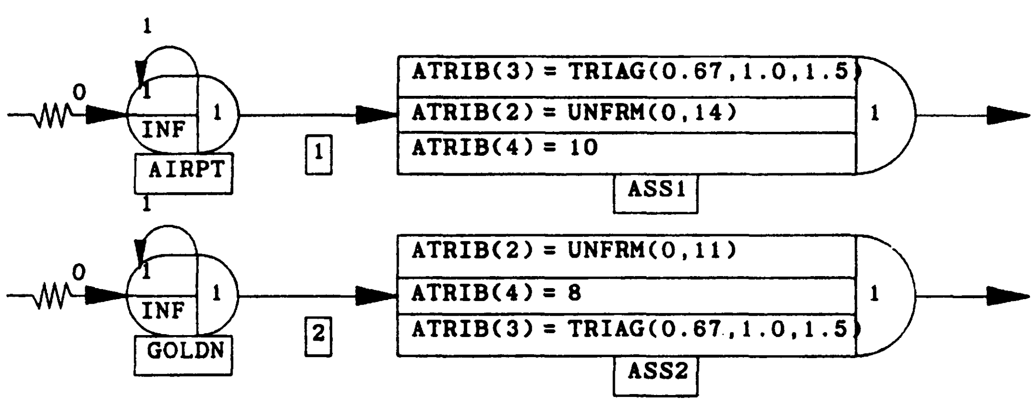

FIGURE 3.1.1(a) : TRIPS TO AND FROM STAPLETON AIRPORT

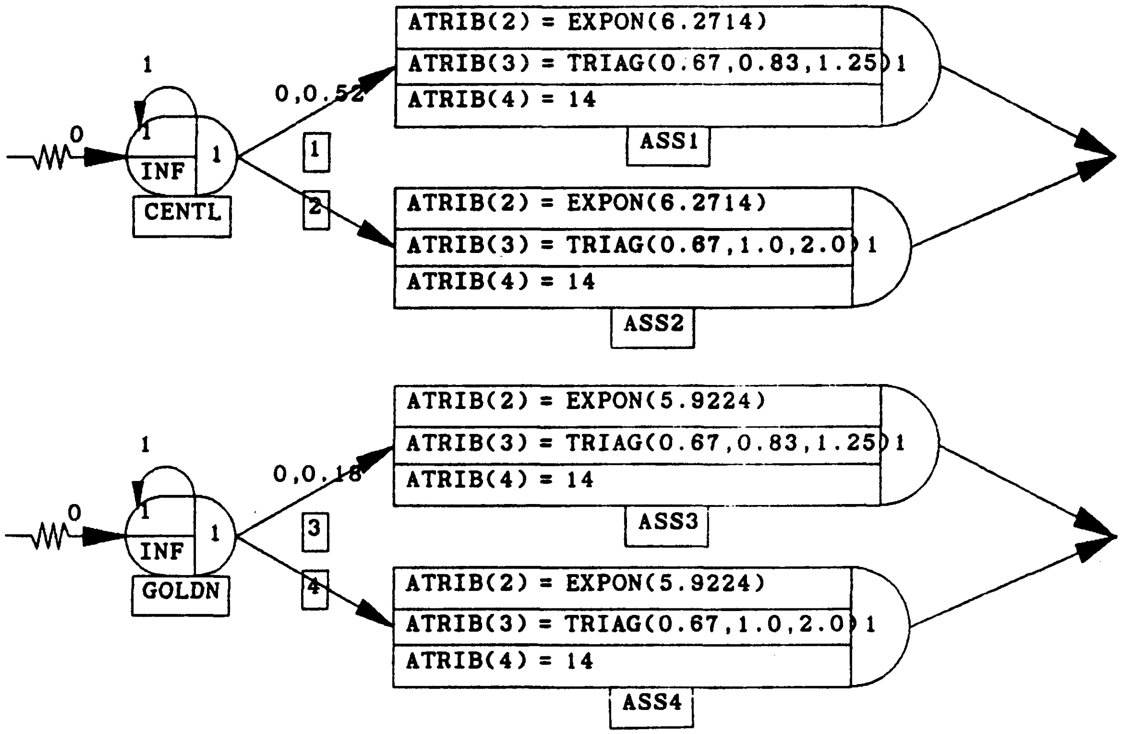

FIGURE 3.1.1(b) : TRIPS TO AND FROM CENTRAL CITY

In this model, each trip is modeled by the creation of entities, representing groups of passengers, at a CREATE node. The time at which an entity is created is stored in attribute 1, ATRIB(1). For instance, trips to the airport (and the times at which passengers arrive to the system) are modeled by the creation of entities at the CREATE node labeled AIRPT, while trips from the airport are modeled by the creation of entities at the CREATE node labeled GOLDN.

For the trips to the airport, the number of passengers that an entity represents and the time it takes to complete a trip are stored into atributes 2 and 3, respectively at the ASSIGN node labeled ASS1.

3.1.2 Modeling Release of Vans Using EVENT and BATCH nodes.

The EVENT node provides an interface between the network portion of the model and the event coding that is written by the modeler. This is especially useful when a modeler is faced with an operation for which a standard network node is not provided. In such cases, the modeler can use the EVENT node to perform the specialized logic required.

The BATCH node is used to accumulate entities to a specified level and to release a single entity which represents the batch. An entity is released from the BATCH node as soon as the sum of attribute 2 of all entities in the BATCH node reaches the threshold value.

The portion of the network that is meant to model the release of vans is given below.

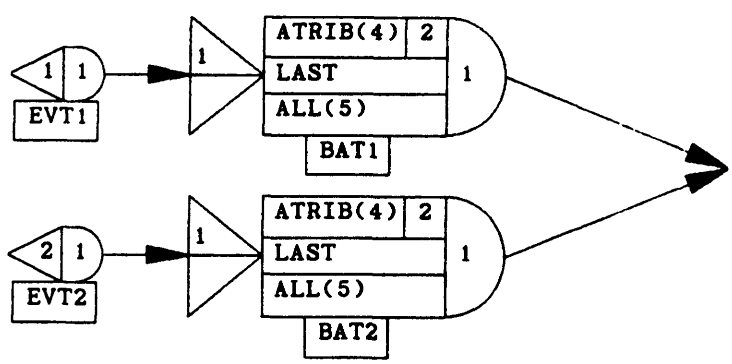

FIGURE 3.1.2(a) : RELEASE OF VANS FOR THE AIRPORT ROUTE.

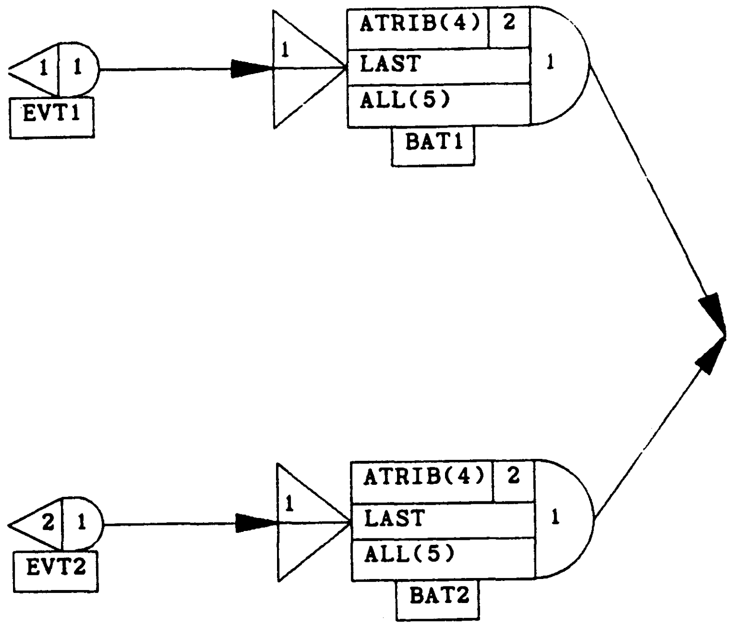

FIGURE 3.1.2(b) : RELEASE OF VANS FOR THE CENTRAL CITY ROUTE.

In the model, the EVENT node and the BATCH node are used to model the release of vans when there are passengers in the system. The release of vans is controlled by the assignment of appropriate values to attibute 4 at an EVENT node, where user inserts (in Fortran) are used to implement the logic associated with the EVENT node.

3.1.3 Modeling Time in System Using the QUEUE, COLCT, and TERMINATE Node.

The QUEUE node is a location in the network where entities wait for service. The disposition of an entity arriving at a QUEUE node depends on the status of the servers that follow the QUEUE node. An entity immewdiately goes into the service activity if there is at least one idle server. Otherwise, the entity waits until a server becomes available, in which case the entity will automatically be taken out of the queue and the service will be initiated.

The COLCT (read as collect) node is used to collect statistics such as the time between arrivals of entities at the COLCT node, and the time interval between the time at which an entity was created and the time at which the entity arrived at the COLCT node.

The TERMINATE node is used to destroy or delete entities from the network. It can also be used to specify the number of entities to be processed in a simulation run.

The portion of the network that models passengers waiting for a van is given below.

