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A SIMULATION-BASED ANALYSIS OF PARKING SYSTEM PERFORMANCE

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ABSTRACT

The application of a microcomputer-based simulation model for analyzing the operation of a parking system is described as well as the model's results and sensitivity in coping with various uncertainties posed by the project's decision makers. Additional sensitivities were investigated based on an extrapolation of the natural growth of traffic flows and variations in vehicle arrival rates. The simulation model was designed to handle time headway, speed, intersections and stop signs, and peak traffic flows. The operational performance measures used for evaluating the system were the number of cars waiting at certain key intersections and at the entrances and exits of the parking structure, and the average amount of time that these cars spent waiting.

1 INTRODUCTION

The urban development transportation project described in this paper arose out of the perception that a critical parking shortage existed for the public and legislative and other state employees in the vicinity of the State Capital Building in Salem, Oregon. Prior to 1987, the Oregon State Parking Management Section had identified a shortfall of 3,000 parking spaces for state employees, alone, in the vicinity of the State Capital Building in Salem, Oregon. Additional cyclical and seasonal demand for parking spaces was being experienced, as for example, during each legislative session and during the income tax filing season. This number was expected to increase with growth of state government. The Oregon Legislature approved the creation of a two-level underground parking structure known as the Capital Mall Parking Structure for some 1,500 cars, at a cost of approximately 17.8 million dollars to relieve this demand for parking. A subsequent parking study (DKS Associates, 1989) was commissioned to assess various structural designs. After the project was approved by the legislature, the City of Salem, Traffic Management Section had concerns about the impact of the proposed parking structure on traffic patterns and delays. These specific concerns included: traffic flows in and around the proposed site, increased pedestrian traffic in the area and traffic growth over time.

2 PROBLEM DESCRIPTION

The area of concern was the network of streets and intersections in and around the proposed site shown in Figure 1. Also shown in Figure 1 is the traffic flow and traffic control structure used in this network. The initial study (DKS Associates, 1989) determined a structure design which allowed for entrance and exit on all four sides of the structure was appropriate due to the traffic measures of capacity and level of service. The City of Salem, Traffic Management Section, however, would only allow entrance and exit from the proposed structure on Chemeketa Street based on the same traffic performance measures. State managers decided that they wanted to use the more familiar measures of the average number of cars waiting and the average waiting time for those cars at various intersections for evaluating the parking system.

At the most general level, they were interested in these measures in the vicinity of the proposed site and at some key intersections, to satisfy city traffic concerns. On a particular level, both the construction and State project managers were worried about these measures, directly in front and inside of the entrances and exits for the proposed structure, due to the city's insistence to place them all on Chemeketa Street.

Chemeketa Street ran through the middle of the top floor of the underground parking structure. All cars bound to and from the structure had to enter and exit from this street. After the modeling project

