SIMULATION MODELLING FOR A BUS MAINTENANCE FACILITY

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ABSTRACT

The Greyhound Lines Dallas Maintenance Facility was congested during peak operating periods. A stochastic model of this facility was developed to determine the resource requirements needed to provide adequate service during periods of peak demand. The structure of the simulation model is described. A representative sensitivity analysis is presented to discuss how this model was used to support facility sizing decisions. Based on our simulation experiments, we concluded that the existing site, with appropriate modifications, could accommodate peak traffic with some room for growth.

1 INTRODUCTION

Greyhound Lines, Inc. is the largest provider of intercity bus transportation (Greyhound 2004). As a result of increased passenger demand, a key mid-continent maintenance facility, located in Dallas TX, was experiencing unacceptable levels of congestion. Site expansion possibilities at the current site were limited, requiring that alternate sites further away from the passenger terminal be considered. Conventional deterministic capacity analysis methods were unable to predict the congestion and indicated optimistic resource utilization at the facility. Greyhound approached The University of Texas at Arlington (UTA) to assist in the development of a data-driven, stochastic discrete event simulation model of the facility to support the capital investment decision making process associated with modifying or replacing the current maintenance facility. This paper presents the model developed by the Greyhound/UTA team and provides a representative example of the types of facility analyses the model was able to support.

Greyhound offers intercity passenger service based on a set of daily *schedules*, defined by an origin, a destination, a departure time, and an arrival time. The number and type of buses that drive a schedule is determined by the passenger demand. Inbound buses drop passengers off at a passenger terminal and receive service at a maintenance facil-

ity. At a maintenance garage, every bus receives a set of standard services needed to support basic operational requirements like: refueling, lavatory service and internal and external cleaning. In addition, each bus has a set of *scheduled maintenance* work to be performed based on the number of miles traveled or the date of last inspection. There may also be other associated process work that results from what is discovered during the routine scheduled inspections. Based on need, buses receive service in one or more *maintenance shops*. Each shop or area has a unique set and quantity of resources and capabilities. After being serviced, the buses are placed in a *ready bus parking area*. Based upon the schedules departing from the terminal, buses are allocated to accommodate passenger demand. *Dead heads* are buses that are driven without passengers to other facilities in order to rebalance the network as a result of fluctuations in customer demand for service at a given location. It is desirable to minimize the number of nonrevenue generating trips that are required.

Some of the challenges that Greyhound faced are listed below:

- The facility was congested during peak operating periods, and there was a long wait for the buses to be serviced.
- The parking space allotted for the buses after all maintenance work was completed, referred to as *ready bus parking*, was insufficient.

We used the WITNESS® Simulation software to develop a discrete event simulation model of the Dallas Greyhound bus maintenance facility. The primary purpose of the model was to determine the minimum level of resources in each of the maintenance areas required to meet predicted peak service demands. Other objectives were to perform scheduled maintenance and inspection tasks along with the additional process work that might be required. With this capability, the model could support the site selection and facility sizing decision making process.

Section 2 of this paper reviews related literature. In section 3, we describe the model, which contains three modules: the inbound module, the maintenance module and the outbound module. Section 4 describes a sensitivity analysis that demonstrates the effects of increasing passenger traffic and section 5 gives directions for future research.

2   LITERATURE REVIEW

Appleby (1999) used a simulation model to demonstrate why buses always come in "bunches" to a bus stop. The effects of road congestion are neglected in his model, and he assumes the passenger arrival process is Poisson. He concludes that the bunching effect is primarily due to erratic passenger inter-arrival rate rather than imperfect scheduling. Li (2000) modeled passenger flow at a train station to evaluate station design, queue management, fare equipment design, and fare policy impacts. Raivio et al (2001) constructed a discrete event simulation model of operations at a maintenance facility of a fleet of Bae Hawk MK51 aircraft. The model identifies critical paths in operations, so they can shorten maintenance turn around times. However a model to determine the resource requirements for an intercity bus maintenance facility has not been considered in academic literature.