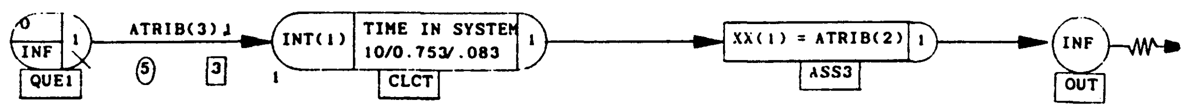

FIGURE 3.1.3(a) : PASSENGERS WAITING FOR VANS - AIRPORT ROUTE.

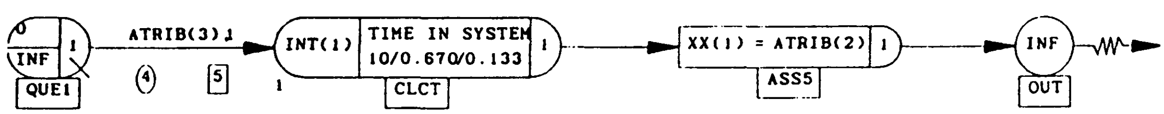

FIGURE 3.1.3(b) : PASSENGERS WAITING FOR VANS - CENTRAL CITY ROUTE.

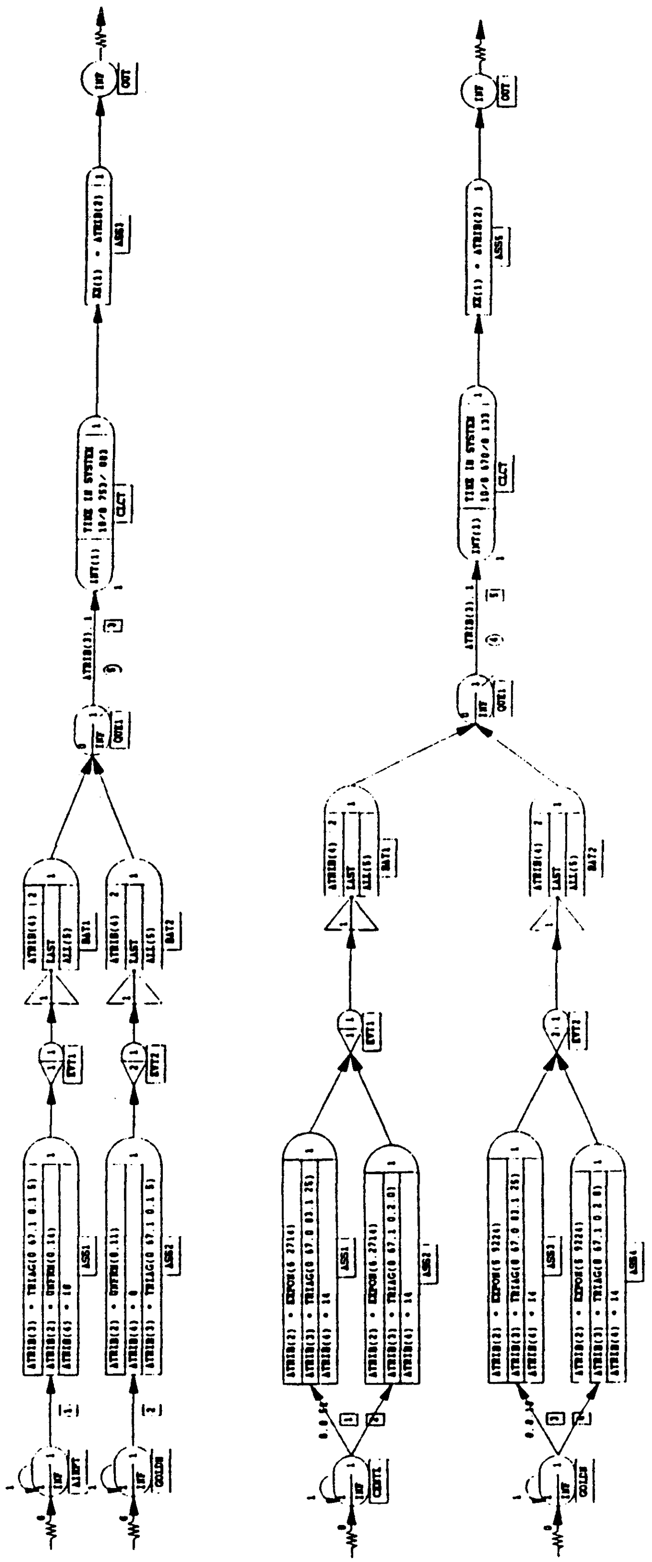

FIGURE 3.1.4 : THE ENTIRE NETWORK MODEL.

In the simulation model, the QUEUE node (labeled QUE1) is used to model passengers waiting for a van. If there is a van available when passengers arrive to the system, the van is immediately released to ferry these passengers to their respective destinations. Otherwise, they wait until there is a van available.

The time it takes a van to complete a trip is a value stored in attribute 3, ATRIB(3). This is in fact a value sampled from an appropriate probability distribution. See ASSIGN node discussed above.

The time that a passenger spends in the system is the time interval between the time at which the passenger was to be picked (time of creation in SLAM jargon) and the time at which the passenger reached his or her final destination. This statistic is calculated for each entity that arrives at the COLCT node and the average time in system is computed at the end of the simulation run.

The TERMINATE node is used to model the departure of passengers from the system. Passengers depart from the system as soon as they reach their destinations. This is modeled by the deletion of entities from the network at the TERMINATE node.

The number of passengers for each trip is maintained in a time persistent global variable, XX(1). This is done for each entity arriving at the ASSIGN node, following the COLCT node. The average number of passengers per trip is calculated at the end of each simulation run.

3.2 Data Input and Analysis

The data that the model uses was obtained from the drivers' logs, the documents that contain such information as the times when, and the locations where, passengers were picked; the number of passengers that were picked from each location; and the total number of passengers in one shift. There are so many service points in the area being serviced that it is almost impossible to model the arrival of passengers at each location as data is so sketchy. This is especially true about home pick-ups and delivery when a person would require such a service only once in a day and from a different location each day. It was for this reason that more attention was paid to the total number of passengers per hour, regardless of the service points from which the passengers were to be picked.

Two weeks worth of data were considered for each route. Since each route essentially consists of two trips, one going to and the other coming from Central City (or Stapleton Airport as the case may be), it was decided that the aggregate number of passengers be computed at each time, at time intervals of one hour, for each trip and the corresponding arithmetic averages were then calculated and employed as estimates of the number of passengers at each time. The use of the arithmetic averages somewhat reduced the variability in the number of passengers at each time for each trip. A summary of these estimates for each trip is given in tables A1 and A2 in the appendix.

Some graphical displays were used to analyze the data. These included box-and-whisker plots, dot plots, graphs of number of passengers against time, and histograms of the number of passengers per hour (See appendix B). Skewness was evident from these graphical displays of data. The graphs of the number of passengers against time revealed the peak hours for each trip. The histograms of the number of passengers per hour suggest that the number of passengers per hour is approximately exponentially distributed for the Central City route whereas it is approximately uniformly distributed for the airport route.

Preliminary analysis of the data extracted from the drivers' logs revealed that about 52% (on average) of the passengers going to Central City were picked from Heritage Square while only 18% of the passengers coming from Central City were going to Heritage Square. This trend may be attributed to the fact that many of the passengers from locations around Heritage Square, who do not make reservations before they travel, prefer to go to Heritage Square to be picked from there as this point is serviced more regularly. The other reason is that the dispatcher may advise prospective passengers from nearby locations to go to Heritage Square to be picked from there as this cuts down on the number of points that a van passes through before heading for the final destination, in this case Central City. There are no home pick-ups and delivery for the Central City route.

The airport route, unlike the Central City route, has a provision for home pick-ups and delivery in the suburban areas of Golden, Lakewood, and Wheatridge. The distribution of passengers is almost evenly distributed over the whole area. The route is operational from 5:00 AM to about 10:00 PM. Departures from the airport are scheduled every thirty minutes.

3.3 Distributional Assumptions and Parameter Estimation

As already pointed out in the introductory section of this chapter, the attributes that are of interest are the time an entity is created, the number of passengers that an entity represents, and the duration of the service activity. The time between creations is deterministic (i.e, an entity is created every one hour), but the number of passengers and the service time corresponding to the entity are stochastic. This means that appropriate probability distributions should be used to model the two stochastic attributes or characteristics.

There are a variety of methods that can be used to identify appropriate probability distributions to model random variables. The ones that are most commonly used are the construction of a histogram, and the probability plots. A distributional assumption is made on the basis of what might arise in the context being investigated, along with the shape of a histogram. Probability plotting is an informal means of evaluating a distributional assumption.

The basic idea behind probability plots is that a special transformation has been applied to the horizontal scale of the assumed distribution function. This transforms all distribution functions of the assumed type into straight lines. If the assumed probability distribution is correct or appropriate, the sample order statistics will be nearly linear when plotted on probability paper. If the distributional assumption is inappropriate, the plotted points will be nonlinear in a systematic fashion. The histograms of the number of passengers per hour (see figures 1 through 4 in the appendix) suggest that the number of passengers per hour is exponentially distributed for the Central City route whereas it is uniformly distributed for the airport route.