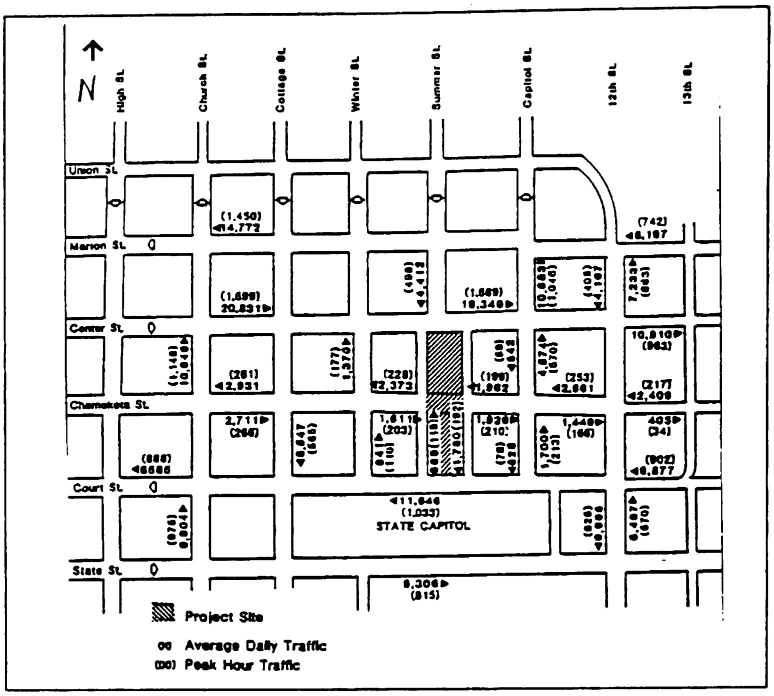

Figure 1: Grid Area of Concern

began, the city agreed to put stop signs on Chemeketa Street, directly before the two structure exits to facilitate traffic flow, despite maintaining that these signs were not necessary. These newly signed intersections became queues for concern that were later added to the model.

The performance measures needed to be tested for their sensitivity to future growth based on a city traffic growth rate of 5 percent per year. A decision to relocate several State agencies into the mall area also created a traffic growth sensitivity. Related to this unexpected growth in vehicle traffic was concern about the sensitivity of the performance measures to a perceived corresponding growth of pedestrian traffic in the grid of concern.

At the request of the Parking Section Manager of the Facilities Division of the Oregon State General Services Agency, a set of simulation models were developed and analyzed for the traffic system shown in Figure 1 to evaluate the performance measures and test their sensitivity to traffic growth and other concerns.

3 MODEL FORMULATION

3.1 Model Design

The simulation models were based on the assumption that all traffic systems can be viewed as consisting of entities (cars, etc.) that move along links that interact with each other and physical facilities. The simulation models were designed using SIMAN Simulation Software (Pegden, 1987) for a 286-based (or higher) IBM or compatible microcomputer. The models handled three situations and two different scenarios. A BASE model addressed the evaluation of performance measures in the Capitol Mall area without a parking structure. An AM model recorded how the AM peak hour traffic with the proposed new structure added changed the BASE situation, and a PM model did the same thing for the PM peak hour with the parking structure. The three models were run under conditions of an assumed normal car population growth in the greater Salem metropolitan area of 5% per year, for the base year of 1990 and each four years thereafter to 2002.

A first scenario accounted for the anticipated change in traffic growth due to the expected relocation of State agencies to the mall area. A second scenario modified the AM and PM peak period models. Instead of creating departures at some constant level over the period of an hour, it created departures at a rate that approximated the 15 minute traffic flow patterns on Chemeketa Street, reported by the City of Salem's, Traffic Management Section, for the respective AM and PM peak hour periods.

The reason for developing the AM and PM models was the expected ingress and egress of cars from the proposed structure. Figure 2 shows the expected ingress and egress, by hour, over a 24 hour period (DKS Associates, 1989). Of note are the dominant data spikes that occur in the AM from 7:00 to 8:00 and in the PM from 4:30 to 5:30. The absolute magnitude of these spikes compared to all other data reported would lead one to believe that running a model over the full 24 hour period to obtain average measures would not show the true nature for those average measures. Since the data spikes were so much greater than any data remotely close to them (including the noon hour period) it was initially felt that the model should only look at the peak hour periods as being the very worst effects that could influence the measures of concern.

To verify this supposition, once the simulation models had been developed and validated for arrivals and departures from the grid of concern, the AM and PM models were run, additionally, twice each. In the first run the data spikes immediately before the commanding spikes were included in the arrival and departure rates during the new two hour time interval formed by combining the data spikes. In the second run the data spikes immediately before and after were included and arrivals varied appropriately over the new three hour time interval. This experiment revealed that the greatest difference between model estimated average results was a factor of 1.0002. These results support the claim that the commanding data spikes during peak AM or PM rush hour stood alone as the most influential in evaluating the proposed model performance measures. Accordingly the remaining analysis was confined to peak AM and PM, rush hour, traffic flows.