3   THE MODEL

Our model includes three modules: the inbound module, the maintenance module, and the outbound module. The *inbound module* generates passengers and buses that enter the terminal. The *maintenance module* performs service on the buses in the facility. The *outbound module* allocates buses from the ready bus parking area to the schedules leaving the terminal.

3.1 Inbound Module

For each schedule arriving at the terminal, the inbound module generates a random number of passengers based upon a probability distribution. The number and type of passengers, the origin of the schedule, and the destination determine the number and types of buses entering the model. When all the buses for a schedule have been allocated, they leave the inbound module. The arrival time of the buses is determined by a random variable associated with the assigned schedule. When the buses arrive at the destination terminal, they enter the maintenance module where further processing is done. Dead heads into the Dallas terminal are embedded in the inbound schedule.

3.2 Maintenance Module

Figure 1 depicts the flow of the buses through the maintenance module. The maintenance module comprises of two major components: service lanes and garage work areas. Each service lane consists of three stations: a pit area, where

the bus is fueled and routine inspection and light maintenance work is performed under the bus, a dump area, where lavatory service is done, and a wash rack, where the exterior of the bus is cleaned. All buses must receive service from all three stations.
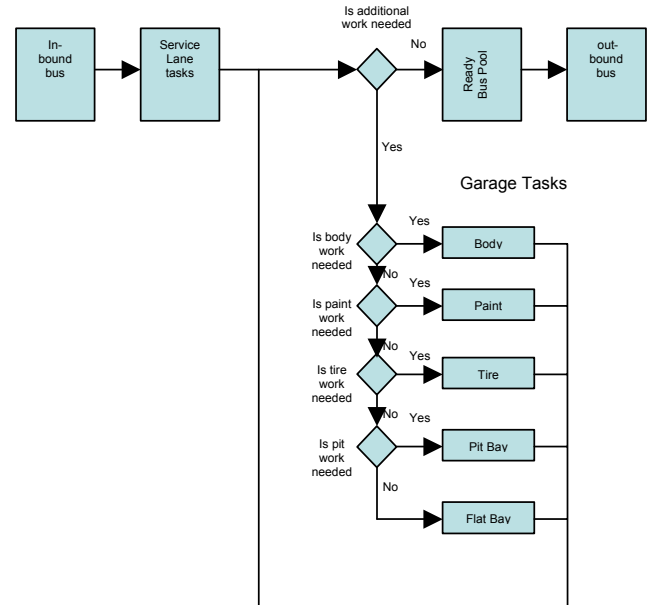

Figure 1: Schematic Representation of the Model

After the buses exit the service lanes, they enter a *garage work decision* element that determines which, if any, of the over 100 standard jobs will be performed on each bus. Each standard job has an associated *work activation code (WAC)*, and its assignment is determined by a Bernoulli random variable. Depending on which WACs are assigned, subsequent Bernoulli random variables determine whether additional work is performed; that is, the probability of performing a certain class of maintenance work is determined only after its associated inspection job has been performed.

Based on the WACs, the work decision machine pushes the buses to one of the several garage areas, which are flat bay, pit bay, tire shop, paint shop, and body shop. After completing all the repair work at the various garage areas, the buses move on to the ready bus parking area. This concludes the work done on the buses in the maintenance module.

3.3 Outbound Module

Similar to the generation of buses in the inbound module, the outbound module allocates buses to the set of schedules leaving the terminal. For each outbound schedule, a random variable generates a number and type of passengers. The outbound module assigns a set of buses from the ready bus parking area to a schedule based upon the requirements of the passengers.

The model was used in site planning projects by Greyhound. Our modeling team worked with facilities designers and evaluated multiple parking configurations in the outbound module to determine anticipated impact on operations. Although the simulation uses the Greyhound parking configuration, alternate configurations are easy to implement.

In addition to outbound schedules, other terminals request dead-head buses. A random variable generates a set of dead-head schedules to send the extra buses at midnight due to the lack of outbound schedules or insufficient number of passengers. Buses exit from the model once they get leave the outbound module.