After a distributional assumption has been made, the next step is to estimate the parameters of the assumed distribution. In a number of cases, the sample mean and the sample variance are used to estimate these parameters.

In the case of an exponential distribution, the reciprocal of the sample mean (of the sample of the number of passengers per hour, as extracted from the drivers' logs) is used to estimate the parameter, the mean of the distribution. Thus, the parameter, α, was estimated by

$$\hat{\alpha} = 1/3.971 \approx 0.252$$

for the trip to Central City. On the other hand, if the assumed distribution is uniform on say $(0,\beta)$, then the parameter, β, is estimated by

$$\hat{\beta} = \{(n+1)/n\} \{\max(X)\} = 10.556$$

for the trip to the airport, where X is a random variable that represents the number of passengers per hour (as extracted from the drivers' logs), and n = 18 observations.
The goodness of fit tests are used to evaluate these distributional assumptions and are discussed in section 3.4.

The service times could not be obtained from the drivers' logs, nor could this type of information be obtained from other existing documents. The only relevant information that was known were the most optimistic time, the most frequent time (mode), and the most pessimistic time in this order. These estimates were obtained in a private conversation with Miss Marguerite Brunel. (Miss Brunel is the assistant manager for the company and has extensive experience, as a driver, dispatcher, and supervisor). The triangular distribution was then employed to model the service times.

3.4 Breakdowns and Scheduled Maintenance

The vans seldom break down. Even when one van has broken down, there is always at least one van on standby that can be used to handle this drop in fleet size. Thus, the impact of a breakdown can easily be swallowed up by the release of a van that was on standby. (The probability that four or more vans will be down at the same time is so remote it need not be considered).

Vans, on the other hand, undergo maintenance quite regularly. Each van is scheduled to undergo maintenance every after 8,000 miles of travel. This event occurs, on average, about once in three months. Since the simulation model has a run length of 24 hours, inducing a breakdown every after 2,160 (= 3x30x24) hours may have very little or no effect at all on the model.

Accidents, by their very nature, are a rare occurrence. However, if they should occur, their effect is again handled by a van on standby.

3.5 Goodness of Fit Tests

After making a distributional assumption and estimating the parameter(s), the goodness of fit tests provide a formal way of evaluating the distributional assumption. Two of these tests are the chi-square test and the Kolmogorov-Smirnov test (Jerry Banks & John S. Carson 1984).

The chi-square test is valid for large sample sizes, for both discrete and continuous distributional assumptions, when the parameters are estimated by maximum likelihood. This test can also accommodate the estimation of parameters from the data, which results in a decrease in the degrees of freedom (one degree of freedom is lost for each parameter estimated). The chi-square also requires that the data be placed in class intervals.

The Kolmogorov-Smirnov test is particularly powerful when sample sizes are small and when no parameters have been estimated from the data. It is also used to test samples from random number generator for uniformity over the interval [0,1]. The test compares the distribution function of the continuous uniform distribution, $F(x) = x$ on [0,1], to the empirical distribution function, $S_N(x)$, of the sample of n observations. As n becomes larger, $S_N(x)$ becomes a better approximation, provided the sample of random numbers is uniformly distributed over [0,1]. In fact, the Kolmogorov-Smirnov test is based on the largest absolute deviation between F(x) and $S_N(x)$ over the range of the random variable. Thus, it is based on the statistic

$$D = \mathrm{Max}\{\mathrm{Abs}(F(x) - S_N(x))\}.$$

For a sample from an interval other than [0,1], the sample should be mapped onto the interval [0,1] by an appropriate one-to-one transformation before the test is employed.

3.5.1 The exponential distributional assumption

An exponential distributional assumption was made for the number of passengers (per hour) for the Central City route. The chi-square with equal probabilities uses class intervals that are equal in probability, rather than in width, when a continuous distributional assumption is being tested. The initial number of class intervals, k, can be computed using the formula

$$k = [n/5]$$

where [n/5] is the largest integer that is less than or equal to n/5.

Oi denotes the observed number of values of **Y** in interval i, and Ei represents the expected number of values of **Y** in interval i (i = 1, 2, 3, 4).

Case 1 : Trip to Central City

Let **Y** denote a random variable representing the number of passengers per hour. Then the alternatives are

H_0 : **Y** is exponentially distributed with mean 0.252

H_1 : **Y** is not exponentially distributed with mean 0.252

The rest of the calculations are as given below.

Interval	O_i	E_i	$(O_i-E_i)^2/E_i$
(0, 1.13]	8	6	2/3
(1.13, 2.72]	5	6	1/6
(2.72, 5.43]	5	6	1/6
(5.43, Inf)	6	6	0
Totals	24	24	1.0

Thus, $X^2_{calc} = 1.0$. But $X^2_{0.05} = 7.81$.

Since the calculated statistic, X^2_{calc}, is less than the critical value, $X^2_{0.05}$, we can not reject the null hypothesis that the number of passengers per hour is exponentially distributed with mean 0.252, at 5 % level of significance.

Case 2: Trip from Central City

The alternatives are

H_0 : Y is exponentially distributed with mean 0.267

H_1 : Y is not exponentially distributed with mean 0.267

The rest of the calculations are as given below.

Interval	O_i	E_i	$(O_i-E_i)^2/E_i$
(0, 1.08]	9	6	
(1.08,2.60]	2	6	1/12
(2.60, 5.20]	9	6	
(5.20,Inf)	4	6	1/12
Totals	24	24	1/6

Since $X^2_{calc} = 1/6 < X^2_{0.05} = 5.02$, we cannot reject the null hypothesis that the number of passengers per hour is exponentially distributed with mean 0.267, at 5 % level of significance.

3.5.2 Uniform Distributional Assumption

A uniform distributional assumption was made for the number of passengers for the airport route. For this assumption, the Kolmogorov-Smirnov test can be used to evaluate the assumption. For this route, two cases arise.

Case 1 : Trip to the airport

Let **Z** denote a random variable representing the number of passengers per hour. Then, the alternatives to be tested are

H_0 : **Z** is uniformly distributed on [0,10]

H_1 : **Z** is not uniformly distributed on [0,10].

Map the values of **Z** onto the interval [0,1] by dividing the **Z**-values by 10.

Applying the Kolmogorov-Smirnov test to the "normalized" values of Z gives the results summarized on the next page.

Thus, applying the Kolmogorov-Smirnov test to the "normalized" values of **Z** gives the results summarized below.

i	i/N	R(i)	D^+	D^-
1	0.056	0.10		0.100
2	0.111	0.10	0.011	0.044
3	0.167	0.10	0.067	
4	0.222	0.20	0.022	0.033
5	0.278	0.30		0.078
6	0.333	0.30	0.033	0.022
7	0.389	0.30	0.089	
8	0.444	0.50		0.111
9	0.500	0.50		0.056
10	0.556	0.60		0.100
11	0.611	0.60	0.011	0.044
12	0.667	0.60	0.067	
13	0.722	0.70	0.022	0.033
14	0.778	0.70	0.078	0.078
15	0.833	0.80	0.033	0.022
16	0.889	0.90		0.067
17	0.944	0.90	0.044	0.111
18	1.000	1.00		0.056

Since $\max(D^+,D^-) = 0.111 < D_{0.05} = 0.309$, we cannot, based on this test, reject the null hypothesis that **Y** is uniformly distributed on the interval [0,10], at 5 % level of significance.

Case 2 : Trip from the airport

Let **Z** denote a random variable representing the number of passengers per hour. Then, the alternatives to be tested are

H_0 : **Z** is uniformly distributed on [0,8]

H_1 : **Z** is not uniformly distributed on [0,8].

Map the values of **Z** onto the interval [0,1] by dividing the **Z**-values by 8.

Applying the Kolmogorov-Smirnov test to the "normalized" values of **Z**, we get the following :

i	i/N	R(i)	D^+	D^-
1	0.056	0.000	0.056	
2	0.111	0.000	0.111	
3	0.167	0.000	0.167	
4	0.222	0.250		0.083
5	0.278	0.250	0.028	0.028
6	0.333	0.375		0.097
7	0.389	0.500		0.167
8	0.444	0.500		0.111
9	0.500	0.500		0.056
10	0.556	0.500		
11	0.611	0.500	0.056	
12	0.667	0.625	0.011	0.014
13	0.722	0.625	0.042	
14	0.778	0.625	0.097	
15	0.833	0.625	0.153	
16	0.889	0.875	0.208	0.042
17	0.944	0.875	0.014	
18	1.000	1.000	0.069	0.056

Since $\max(D^+,D^-) = 0.208 < D_{0.05} = 0.309$, we cannot, based on this test, reject the null hypothesis that **Z** is uniformly distributed on the interval [0,8], at 5 % level of significance.

3.6 Design of Simulation Experiments

Two of the objectives of the study are to investigate the impact of a rise in passenger volume by 10, or 20 %, on the current fleet of vans and to determine a near optimal fleet size. These two objectives, to some extent, dictate the alternatives to be simulated.