3.2 Model Structure

The model structure for the BASE, AM, and PM models reflected a similar process. The models started by determining what, where and how, any given car would proceed in the grid of concern. For traffic lights, cars could "go" if they had a yellow or green light. Cars that could "go" would proceed to their next destination at some speed. They also would be regulated and synchronized, so as not to cause any collisions or inappropriate delays at any intersection. Streets that did not have traffic lights on them were modeled to prevent opposing traffic flows from occupying the intersection at the same time to avoid collisions and allow for an appropriate headway movement time to advance cars after stopping at the signs. Figure 3 depicts a flow diagram of the basic model structure.

After accounting for what, where, and how a car could proceed, a series of statements created arrivals

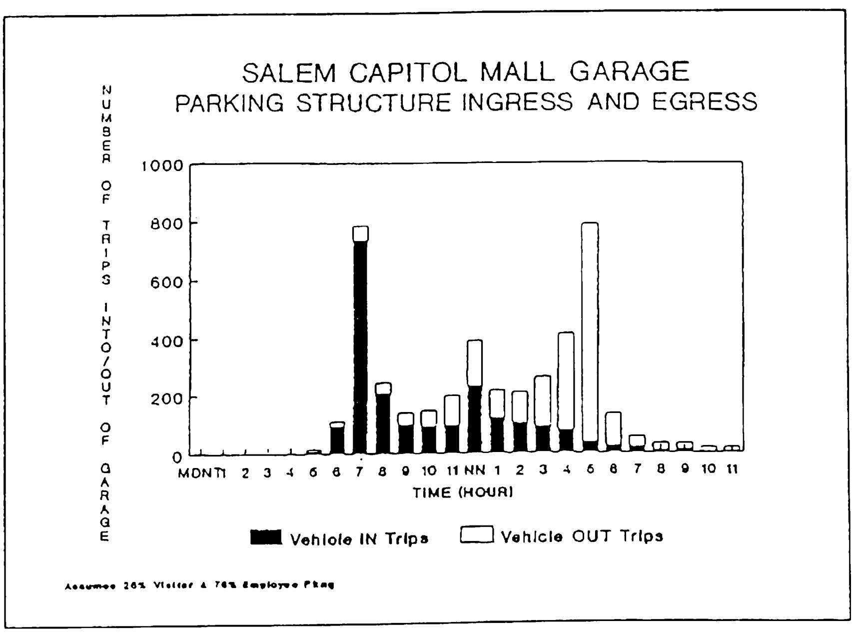

Figure 2: Expected Ingress/Egress from Parking Structure

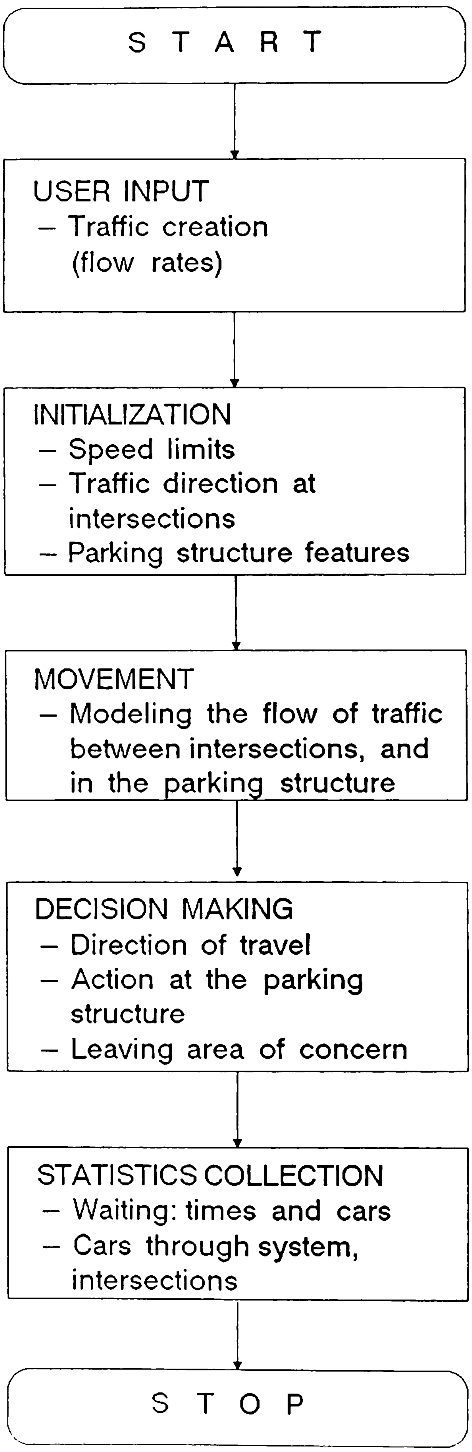

Figure 3. Simulation Model Structure

to the grid of concern. The models made creations from a theoretical distribution over the period of the rush hour, albeit AM or PM rush hour. Where Chemeketa street was concerned, a routine was called to separate the background level of traffic (i.e., the normal traffic flow if a structure had not been placed there) from the new traffic destined for the structure.

The remainder of the models' structure pertained to actions that a car must take at each intersection it encountered on the way to its ultimate destination. This was basically executing a left or right turn or going straight and traveling to the next intersection enroute to the final destination. Three set of routines were provided for modeling these decisions. The first set of routines applied to the intersections in the grid of concern for all modes (lanes) in directions where actions could occur. The second set applied to the pseudo-waiting areas immediately in front of the entrances to the structure, where cars had to take actions. Finally, the third set modeled links that took cars beyond the grid of concern.

4 ESTIMATION OF MODEL DATA

4.1 General

Traffic modelling consists of accounting for traffic demand, supply, and control through known traffic characteristics and analysis techniques that yield some performance measures. This requires one to develop three basic inputs, which include: traffic "flow data" (i.e., directional counts, directional control and delays, and movement headway times), traffic "speed data" (i.e., the rate of movement in any given section of roadway), and traffic "density data" (i.e., effects of platooning of cars, and unit interaction due to limits on lanes and driving habits with respect to spacing of cars on any given section of roadway). In developing this application a traffic density module was not explicitly included due to the adequacy of the roadway level of service in the grid area of concern for all scenarios over the problem time horizon. Such a module could easily be developed and added to the model structure.

4.2 Flow Data

Traffic flow data for 1990 was estimated based on information obtained from the Salem's Traffic Management Section. Figure 1 shows both the 24 hour traffic count and the peak hour traffic count, in parenthesis. For some intersections, the city did not have primary data; estimates were made based on the closest similar intersection to the actual one being modeled, as gleaned from the city's records. Once the data for 1990 was estimated, the assumption of 5 percent growth was then used to test the performance measures for traffic increase over time.

It is well reported that the arrival of a car at an intersection can be described as a Poisson distributed random variable, that is, interarrival times are Exponentially distributed (May, 1990). In the model, arrivals are modeled using their interarrival time based on the traffic flow data shown in Figure 1.

The percent of traffic turning left or right or going straight at each intersection and at the entrances and exits to the proposed structure were also based on historical traffic flow analysis worksheets provided by the City of Salem, Traffic Management Section. These documents recorded directional flow counts for cars, pedestrians, and bicycles for most intersections in the grid of concern.

4.3 Headway Times

Time headway is the interval between the arrival of cars at some observation point. Originally, the models used a city, traffic section provided, "expert's guess," at the times required to make left, right, and straight through maneuvers. Initial testing showed the performance measures of concern to be sensitive to small variations of these experienced guesses. Reasons included: the volume of traffic at the time a turn was being made, the number of pedestrians in a walkway, whether or not the intersection's signal was a light or stop sign and whether or not the driver actually stopped then started or rolled through the intersection. To obtain more accurate estimates, data was collected at various intersections over a period of two months. A time plot of the data showed that the data could be grouped based on similarity. However, within each group there appeared to be a wide range of variance.