4 VERIFICATION AND VALIDATION

The output obtained from the model was verified by comparing it against known historical data like the daily schedules, yearly utilization labor per task and the number of dead-heads. The output was found to be within the expected performance range. Some of the values obtained were global and represented the entire Greyhound network, hence we calibrated those values to represent the Dallas facility. The Greyhound staff reviewed the statistical and graphical model outputs and validated that it adequately represented the facility during peak demand periods.

5 SENSITIVITY ANALYSIS

A sensitivity analysis was performed to determine the number of service lanes required for smooth flow of operations. We simulated several scenarios with a variety of service lanes and passenger loads. We considered the following four measures in the sensitivity analysis:

- The maximum number of buses waiting in front of the service lane;
- The average number of buses in front of the service lanes;
- The average time that the buses waited in front of the service lanes;
- The percentage utilization of the service lanes.

The probability distributions in the simulation experiments were fitted distributions based upon historical data. In addition to these distributions, we made the following assumptions for the experiments:

- The probability of a WAC being assigned to a bus is determined by the total number of jobs of that class performed per year divided by the total number of buses serviced across the maintenance network in that year over all facilities.
- The service time distributions were developed from 51,240 maintenance records nationwide, and adjusted to match Dallas averages.

- The distributions for the duration of an inbound schedule includes an additional 25 minutes to travel from the passenger terminal to the maintenance facility.
- The simulated timetable and the number of passengers were based upon the week with the highest load in the summer of 2000.

Table 1 displays the results from a representative set of simulated experiments with four service lanes. The column labeled "pass load" shows the percentage increase in passenger loads for each experiment. Column "buses" is the average number of buses serviced per day, and "max buses" and "avg buses" indicate the maximum and average number of buses waiting for service. The "wait time" provides the average number of minutes the buses waited for service, and "% util" indicates the percentage utilization of labor in the pit station. The results were generated from an average of 100 replications of a 30 day operating period at the facility. Each row of the table represents the results of increasing the number of passengers in increments of 5% above the base peak load.

Table 1: Results for Experiments with 4 Service Lanes

Pass Load	Buses	Max Buses	Avg. Buses	Wait Time	% Util.
Base	118.3	16.9	2.1	26.2	87.3
5%	120.6	17.9	2.4	29.6	88.7
10%	122.5	19.9	3.1	36.7	90.4
15%	125.0	21.5	3.9	44.7	92.3
20%	128.4	26.8	6.1	68.2	94.8
25%	131.6	34.7	10.1	110	96.9
30%	133.8	75.5	35.3	373.1	98.8
35%	134.2	132.1	65.4	679.1	98.9

The performance was analyzed based on increased passenger load with critical factors being the number of buses waiting for service, the time the buses had to wait to get service and the percentage utilization of labor in that area. The maximum time that the buses could wait for service was 45 minutes and the realistic percentage utilization of workers, including allowances was set at 90. Hence from this representative study we can conclude that the ideal load the facility could take would lie between 10% and 15% in the table.

Similar sensitivity analysis was done to determine the maximum required parking facilities and the resource requirements in the various garage areas. The analysis performed was used as a component in the decision making process by Greyhound management. Based on our results some light maintenance work was transferred to the service lanes and the number of service lanes was increased from two to four. This implementation enabled them to operate

at their peak load comfortably while still having some room for growth. Consequently, we concluded that having four service lanes would ideally serve the facility.

6 FUTURE RESEARCH

We are currently using the generic structure of this model to support resource requirements studies for multiple facilities within Greyhound maintenance network. We plan to expand the modeling capabilities of the simulation to predict the cost of providing various types of service at each of the maintenance facilities. In order to capture the impact of service provision decisions, the interdependencies that exist amongst the facilities in the network must be modeled. This will require the development of a maintenance network model which will effectively contain anywhere between ten to twenty interlinked facilities models of the scope discussed in this paper. In addition, the model will have to support the concept of persistent buses that circulate throughout the Greyhound network.

In order to represent the cost of providing service accurately, Activity Based Costing (ABC) will have to be added to the model. The resulting closed network model will allow Greyhound to determine the most economical number, and location of garages, the number and types of buses, and the best schedule patterns to best service customer demands.

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