3.6.1 Percentage Rise in Passenger Volume

To investigate the impact of a percentage rise in passenger volume by 10 % and 20 % gives rise to two alternatives to be simulated. To do this, some statistical tools are used to determine the probability distribution of a function of a random variable, say **X**, the probability distribution of which is already known. The methods that were employed are the distribution function technique and the transformation technique. Using these techniques enables us to find the probability distributions of the new random variables, namely

$\mathbf{Y_1 = 1.1X}$, and $\mathbf{Y_2 = 1.2X}$

For the exponential distribution, the new parameters were found to be the product of the old parameters and the factors 1.1, and 1.2 respectively.

For the uniform distribution, the new parameters were obtained using the distribution function technique and were also found to be the products of the old parameters and the factors 1.1, and 1.2, respectively.

3.6.2 Changes in Fleet Size

To determine the near optimal fleet size, we need some optimization criterion and its associated constraints. In this study, the optimization criterion is to maximize the utilization of the vans subject to minimal average delay for the passengers. Hence, the alternatives to be simulated will be based on the set of fleet sizes that need to be analyzed and compared. The measures of performance to be used are the average van utilization, the length of waiting lines, and the delays of passengers. These measures of performance will be calculated and the corresponding scenarios compared based on these measures.

3.6.3 Number Of Replications

Output data from the simulation inherently exhibits random variability when random numbers (or random variates as the case may be) are generated to produce the values of the input variables. Thus, two different streams of random numbers will produce two sets of output that will probably be different. Statistical analysis will therefore be used to determine the number of simulation runs for each scenario simulated, and to estimate the variance of the various measures of system performance to be used to compare the scenarios. The number of simulation runs required, R is the minimum value of R satisfying the inequality

$$R > (t_{\alpha/2,R-1}\ S_0)^2/\varepsilon^2 \qquad \text{(J. Banks \& J. S. Carson,II 1984)}$$

where S_0 is the sample standard deviation, and ε is the desired accuracy. For instance, for $\alpha = 0.05$, and for the degree of accuracy, $\varepsilon = 0.02$, an initial estimate of R is given by

$$R_0 > (z_{\alpha/2},\ S_0)^2/\varepsilon^2 = 30.44.$$

where $S_0 = 0.0563$.

Hence choose R_0 = 31 and the rest of the computation is as given below.

R	31	32	33	34
$t_{0.025,R-1}$	2.0423	2.0395	2.0369	2.0345
$(t_{0.025,R-1}\ S_0)^2/\varepsilon^2$	33.05	32.96	32.88	32.80

Since 33 is the minimum R satisfying the inequality above, we choose R = 33. Using the same procedure as above, the number of simulation runs was determined for each scenario and the maximum of the values thus obtained, 33, was used as the required number of simulation runs to be made for each scenario.

3.7 User Inserts and Model Verification

As already noted in the previous sections, each route essentially consists of two trips and uses its own allocation of vans. (The network model was built in SLAM). The vans are assumed to be identical servers, which makes sense since they are of the same capacity and are functionally identical. Each trip is modeled using a CREATE node, and entities from two different CREATE nodes can not be routed to the same BATCH node as this would violate the constraint that a van carries only passengers going in the same direction.

The time in system is collected using the collect, COLCT, node and the number of passengers in the system, on average, at any given time is maintained using a time persistent global variable.

A van is released when there is at least one passenger to be picked. This is modeled by the release of an entity from the batch node. Since the number of passengers is not known in advance, the threshold value, which determines the release of an entity from the batch node, should also vary with the number of passengers at a given point in time. This is modeled by the EVENT node using user written inserts (in Fortran).

The verification process, which refers to the comparison of the conceptual model with the computer code that implements it, was done mainly by getting the model to print all the attributes of interest and then examining the summary and trace reports for reasonableness. Several entities were traced through the system, examining the logic in each case. For instance, if the number of passengers was less than one, then the release of that entity from a batch node would indicate that the model was not giving consistent results.

3.8 Model Calibration and Validation

Validation is the process of determining that a model that was developed was an accurate representation of the real system. This process is usually achieved through calibration, an iterative process of comparing the model to the actual system behavior, and using the discrepancies between the two, and the insights thus gained, to improve the system. The comparison of the model to the real system is conducted using a variety of tests, both subjective and objective tests.

To calibrate the model, the data on the system's behavior and the corresponding data produced by the model were used. Then, a statistical test was conducted to compare the average number of passengers from the actual data and the average number of passengers obtained from the output data. The statistical test was carried out as follows :

Case 1 : Stapleton Airport

The average number of passengers, obtained from the actual data, for the airport route was 144. Hence, the alternatives to be tested are

$H_0 : E(X) = 144$

$H_1 : E(X) \neq 144$

$\alpha = 0.05$, $n = 33$

Sample mean, $\overline{X} = 147$

Standard deviation, $S = 12.47$

Test statistic is $t = \sqrt{n}(\overline{X} - \mu)/S = 1.382$

But $t_{0.025,32} = 2.0369$

Since $t = 1.382 < t_{0.025,32} = 2.0369$, we cannot, based on this test, reject the null hypothesis that

$$E(X) = 144$$

at $\alpha = 0.05$ level of significance. Hence, we can not conclude that the model is inadequate.

Case 2 : Central City

The average number of passengers, obtained from the actual data, for the airport route was 174. Hence, the alternatives to be tested are

$H_0 : E(X) = 174$

$H_1 : E(X) \neq 174$

$\alpha = 0.05, \; n = 25.$

Sample mean, $\overline{X} = 179$

Standard deviation, $S = 13.72$

Test statistic is $t = \sqrt{n}(\overline{X} - \mu)/S = 1.822$

But $t_{0.025,24} = 2.0639$

Since $t = 1.822 < t_{0.025,24} = 2.0639$, based on this test, we can not reject the null hypothesis that

$$E(X) = 174$$

at $\alpha = 0.05$ level of significance. Thus, there is not enough reason to conclude that the model is inadequate so that the model can advance to the next stage of validation.

A new sample of drivers' logs was collected and used to validate the model. Using the same statistical test conducted above, the validity of the model was rejected. The model was then iteratively revised and the statistical test conducted until the model could not be rejected using the same test. It was at this point that the model was run to obtain the van utilization and the rest of the results reported in chapter 4.

CHAPTER 4

RESULTS, RECOMMENDATIONS AND TOPICS FOR FURTHER STUDY

4.0 SLAM II Summary Report

The SLAM II summary report displays the statistical results for the simulation and it is automatically printed at the end of each simulation run. A typical summary report for each simulated scenario is included in the appendix. The report consists of a general section giving the project description, analyst's name, and the desired number of runs, followed by the statistical results by type. The most important of these statistics are :

(a) the average van utilization,

(b) the average time a passenger spends in the system,

(c) the average number of passengers in the system,

(d) the maximum number of vans that can be used at any time,

(e) the average waiting time for a passenger,

(f) the observed number of entities that passed through the system.

A summary of these statistics is collected and 95% confidence intervals are constructed for each statistic and for every scenario simulated.

The observed number of entities that passed through the system, known as the entity count, corresponds to the average number of trips that were made during a day.

The average server utilization is (in SLAM II) defined as the average number of entities in service over time. Since each server can admit only one entity at a time, this statistic corresponds to the average number of servers (vans in this case) that are busy over time. Hence, the percentage van utilization may be obtained by dividing the average van utilization by the total number of vans available, and then multiplying the quotient by 100.

4.1 Percentage Van Utilization.

Determining van utilization is one of the objectives of this study. To do this, 33 simulation runs of the model were made and the corresponding summary reports were produced, one for each run. The average van utilization (obtained from the file statistics of each summary report) was collected for each simulation run and these values were used to construct the 95 % confidence intervals for the average van utilization. A summary of these confidence intervals is given in the table below.

TABLE 4.1.1 : AVERAGE VAN UTILIZATION

Route	Mean	Interval
Airport	1.987	(1.973, 2.000)
Central	1.906	(1.898, 1.914)

Table 4.1.1 shows that the average van utilization, θ, lies in the interval

$$1.973 < \theta < 2.000$$

for the airport route whereas it lies in the interval

$$1.898 < \theta < 1.914$$

for the Central City route. Thus, with 95% confidence, we can conclude that the average number of vans that are busy over time is approximately two for both of the routes.

Another way of analyzing van utilization is by determining the proportion of the total number of vans available that are busy over time. We can do this by using a new measure of performance, called effective van utilization, which is defined as the proportion of the total number of vans that are busy over time. Thus, effective van utilization, ρ, is given by

$$\rho = \theta/\beta \qquad (4.1)$$

where θ = the average van utilization, and

β = the total number of vans available.

The effective van utilization is computed in each case and its 95 % confidence intervals constructed. These confidence intervals are summarized in the table below.

TABLE 4.1.2 : EFFECTIVE VAN UTILIZATION

Route	Mean	Interval
Airport	0.397	(0.395, 0.400)
Central	0.476	(0.474, 0.479)

Table 4.1.2 shows that the effective van utilization lies in the interval

$$0.395 < \rho < 0.400$$

for the airport route which represents van utilization of approximately 40 %, whereas it lies in the interval

$$0.474 < \rho < 0.479$$

in the case of the airport route, which represents van utilization of approximately 48 %.