A series of statistical tests were performed to analyze the grouped data and to fit appropriate statistical distributions (White, 1991). The results of this effort was that data sets were grouped into two categories: 4-way stop sign situations and traffic light situations. Goodness-of-fit tests for distribution fitting showed that several candidate distributions passed the selection criteria. When this occurs, hopefully, the literature on traffic modeling will have reported that experience shows one candidate better than the next. Though citing several model applications based on theoretical distributions which included erlang, gamma and lognormal distributions, the literature did not identify one as being better than any of the others.

The Weibull and the lognormal distributions were used in the model. To test the effectiveness of the Weibull against the lognormal, the model was run with a lognormal distribution substituted for the Weibull for movement headway time. The results yielded a maximum difference in numbers of cars waiting of plus one, and a waiting time minimum and maximum differences of 0.6 and 2.4 seconds, respectively. These results simply argue that use of the Weibull distribution versus the lognormal for time headway did not significantly effect the results of the model.

4.4 Speed

In the model, speed was important as an input parameter needed to introduce random variation in the rate of movement of cars within the grid of concern. Speed is influenced, most, by the freedom or interruption of traffic flow. Interrupted flow occurs in urban settings where traffic signals, traffic signs, rail traffic and pedestrian traffic impede the free flow of cars on a street. Movement between intersections has already been described as occurring at some variable rate as determined by a Normal variate (May, 1990); the mean of the normal distribution was assumed to be the posted speed limit. The computer code for the simulation models, input data and statistical tests evaluation are described in detail in White (1991).

4.5 Model Verification

A set of initial runs were made to compare the system performance under stochastic variables with the city's current traffic flow numbers. The computed average figures that the BASE model generated after an initial set of runs for traffic flow on Chemeketa Street, the street of concern, was evenly balanced with the model generating +0.32% more traffic flow. Similarly, the AM and PM models showed the same error to be quite small, 2 to 5 percent less than what it was supposed to be. This was less than 10 cars difference entering or leaving the parking structure. This showed that the models were performing basically as expected in the grid of concern.

5 SUMMARY OF RESULTS

5.1 Parking Structure Analysis

The maximum number of cars expected to be waiting at the proposed structure exits during the peak AM and PM traffic period, beginning in a base year of 1990 and every four years thereafter until 2002, are shown in Tables 1 and 2. It should be noted that average measures can be deceiving as a management guide. The maximum measures were actually of more

Table 1: Cars in Peak AM Period

Location	Year	Max # Cars	+ or -	Ave # Cars	+ or -
West Exit	1990	1	1	0	1
	1994	1	1	0	1
	1998	1	1	0	1
	2002	1	1	0	1
East Exit	1990	1	1	0	1
	1994	1	1	1	1
	1998	2	1	1	1
	2002	2	1	1	1

Table 2: Cars in Peak PM Period

Location	Year	Max # Cars	+ or -	Ave # Cars	+ or -
West Exit	1990	3	1	1	1
	1994	3	1	1	1
	1998	3	1	1	1
	2002	4	1	1	1
East Exit	1990	5	1	2	1
	1994	5	2	3	1
	1998	6	3	4	1
	2002	8	4	5	1

Table 3: Wait Time (sec.) Peak AM Period

Loca-tion	Year	Max Wait	+ or -	Ave Wait	+ or -
West Exit	1990	6.05	1.22	4.70	1.21
	1994	6.49	2.23	4.74	2.21
	1998	10.19	4.33	4.93	2.23
	2002	10.57	4.34	4.94	2.23
East Exit	1990	6.90	3.21	4.77	2.22
	1994	7.89	3.22	4.92	3.21
	1998	9.44	3.23	4.95	2.23
	2002	12.79	2.45	4.97	1.24