The average number of passengers who use a particular route in a day was estimated by the product of the number of entities that passed through system, entity count, and the average number of passengers in the system. The 95 % confidence intervals for this statistic were constructed for each route and they are given in the table below.

TABLE 4.1.3 : NUMBER OF PASSENGERS/DAY

Route	Mean	Interval
Airport	185	(181, 188)
Central	242	(236, 248)

Thus, on average, there are 185 passengers using the airport route in a day whereas there are, on average 242 passengers for the Central City route in a day. It should be mentioned that the actual passenger counts may deviate considerably from this interval but with 95 % confidence, these passenger counts, on average, lie in the intervals given in the table above.

The maximum number of vans that were busy at any given time during the simulation for each route, as obtained from the service activity statistics, was 4. This is the minimum number of vans that are required to handle the both the airport and Central City routes without causing any passenger delays. In other words, this is the minimum number of vans that are required if the objective is to ensure that at least one van is available whenever a that are required if the objective is to ensure that at least one van is available whenever a group of passengers arrive to the system. There were no passenger delays when 4 vans were used for the Central City route or when 5 vans were used for the airport route.

4.2 Impact of Changes in Passenger Volume on Van Utilization

The second objective of this study was to determine the impact of changes (increase or decrease) in passenger volume on the van utilization. To do this, these changes in passenger volume were simulated and confidence intervals were constructed for both the average van utilization, and the effective van utilization. The scenarios that were simulated for each route were 10 % decrease in passenger volume, 10 % increase in passenger volume and 20 % increase in passenger volume.

The 10 % decrease in passenger volume was motivated by the possibility of a decline in the gambling business at Central City which would inevitably spell a decrease in passenger volume for the Central City route. It was also considered for the airport route just to investigate how a 10 % decrease in passenger affects the van utilization.

The 10 %, and 20 % rise in passenger volume were motivated by the anticipated rise in passenger volume as a result of the planned expansion of the service area to include Arvada and South-West Lakewood, let alone the prospects of the new Denver International Airport currently under construction. This expansion directly affects the airport route, although the scenario was also considered for the Central City route for which passenger volume has steadily been rising.

Tables 4.2.1 and 4.2.2 contain the summary of results regarding the impact of changes in passenger volume on van utilization. The changes in average van utilization, and effective van utilization are given relative to the current average van utilization and effective van utilization, respectively. A negative change in van utilization indicates that there is a drop in van utilization whereas that which is positive indicates an increase in van utilization.

TABLE 4.2.1 : AVERAGE VAN UTILIZATION

	10 % Decrease			10 % Increase		
Route	Mean	Interval	Change	Mean	Interval	Change
Airport	1.968	(1.952, 1.984)	-0.019	2.002	(1.990, 2.014)	+0.015
Central	1.864	(1.843, 1.885)	-1.864	1.930	(1.921, 1.938)	+0.024

	20 % Increase			Current Passenger Volume		
Route	Mean	Interval	Change	Mean	Interval	Change
Airport	2.007	(1.996, 2.019)	0.020	1.987	(1.973, 2.000)	+0.000
Central	1.951	(1.942, 1.959)	0.045	1.906	(1.898, 1.914)	+0.000

TABLE 4.2.2 : EFFECTIVE VAN UTILIZATION

	10 % Decrease			10 % Increase		
Route	Mean	Interval	Change	Mean	Interval	Change
Airport	0.394	(0.390, 0.397)	-0.003	0.400	(0.398, 0.403)	+0.003
Central	0.466	(0.461, 0.471)	-0.010	0.482	(0.480, 0.485)	+0.006

	20 % Increase			Current Passenger Volume		
Route	Mean	Interval	Change	Mean	Interval	Change
Airport	0.401	(0.399, 0.404)	0.004	0.397	(0.395, 0.400)	+0.000
Central	0.488	(0.486, 0.490)	0.012	0.476	(0.474, 0.479)	+0.000

The tables above show that a 20 % rise in passenger volume results in approximately 49 % van utilization for the Central City whereas an equal rise in passenger volume for the airport route yields about 40 % van utilization.

The tables also show that a change in passenger volume of 10 or 20 % results in a very small change in van utilization. This is mainly due to the fact that a van can take groups of passengers of up to maximum size of 10 for the Stapleton Airport route and groups of up to maximum size of 14 for the Central City route so that a good part of this increase is "absorbed" by the respective capacities of the vans. For instance, if the average number of passengers for the airport route is increased by 10 %, then there will be only 19 more passengers over a period of 18 hours. Since there are five vans, this rise in passenger volume may, depending on the arrival pattern of the passengers, be handled without requiring additional trips by the vans.

The maximum number of vans that are busy (for each route) at any given time during the simulation is 4. There are no passengers delayed.

The average number of passengers in the system varies directly with the change in passenger volume. For instance, a 10 % rise in passenger volume gives rise to an increase of about 10 % in the average number of passengers in the system.

This analysis suggests that the current fleet of vans can effectively handle a rise in passenger volume of up to 20 %. This assertion makes sense, going by the results of this model, since there are, on average, about 7 passengers per trip for the Central City route and this is only half the capacity of a van servicing the route. On the other hand, there are, on average, approximately 7 passengers for each trip for the airport route, which is 70 % of the capacity of a van servicing the route. Thus, depending on the arrival pattern of the passengers, this rise in passenger volume may be handled without making additional trips.

The data for the scenarios considered in this section is given in the appendix.

4.3 Minimum fleet size that minimizes maximum delay

The third objective of this study was to determine a near optimal fleet size for each route that minimizes the maximum possible passenger delay. This ensures that the passengers do not wait for too long. From the previous sections, it was found that the maximum number of vans that could be used at any given time during the simulation was four (4). Hence 4 is one of the candidates for the minimum number of vans that handle the demand for service without causing too much delay to the customers. The other measures of performance that are considered, in addition to passenger delay, include average van utilization, the effective van utilization, the maximum length of the queue, and the average waiting time for all entities that arrived to the file, including those entities that did not wait.

It was learnt that the average van utilization is the same for all fleet sizes greater than or equal to 4. Hence, the other fleet sizes that were considered are 2 and 3. All the three cases are considered below.

4.3.1 Using 4 or More Vans.

The average van utilization (obtained from the service statistics) was collected for each scenario simulated in this section and these values were later used to construct the 95 % confidence intervals for this measure of performance. A summary of the confidence intervals that were constructed is as given in the table 4.2.1 in section 4.2 above.

There were no passengers delayed when the number of vans was greater than or equal to 4. Therefore the maximum possible passenger delay was zero. The rest of the analysis is the same as that given in section 4.2

4.3.2 Using Only 3 Vans.

Using the file statistics, the average number of vans was collected and the 95 % confidence intervals were constructed. A summary of these confidence intervals is given on the next page.

Table 4.3.1 : AVERAGE VAN UTILIZATION (3 VANS)

	Curnt Pass. Volume		10 % Increase		20 % Increase	
Route	Mean	Interval	Mean	Interval	Mean	Interval
Airport	1.984	(1.971, 1.996)	1.999	(1.988, 2.010)	2.005	(1.994, 2.015)
Central	1.904	(1.896, 1.913)	1.928	(1.919, 1.937)	1.949	(1.940, 1.958)

Table 4.3.2 : EFFECTIVE VAN UTILIZATION (3 VANS)

	Curnt Pass. Volume		10 % Increase		20 % Increase	
Route	Mean	Interval	Mean	Interval	Mean	Interval
Airport	0.661	(0.657, 0.665)	0.666	(0.663, 0.670)	0.668	(0.665, 0.672)
Central	0.635	(0.632, 0.638)	0.643	(0.640, 0.646)	0.650	(0.647, 0.653)

The two tables above show that using 3 (instead of 4) vans for the current passenger volume yields an average van utilization, θ, in the interval

$$1.971 < \theta < 1.996$$

for the airport route. This means that, on average, approximately 2 vans are busy in the case of the airport route. On the other hand, using three vans for the Central City route (for current passenger volume) results in an average van utilization in the interval

$$1.898 < \theta < 1.913.$$

Again, there are, on average, approximately two vans that are busy for the Central City route.

The maximum number of vans that are busy at any given time is 3 in all cases.

The current effective van utilization for the airport lies in the interval

$$0.657 < \rho < 0.665$$

which is about 66 % van utilization. This represents an increase of about 66 % in percentage van utilization when compared with that obtained using 4 or more vans.

For the Central City route, using only 3 vans yields a current effective van utilization that lies in the interval

$$0.632 < \rho < 0.638$$

which is about 64 % van utilization. This represents an increase of about 33 % in the percentage van utilization in comparison with that obtained when 4 or more vans are being used.

The maximum queue length, obtained from the file statistics of the summary report, 1. This means that the maximum number of entities that ever waited was 1.

The average delay for the entities was also obtained from the file statistics.

Since the average delay is the average waiting time of the entities that were maintained in the file, including those entities that did not wait, the total delay that during the simulation can be estimated by the product of entity count and the average waiting time. Since the maximum queue length is one, then the maximum delay possible that an entity experiences is given by the product of the entity count and the average delay. Using this estimate, the 95 % confidence intervals were constructed for the maximum passenger delay. These confidence intervals are summarized in the table below.

Table 4.3.3 : MAXIMUM PASSENGER DELAY (3 VANS)

	Curnt Pass. Volume		10 % Increase		10 % Increase	
Route	Mean	Interval	Mean	Interval	Mean	Interval
Airport	0.565	(0.425, 0.705)	0.565	(0.433, 0.697)	0.604	(0.463, 0.745)
Central	0.617	(0.500, 0.735)	0.790	(0.636, 0.945)	0.834	(0.659, 1.010)

Table 4.3.3 shows that under the current passenger volume for the airport route, the maximum passenger delay, δ, lies in the interval

$$0.425 < \delta < 0.705 \text{ in hours.}$$

Using the mean to estimate this measure of performance, we see that, on average, the maximum possible delay that a group of passengers can experience is about 34 minutes. For the Central City route, the maximum passenger delay lies in the interval

$$0.500 < \delta < 0.735 \text{ in hours.}$$

Thus, on average, the maximum delay caused to a group of passengers is roughly 37 minutes. Going by these results, use of the mean to estimate the maximum passenger delay results in passenger delays of more than thirty minutes in each case.

Remark : Using the average delay would under-estimate the delay that a group of passengers experiences because of the way the average delay is defined. The average delay includes the zero times for the entities that did not wait. This implies that if the number of entities that waited is small, the average delay will also be small even when the entities that waited were delayed for a long time. The other statistics that are useful in deciding whether to use the average delay (as defined in SLAM II) are the average queue length, and the maximum queue length. In this section, the average was small (in fact closer to zero) which implies that every entity that waited was delayed by much more the average waiting time. It was for this reason that maximum passenger delay was used in the analysis.

Thus, using 3 (instead of 4) vans results in higher van utilization than is the case when 4 or more vans are used. The bad news, however, is that using only 3 vans results in longer passenger delays than is the case when 4 or more vans are used.

4.3.3 Using Only 2 Vans

The measures of performance that are of interest include the average delay, the average queue length, the maximum queue length, the average van utilization and the entity count. The effective van utilization was calculated using equation 4.1. The confidence intervals for the effective van utilization were constructed in each case and the summary of these confidence intervals is given below.

TABLE 4.3.4 : EFFECTIVE VAN UTILIZATION (2 VANS)

	Curnt Pass. Volume		10 % Increase		20 % Increase	
Route	Mean	Interval	Mean	Interval	Mean	Interval
Airport	0.956	(0.945, 0.967)	0.959	(0.948, 0.970)	0.959	(0.949, 0.970)
Central	0.922	(0.901, 0.942)	0.930	(0.912, 0.948)	0.935	(0.919, 0.952)

Table 4.3.4 shows that under the current passenger volume for the airport route, the effective van utilization, ρ, lies in the interval

$$0.945 < \rho < 0.965$$

which is van utilization of roughly 96 %, contrasted with about 40 % van utilization that is obtained when there are 5 vans for this route. This van utilization represents an increase of approximately 140 % in the van utilization in comparison with that obtained when using 4 vans.

In the case of the Central City route, the same analysis results in effective van utilization, ρ, in the interval

$$0.901 < \rho < 0.942$$

which is van utilization of approximately 92 %, in contrast to the van utilization of 48 % resulting from using 4 vans. This represents about 92 % increase in percentage van utilization.

The maximum queue length, extracted from the file statistics, was collected for each simulation run and its 95 % confidence intervals were for the statistic.

The summary of these intervals is given in the table below.

Table 4.3.5 : MAXIMUM QUEUE LENGTH (2 VANS)

	Curnt Pass. Volume		10 % Increase		20 % Increase	
Route	Mean	Interval	Mean	Interval	Mean	Interval
Airport	2.788	(2.484, 3.092)	2.788	(2.484, 3.092)	2.788	(2.484, 3.092)
Central	3.182	(2.833, 3.530)	3.212	(2.828, 3.596)	3.364	(2.879, 3.848)

Using the table above, under the current passenger volume for the airport route the maximum queue length, γ, lies in the interval

$$2.484 < \gamma < 3.092$$

whereas the same analysis for the Central City route gives the maximum queue length in the interval

$$2.833 < \gamma < 3.530$$

It is worth mentioning that the entities that are in the queue are actually groups of passengers, and not individual passengers.

The other statistics are also summarized in the tables below.

Table 4.3.6 : AVERAGE DELAY (2 VANS)

	Curnt Pass. Volume		10 % Increase		20 % Increase	
Route	Mean	Interval	Mean	Interval	Mean	Interval
Airport	0.349	(0.283, 0.416)	0.378	(0.301, 0.455)	0.397	(0.316, 0.477)
Central	0.457	(0.352, 0.561)	0.465	(0.359, 0.571)	0.498	(0.647, 0.619)

Table 4.3.7 : MAXIMUM PASSENGER DELAY (2 VANS)

	Curnt Pass. Volume		10 % Increase		20 % Increase	
Route	Mean	Interval	Mean	Interval	Mean	Interval
Airport	3.782	(3.285, 4.279)	4.046	(3.498, 4.595)	4.258	(3.679, 4.837)
Central	5.380	(4.649, 6.120)	5.385	(4.676, 6.085)	5.713	(4.827, 6.598)

Table 4.3.6 shows that under current passenger volume for the airport route, the average passenger delay, φ, lies in the interval

$$0.283 < \varphi < 0.4156 \text{ in hours.}$$

Thus, the average delay lies between 17 minutes and 25 minutes.

The same analysis when applied to the Central City route yields an average delay of about 27 minutes and it lies in the confidence interval

$$0.352 < \varphi < 0.651 \text{ in hours}$$

and is equivalent to an average delay of between 21 minutes and 34 minutes.

Table 4.3.7 shows that under the current passenger volume for the airport route, the maximum delay caused to a group of passengers lies in the interval

$$3.782 < \delta < 4.279$$

whereas it lies in the interval

$$4.649 < \delta < 6.120$$

in the case of the Central City route.

From the preceding results, it was found that the van utilization is highest when only two vans are used in each route.

The bad news is that the average passenger delay is a lot higher than is the case when 3 or more vans are used. Since the objective is to maximize van utilization subject to minimal passenger delay, the scenario in which only 2 vans are used should not be adopted.

Using only 3 vans has the disadvantage that the passengers that wait are delayed for a considerable period of time. The real concern is that passengers who are affected by this delay may lose confidence in the company and may be lost to a competitor.

The only option that does not involve passenger delay is that in which 4 vans are used for each route and is in fact the minimum number of vans that is required to handle demand for service with minimal passenger delay. Thus, basing the decision purely on the these results, 4 vans are recommended for each route.

4.4 Recommendations

On the basis of the results discussed above, 4 is the fleet size that is required for each route since it involves very little risk of passengers being delayed for too long.

4.5 Topics for Further Study

One of the underlying assumptions of the model developed in this thesis is that there are no peak hours and that every day is equally busy. It is for this reason that the model is not suitable for predicting the number of passengers that use a particular route in a day. It is, however, suitable for determining the minimum number of vans that are required to ensure that no passengers are delayed too long, and this happens to be the purpose for which it was developed.

The other considerations for further study include

(a) redefining the concept of van utilization to include number of passengers that a van carries when it is dispatched. There is ,of course, a difference between a van that is full and that which is almost empty. This difference should be incorporated in the definition for van utilization.

(b) redefining the optimization criterion to include operating costs. This model does not take into account the operating costs involved in running these vans.

(c) a mechanism for dealing with transfers and the fact that a van may be dispatched even when there are no passengers.

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APPENDIX A : DATA INPUT TO THE SIMULATION MODEL

TABLE A1 : THE AIRPORT ROUTE

	To the Airport		From the Airport	
Obsn	Time	Pass	Time	Pass
1	0	1	0	0
2	1	5	1	0
3	2	9	2	0
4	3	9	3	2
5	4	5	4	2
6	5	6	5	4
7	6	6	6	5
8	7	7	7	4
9	8	10	8	4
10	9	8	9	4
11	10	6	10	7
12	11	7	11	7
13	12	3	12	5
14	13	3	13	8
15	14	3	14	5
16	15	2	15	4
17	16	1	16	5
18	17	1	17	3

Time 0 corresponds to 5:00 AM and 17 coresponds to 10:00 PM.

Pass represents the number of passengers.

TABLE A2 : THE CENTRAL CITY ROUTE

	To Central City		From Central City	
Obsn	Time	Pass	Time	Pass
1	0	3	0	1
2	1	7	1	1
3	2	17	2	1
4	3	7	3	1
5	4	5	4	1
6	5	2	5	2
7	6	3	6	1
8	7	1	7	1
9	8	2	8	3
10	9	2	9	3
11	10	10	10	5
12	11	12	11	7
13	12	9	12	15
14	13	2	13	12
15	14	5	14	4
16	15	3	15	3
17	16	2	16	2
18	17	1	17	5
19	18	1	18	5
20	19	0	19	4
21	20	0	20	3
22	21	0	21	14
23	22	0	22	1
24	23	0	23	1

Time 0 corereesponds to 5:00 AM while 23 corresponds to 4:00 AM.

Pass represents the number of passengers.