Table 4: Wait Time (sec.) Peak PM Period

Location	Year	Max Wait	+ or -	Ave Wait	+ OR -
West Exit	1990	15.5	1.14	5.99	1.13
	1994	18.41	2.21	6.16	2.13
	1998	19.44	4.25	6.18	2.30
	2002	22.87	4.31	6.59	2.30
East Exit	1990	24.98	3.13	7.34	2.13
	1994	25.72	3.22	8.30	3.33
	1998	27.49	3.23	8.63	2.34
	2002	34.35	2.34	9.22	1.21

importance in answering the questions posed by management. The plus and minus figure represented in the tables is the value of the computed confidence interval. Thus, for the year 1990, the maximum number of cars waiting at the East exit vary between 4 and 6 at a 95% confidence level.

Focusing on the maximum number of cars that could wait in line at either exit in either the AM or PM period one should note that the maximum possible value was 8 cars plus or minus 4 cars. This argued that one would not expect the maximum possible number of cars to be great enough to block either of the two interior ramps (a concern of the construction and State project managers).

The waiting times at the proposed structure exits during the peak AM and PM peak periods over the evaluation horizon are shown in Tables 3 and 4. These numbers are given with a statistical confidence of 95%. As before, the values of most interest to management were those in the maximum column as these represented the worst case. These results highlighted the fact that afternoon peak hour flows represented the greatest potential peak-hour waits.

5.2 Pedestrian Traffic Effect

The AM and PM models were tested for sensitivity to increases in the level of pedestrian traffic in the grid of concern. The pedestrian traffic was increased by a factor of 1.5, 2, 2.5 and 3. The graph shown in Figure 4 depicts the effects of these changes on the average waiting time at the West exit of the structure. Even after tripling the pedestrian traffic level, the average waiting time only changed by less than three seconds. It was thus reasonable to assume that the effects of pedestrian traffic will be negligible with regard to the operation of the structure.

5.3 Variation Within Peak Hours

In the analysis presented above, the departure rate of vehicles from the structure was constant for the peak period. A management concern was variation in the departure rate within a peak hour (e.g., employees leaving work in platoons instead of at a constant rate). To address this, a modified model created departures at rates which matched the peak hour fifteen minute traffic flow during the AM and PM rush hour. The graphs in Figures 5 and 6 show the results of this altered creation as it effected the average waiting time at the structure. The results demonstrated no significant change in output between the basic AM and PM models and the modified versions.

5.4 Discussion of Results

The analysis concluded that there were no significant problems with the design of the structure as it was being proposed. This was true regardless of the scenario of normal city vehicle growth (5% per year), added pedestrian traffic (tripled), added new vehicle traffic due to the addition of new State agencies in the mall area, or the reasonable variation of the number of simultaneous departures from the structure (based on current peak hour fifteen minute traffic flow counts). These results being accepted by the State project managers at the Facilities Division of the General Services Agency as validating the anticipated design, the construction of the structure was completed in May of 1992.

The values for output measures lead one to conclude that the City's failure to close Chemeketa Street to outside traffic (in spite of recommendations in the earlier engineering study to the contrary) would not seriously effect cars entering or leaving the structure. The design with all exits and entrances being located on Chemeketa Street was, thus, still sound. Average waits for cars exiting the structure during the peak PM hour were not expected to exceed 4 seconds exiting Westbound nor 5 seconds exiting Eastbound.