APPENDIX B : GRAPHICAL DISPLAYS

TRIPS TO THE AIRPORT

```
     .         .              .
     :    .    :         :    :    :    .    :    .
+---------+---------+---------+---------+---------+-------Pass
0.0      2.0       4.0       6.0       8.0      10.0
```

Figure B1(a) : Dot Plot of Passengers.

```
               ---------------------
     ----------I            +      I---------------
               ---------------------
+---------+---------+---------+---------+---------+-------Pass
0.0      2.0       4.0       6.0       8.0      10.0
```

Figure B1(b) : Box Plot of Passengers.

```
Histogram of Pass   N = 18

Midpoint   Count
       1       3  ***
       2       1  *
       3       3  ***
       4       0
       5       2  **
       6       3  ***
       7       2  **
       8       1  *
       9       2  **
      10       1  *
```

Figure B1(c) : Histogram of Passengers.

TRIPS FROM THE AIRPORT

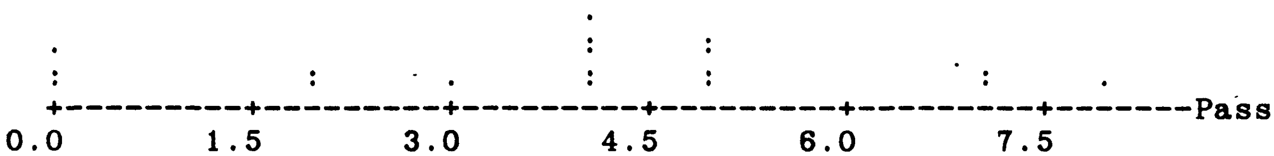

Figure B2(a) : Dot Plot of Passengers.

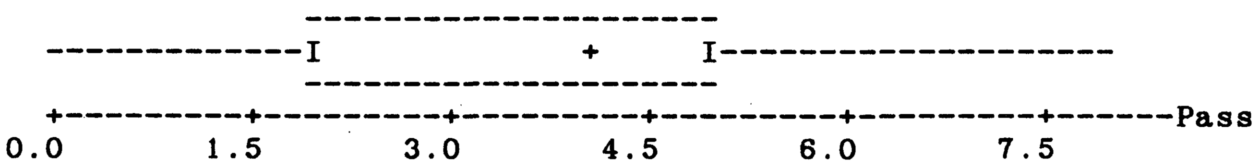

Figure B2(b) : Box Plot of Passengers.

```
Histogram of Pass   N = 18

Midpoint   Count
       0       3  ***
       1       0
       2       2  **
       3       1  *
       4       5  *****
       5       4  ****
       6       0
       7       2  **
       8       1  *
```

Figure B2(c) : Histogram of Passengers.

TRIPS TO CENTRAL CITY

```
       .
 .     :  .
 :     :  :       :         :         .   .      .                .
-------+---------+---------+---------+---------+---------Pass
      3.0       6.0       9.0      12.0      15.0      18.0
```

Figure B3(a) : Dot Plot of Passengers.

```
        ----------------
    ---I  +            I----------------                *
        ----------------
-------+---------+---------+---------+---------+--------Pass
      3.0       6.0       9.0      12.0      15.0
```

Figure B3(b) : Box Plot of Passengers.

```
Histogram of Pass   N = 19

Midpoint   Count
       2       8  ********
       4       3  ***
       6       2  **
       8       2  **
      10       2  **
      12       1  *
      14       0
      16       0
      18       1  *
```

Figure B3(c) : Histogram of Passengers.

TRIPS FROM CENTRAL CITY

```
.
:
:
:       :       .
:   :   :   :   :       .                   .       .   .
------+---------+---------+---------+---------+---------+-Pass
     2.5       5.0       7.5      10.0      12.5      15.0
```

Figure B4(a) : Dot Plot of Passengers.

```
-----------------
I       +       I--------                   *       *   *
-----------------
------+---------+---------+---------+---------+---------+Pass
     2.5       5.0       7.5      10.0      12.5      15.0
```

Figure B4(b) : Box Plot of Passengers.

```
Histogram of Pass   N = 24

Midpoint   Count
       2      11   ***********
       4       6   ******
       6       3   ***
       8       1   *
      10       0
      12       1   *
      14       1   *
      16       1   *
```

Figure B4(c) : Histogram of Passengers.

Table C1 : Airport Route Under Current Passenger Volume.

Run #	T.I.S	N.I.S	VUtil	E-Cnt	T-Pass	Eff-Util
1	1.09	5.888	2.161	34	200.192	0.4322
2	1.04	5.635	2.019	34	191.590	0.4038
3	1.06	5.766	2.044	34	196.044	0.4088
4	1.05	5.942	2.028	33	196.086	0.4056
5	1.05	5.642	1.998	31	174.902	0.3996
6	1.05	5.615	1.973	31	174.065	0.3946
7	1.05	5.612	1.972	33	185.196	0.3944
8	1.05	5.534	1.969	32	177.088	0.3938
9	1.05	5.606	1.959	31	173.786	0.3918
10	1.05	5.583	1.951	31	173.073	0.3902
11	1.04	5.577	1.950	34	189.618	0.3900
12	1.05	5.523	1.956	31	171.213	0.3912
13	1.05	5.492	1.966	33	181.236	0.3932
14	1.05	5.549	1.968	33	183.117	0.3936
15	1.05	5.521	1.962	30	165.630	0.3924
16	1.05	5.528	1.971	34	187.952	0.3942
17	1.05	5.518	1.978	33	182.094	0.3956
18	1.06	5.607	1.989	34	190.638	0.3978
19	1.06	5.591	1.991	33	184.503	0.3982
20	1.06	5.658	2.000	33	186.714	0.4000
21	1.06	5.645	1.993	31	174.995	0.3986
22	1.06	5.701	1.993	31	176.731	0.3986
23	1.06	5.747	1.991	34	195.398	0.3982
24	1.06	5.726	1.986	31	177.506	0.3972
25	1.06	5.760	1.979	31	178.560	0.3958
26	1.06	5.792	1.978	32	185.344	0.3956
27	1.06	5.852	1.983	35	204.820	0.3966
28	1.06	5.858	1.976	30	175.740	0.3952
29	1.06	5.886	1.977	32	188.352	0.3954
30	1.06	5.899	1.979	33	194.667	0.3958
31	1.06	5.913	1.976	32	189.216	0.3052
32	1.06	5.935	1.973	31	183.985	0.3946
33	1.06	5.983	1.971	33	197.439	0.3942

Table C2 : Central City Route Under Current Passenger Volume.

Run #	T.I.S	N.I.S	VUtil	E-Cnt	T-Pass	Eff-Util
1	1.12	5.696	1.901	40	227.840	0.4753
2	1.11	5.380	1.932	41	220.580	0.4830
3	1.10	5.573	1.911	40	222.920	0.4778
4	1.11	6.011	1.953	44	264.484	0.4883
5	1.10	5.869	1.935	39	228.891	0.4838
6	1.09	6.038	1.922	42	253.596	0.4805
7	1.09	5.963	1.920	40	238.520	0.4800
8	1.10	5.959	1.934	43	256.237	0.4835
9	1.09	6.093	1.931	42	255.906	0.4828
10	1.10	6.080	1.919	36	218.880	0.4798
11	1.11	6.219	1.925	40	248.760	0.4813
12	1.11	6.233	1.933	40	249.320	0.4833
13	1.11	6.169	1.932	42	259.098	0.4830
14	1.11	6.102	1.939	41	250.182	0.4848
15	1.11	6.000	1.920	35	210.000	0.4800
16	1.12	5.986	1.919	40	239.440	0.4798
17	1.12	5.896	1.916	39	229.944	0.4790
18	1.11	5.953	1.891	35	208.355	0.4728
19	1.11	6.112	1.883	39	238.368	0.4708
20	1.10	6.035	1.880	41	247.435	0.4700
21	1.11	6.032	1.882	39	235.248	0.4705
22	1.11	5.985	1.874	36	215.460	0.4685
23	1.10	5.971	1.874	43	256.753	0.4685
24	1.10	6.086	1.876	40	243.440	0.4690
25	1.11	6.126	1.885	40	245.040	0.4713
26	1.11	6.147	1.885	39	239.733	0.4713
27	1.11	6.122	1.890	41	251.002	0.4725
28	1.11	6.145	1.884	37	227.365	0.4710
29	1.11	6.169	1.889	43	265.267	0.4723
30	1.11	6.210	1.887	40	248.400	0.4718
31	1.11	6.255	1.891	42	262.710	0.4718
32	1.11	6.276	1.888	40	251.040	0.4720
33	1.11	6.252	1.895	45	281.340	0.4738

Table D1 : 10 % Increase in Passenger Volume - Airport Route

Run #	T.I.S	N.I.S	VUtil	E-Cnt	T-Pass	Eff-Util
1	1.09	6.476	2.161	34	220.184	0.4322
2	1.04	6.198	2.019	34	210.732	0.4038
3	1.06	6.342	2.044	34	215.628	0.4088
4	1.05	6.537	2.028	33	215.721	0.4056
5	1.05	6.131	2.013	31	196.192	0.4026
6	1.05	6.114	1.985	31	189.534	0.3970
7	1.05	6.120	1.983	33	201.960	0.3966
8	1.05	6.002	1.986	32	198.066	0.3972
9	1.05	6.091	1.974	31	188.821	0.3948
10	1.05	6.073	1.965	31	188.263	0.3930
11	1.04	6.039	1.968	34	211.365	0.3936
12	1.05	5.989	1.973	31	185.659	0.3946
13	1.05	5.954	1.991	33	208.390	0.3982
14	1.05	6.023	1.991	33	198.759	0.3982
15	1.05	5.997	1.983	30	179.910	0.3966
16	1.05	6.010	1.991	34	204.340	0.3982
17	1.05	6.000	2.000	33	204.000	0.4000
18	1.06	6.102	2.010	34	207.904	0.4020
19	1.06	6.088	2.011	33	200.904	0.4022
20	1.06	6.164	2.019	33	203.412	0.4038
21	1.06	6.152	2.013	31	196.864	0.4026
22	1.06	6.216	2.013	31	192.696	0.4026
23	1.06	6.270	2.010	34	213.180	0.4020
24	1.06	6.249	2.004	31	193.719	0.4008
25	1.06	6.288	1.996	31	194.928	0.3992
26	1.06	6.325	1.994	32	202.400	0.3988
27	1.06	6.393	1.999	35	223.755	0.3998
28	1.06	6.401	1.991	30	192.030	0.3982
29	1.06	6.419	1.994	32	211.827	0.3988
30	1.06	6.435	1.995	33	212.355	0.3990
31	1.06	6.452	1.992	32	206.464	0.3984
32	1.06	6.478	1.988	31	200.818	0.3976
33	1.06	6.532	1.988	33	215.556	0.3976

Table D2 : 10 % Increase in Passenger Volume - Central City Route.

Run #	T.I.S	N.I.S	VUtil	E-Cnt	T-Pass	Eff-Util
1	1.11	6.005	1.992	42	252.210	0.4980
2	1.11	5.788	1.977	41	237.308	0.4943
3	1.10	6.173	1.935	40	246.920	0.4838
4	1.10	6.644	1.971	44	292.336	0.4928
5	1.10	6.479	1.955	40	259.160	0.4888
6	1.09	6.661	1.939	42	279.762	0.4848
7	1.09	6.576	1.935	40	263.040	0.4838
8	1.09	6.558	1.952	44	288.552	0.4880
9	1.09	6.705	1.947	42	281.610	0.4868
10	1.10	6.690	1.933	36	240.840	0.4833
11	1.10	6.844	1.938	40	273.760	0.4845
12	1.11	6.858	1.945	40	274.320	0.4863
13	1.11	6.785	1.950	43	291.755	0.4875
14	1.11	6.677	1.959	42	280.434	0.4898
15	1.11	6.567	1.939	35	229.845	0.4848
16	1.11	6.554	1.937	40	262.160	0.4843
17	1.11	5.454	1.934	40	258.160	0.4835
18	1.11	5.503	1.915	37	240.611	0.4788
19	1.11	6.678	1.908	40	267.120	0.4770
20	1.10	6.587	1.906	42	276.654	0.4765
21	1.11	6.586	1.907	39	256.854	0.4768
22	1.11	6.531	1.900	37	241.647	0.4750
23	1.10	6.578	1.899	43	282.854	0.4748
24	1.10	6.686	1.900	40	265.880	0.4750
25	1.11	6.711	1.910	41	274.126	0.4775
26	1.11	6.687	1.908	39	261.729	0.4770
27	1.11	6.714	1.914	42	280.854	0.4785
28	1.11	6.742	1.907	37	248.418	0.4768
29	1.11	6.788	1.912	43	289.906	0.4780
30	1.11	6.839	1.911	40	271.520	0.4778
31	1.11	6.862	1.914	42	287.238	0.4785
32	1.11	6.839	1.913	41	281.342	0.4783
33	1.11	6.839	1.919	45	307.665	0.4798

Table E1 : Central City Statistics Summary - Using Only 3 Vans.

Run #	TIS	NIS	VUtil	Av-Dlay	E-Cnt	M-Dlay	Eff-Util
1	1.14	5.534	1.901	0.019	34	0.646	0.6334
2	1.12	5.400	1.932	0.008	34	0.272	0.6440
3	1.12	5.645	1.911	0.014	33	0.462	0.6370
4	1.12	6.057	1.953	0.018	33	0.594	0.6510
5	1.12	5.904	1.934	0.004	30	0.120	0.6445
6	1.10	6.067	1.922	0.000	31	0.000	0.6407
7	1.11	6.042	1.920	0.032	33	0.056	0.6400
8	1.11	6.030	1.934	0.028	32	0.896	0.6447
9	1.11	6.147	1.930	0.021	31	0.896	0.6433
10	1.12	6.131	1.917	0.018	31	0.651	0.6390
11	1.12	6.231	1.923	0.025	34	0.558	0.6410
12	1.13	6.239	1.929	0.041	31	0.850	0.6430
13	1.13	6.169	1.936	0.017	33	1.271	0.6430
14	1.13	6.109	1.917	0.018	33	0.561	0.6453
15	1.13	6.005	1.917	0.014	30	0.594	0.6390
16	1.13	6.003	1.913	0.010	34	0.420	0.6390
17	1.13	5.912	1.889	0.004	33	0.340	0.6300
18	1.13	5.893	1.881	0.004	34	0.132	0.6270
19	1.12	6.018	1.878	0.024	33	0.136	0.6260
20	1.12	5.945	1.880	0.011	33	0.792	0.6240
21	1.12	5.936	1.872	0.038	31	0.363	0.6240
22	1.12	5.895	1.872	0.024	31	1.178	0.6247
23	1.12	5.889	1.874	0.009	34	0.744	0.6280
24	1.12	6.007	1.884	0.033	31	0.306	0.6277
25	1.13	6.050	1.883	0.038	31	1.023	0.6293
26	1.13	6.093	1.888	0.033	32	1.178	0.6273
27	1.13	6.069	1.882	0.018	35	1.056	0.6290
28	1.13	6.090	1.887	0.010	30	0.630	0.6287
29	1.13	6.124	1.886	0.023	32	0.300	0.6300
30	1.13	6.166	1.890	0.014	33	0.736	0.6290
31	1.13	6.195	1.887	0.019	32	0.462	0.6313
32	1.13	6.226	1.894	0.017	31	0.608	0.6377
33	1.13	6.210	1.917	0.027	33	0.527	0.6297

Table F1 : Central City Summary of Statistics - Using Only 2 vans

Run #	TIS	NIS	VUtil	QL	Av-Dlay	E-Cnt	M-Dlay	0.9485
1	1.46	6.509	1.897	3	0.321	39	4.1730	0.9600
2	1.39	5.352	1.920	3	0.291	41	3.9770	0.9070
3	1.69	6.509	1.814	3	0.565	39	7.3450	0.9885
4	1.81	6.319	1.977	4	0.717	42	7.5285	0.9130
5	1.20	6.058	1.826	2	0.115	39	2.2425	0.9180
6	1.42	7.267	1.836	4	0.367	42	3.8535	0.9410
7	1.43	5.518	1.882	2	0.323	40	6.4600	0.9885
8	1.62	5.746	1.977	3	0.503	42	7.0420	0.9185
9	1.43	7.665	1.837	3	0.372	40	4.9600	0.8565
10	1.37	6.335	1.713	4	0.258	33	2.1285	0.9400
11	1.46	7.945	1.880	3	0.407	38	5.1553	0.9520
12	1.55	6.852	1.904	4	0.436	38	4.1420	0.9320
13	1.44	5.447	1.864	3	0.371	40	4.9467	0.9790
14	1.84	6.433	1.958	4	0.656	39	6.3960	0.8250
15	1.33	4.786	1.650	3	0.191	35	3.3425	0.9415
16	1.87	5.859	1.883	2	0.667	38	5.9150	0.9290
17	1.60	4.686	1.858	2	0.455	39	1.9075	0.7375
18	1.13	6.121	1.475	2	0.109	35	4.2900	0.8520
19	1.25	9.503	1.704	3	0.220	39	5.8220	0.9090
20	1.34	4.099	1.818	2	0.284	41	6.3440	0.9540
21	1.66	6.094	1.908	3	0.488	39	2.5725	0.8320
22	2.82	5.743	1.664	4	0.147	35	4.4240	0.9355
23	1.64	5.832	1.871	6	0.316	42	5.1893	0.9035
24	2.01	8.332	1.807	3	0.561	37	9.7370	0.9990
25	1.18	6.323	1.998	4	1.498	39	6.5520	0.9220
26	1.65	7.481	1.844	2	0.504	39	8.7360	0.9405
27	1.34	5.719	1.881	3	0.896	39	2.4480	0.8415
28	1.81	7.320	1.683	2	0.136	36	7.5167	0.9650
29	1.60	6.004	1.930	4	0.550	41	4.5000	0.9235
30	2.34	6.457	1.847	4	0.225	40	6.8573	0.9770
31	1.87	7.635	1.954	5	0.669	41	5.0540	0.8855
32	1.60	7.369	1.771	4	0.532	38	9.7990	0.8855
33	1.34	6.928	1.993	4	1.195	41	4.9600	0.9965