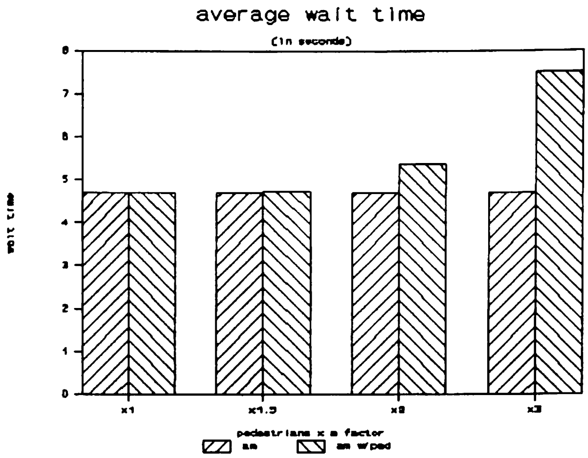

Figure 4: Pedestrian Effects on Wait Time

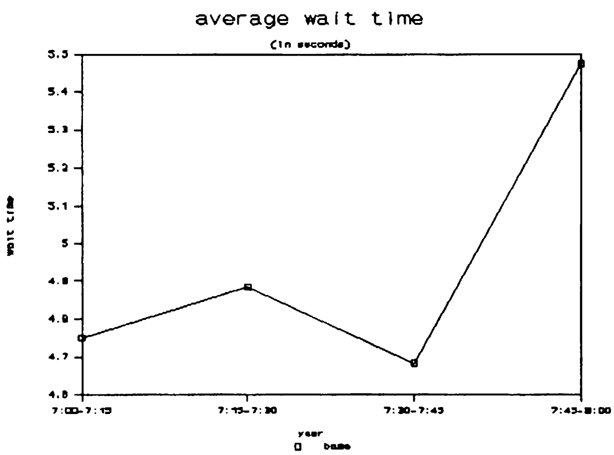

Figure 5: AM Wait Time with 15 Minute Scenario

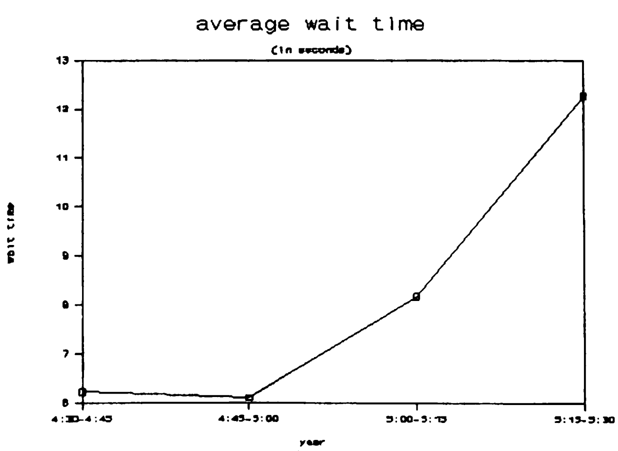

Figure 6: PM Wait Time with 15 Minute Scenario

In no case could they have exceeded 16 seconds exiting Westbound nor 25 seconds exiting Eastbound as a maximum in the base year.

The impact of pedestrian traffic on the parking system was negligible enough to disregard as a design issue. In 10 days worth of observing pedestrians cross signed and unsigned streets in the grid of concern, no more than 12 instances were observed where cars actually took evasive action (slowing down or stopping) to avoid pedestrians crossing the street.

6 CONCLUSIONS

A computer simulation approach was used to model and analyze a parking system. A PC-based simulation offered a more flexible format for the application. It was more interactive, with key managers able to directly access the program to make or direct various scenarios. Being written in desk-top software, the model was less intimidating from a programming stand-point. However, the application took longer to run on the personal computer. Since the Traffic Management Section owned several PC's, the program run time was transparent to the overall project as a cost. Because the performance measures could also be developed in queuing model language more familiar to construction and project managers, the PC-based simulation was judged to be a superior application to the software available at the City of Salem, Traffic Management Section.

Simulation was not only viable but proved to be very powerful in describing the relationships among different model parameters, and in investigating the sensitivity of the performance measures to changes in amount of pedestrian and regular traffic flows in and around the proposed parking structure. The ability to consider such sensitivity issues improves the predictive accuracy of the system and enhances the system's validity over time. It should be added that the model could be used to examine the effects of changes to several other factors such as varying types of vehicles, posted speed limits, traffic light cycle and offset times, and the addition or deletion of traffic lanes in the grid of concern.

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