LIFE CYCLE COST AS A CRITERION FOR OPTIMIZING THE CAPACITY OF VEHICLE TERMINALS

Jason C. Yu and Wilbert E. Wilhelm, Jr., Department of Civil Engineering, Virginia Polytechnic Institute and State University

The goal in planning and developing transportation terminal facilities is to provide capacity adequate to meet most demand. Capacity should be such that no substantial portion goes unused for so much of the time that the facility becomes uneconomical. Thus, some caution must be exercised in determining the optimum capacity for the normal period of demand pattern. This study was an attempt to develop a model that would specify the optimum vehicle storage capacity of a typical terminal facility over its entire life cycle. In approaching this objective, simulation methodologies, economic analysis, and statistical methods were blended and directed toward a practical solution of the problem. Specifically, the economic trade-off and the level-of-service concept were used to assist in the cost-effectiveness analysis. For illustration purposes, a microscopic model describing an individual terminal of the minicar transit system was formulated, tested, and refined. The resulting model is intended to be general and flexible enough to be used in planning the terminal capacity of any transportation mode.

•WITH the steady increase in traffic volume on highly congested urban streets, many potential solutions to the resulting transportation problems have been examined, including alteration of the existing travel mode and completely new transportation systems. Many of these innovations have been presented in experimental form in an attempt to reduce urban street congestion. Yet, the urban traveler still prefers the comfort, convenience, flexibility in routing, and manageable cost of his own private vehicle. Transportation system studies (1, 8) have examined the feasibility and desirability of introducing a system of small, electrically powered vehicles (minicars) into the highly populated urban area. This system provides users with the direct benefit of the standard private automobile and, at the same time, reduces urban congestion, noise, and pollution. A fleet of these small vehicles collects and distributes people on a rental basis. The proposed operating system would restrict the minicar movement between specially designed terminals. A user would rent a vehicle at the terminal nearest his origin, drive to the terminal nearest his destination, and leave the vehicle at the destination terminal. A large number of terminals would be provided either through adaptation of existing parking facilities or by construction of new ones. The terminal would be used both for vehicle storage and as a system access point.

A study by Yu (13) examined the improvement in parking space utilization when the minicar system is introduced. It was concluded that the ability of this system to pack more cars into the given amount of parking space can strongly and favorably influence the urban parking situation. Another interesting aspect of this system would be the determination of the optimal storage capacity of terminals. If each point served by a terminal reaches a peak accumulation of parked vehicles at the same time each day, the terminal would have to be sized at a uniform maximum. However, this is not

Sponsored by Task Force on Application of Economic Analysis to Transportation Problems.

realistic because all points will not reach a peak simultaneously so that either the timing functions of all demand points within an area served must be known or else the demand of all points at the time the terminal sees its peak load must be known. Also, the duration of vehicle storage for each individual trip also has significant bearing on the required terminal capacity.

The minicar transit mode would have many characteristics similar to the automobile, inasmuch as only licensed drivers use both modes. Therefore, arrival rates and departure rates for the two modes will have comparable characteristics. However, several important factors will differ. A previous study (14) showed that each minicar terminal would provide service to a bounded area within the CBD. Thus, the terminal must be expected to serve a particular set of customers whose trips either originate or terminate within this area near the terminal. Because all minicars will be alike, customers will be indifferent as to which one they use. A customer may select any available minicar when departing from the terminal. A particular minicar, therefore, will not be parked in the terminal until a certain customer returns to find the car for his departure trip. Most automobile parking facilities charge a graduated fee based on the parking duration. Because of the indifference between minicars, a fixed, prorated portion of the total rental cost of the minicar may be allocated to the operation of terminals. Because the fleet system will require a large initial investment and because it is intended as a benefit to society in general, it has been proposed that such a system be financed with public funds (1, 8). If this were done, it would be more appropriate to optimize the system on the basis of minimum total cost rather than maximum profit.

The main objective of this study was to provide a solution technique to determine the optimum capacity of minicar terminals. Because this optimum is found by balancing the cost of waiting to enter the terminal when it is filled to capacity with the cost of providing additional parking spaces in the facility, the procedure makes allowance for some planned waiting. Further objectives of this study were to determine the optimum capacity of a facility over its entire life cycle by considering changes in both the demand and total investment cost for a life cycle terminal capacity. Although the solution method developed was directly applied to the minicar transit system, the basic model with only minor changes should be applicable to other systems, such as automobile parking facilities, seating capacity on buses and trains, and other service facilities.

METHOD OF APPROACH

The study was concerned with determining the optimum economic capacity. There are occasional periods of high demand for which it would be uneconomical to provide quick and easy accommodation to every customer. To accommodate this demand without losing customers' goodwill would require a vast amount of parking spaces, most of which would be unused during the rest of the time period. In other words, when capacity of a facility is planned, it is assumed that occasional and infrequent periods of some overload will occur and will be tolerated. One solution to this dilemma may be the inclusion in the design of the ability to expand without rebuilding the entire facility to accommodate growth if and when needed.

Facility operation may be viewed as a queuing system in which the server (facility) is capable of serving a number of parked vehicles at any time and the service rate is the vehicle parking duration. Arrivals and services are stochastic processes that, for each trip purpose, are functions of time of day and day of the year. If the facility is filled to capacity at the time of arrival of a vehicle, the vehicle must enter a queue and wait for a storage space to become available. For an individual facility, the queue may build along the aisles within the facility or at the entrances to the facility.

Demand Representation

Demand patterns for the minicar terminal are difficult to forecast because the vehicle represents an innovation to transportation, and no historical trends on which to base predictions exist. However, the mode has many characteristics similar to the standard private automobile, and these were used to model the demand for the terminal under study.

Trip purpose, periodical demand fluctuations within a year, and year of the terminal life cycle have all had an important influence on the arrival rate (demand) of vehicles at the terminal. This study attempted to represent these fluctuations in demand as they might actually occur. The arrival process was assumed to be a Poisson distribution because it appears to fulfill all basic assumptions on which the Poisson process is defined (5):

1. The process $\{N(t), t > 0\}$ has independent increments.
2. In any small interval there is a positive probability that an arrival will occur, but it is not certain that an arrival will occur.
3. In sufficiently small intervals, at most one arrival can occur.
4. The process has stationary increments within each hour of day. Daily arrivals actually are distributed according to a nonhomogeneous Poisson process inasmuch as the mean rate of arrivals changes each hour of day.

In this study, four trip purposes that would correspond to local trips in a minicar system were assumed: work, shop, business (each to and from the CBD), and the intra-CBD trips (including all trip purposes). Each trip purpose was assigned a different arrival rate (mean of a Poisson distribution) over each hour of the day so that 40 distributions were used over each 10-hour day by the four trip purposes. The seasonal fluctuations were modeled by applying a daily adjustment factor to each distribution to adjust the mean of all arrival distributions within each day. Although this factor is actually a function of the day within a year, the study used a normal distribution and selected the adjustment factor as a random deviation from this distribution for each day. Year-to-year fluctuation was represented by a similar factor based on the assumed growth rate.

The duration of time that each minicar spends in the terminal depends on the departure demand for vehicles at a particular facility. To reflect this random process required that the parking duration for a given arrival be a random deviation generated from a normal distribution, where different normal distributions were assumed for each trip purpose and hour of day according to the arrival time. Because all minicars are alike, a customer uses any available minicar when leaving the terminal. For any given minicar, then, the arrival process is independent of the departure process. Independent departure rates could be used instead of the approach used in this study.

Figure 1 shows the assumed mean arrival rates by hour of day for each trip purpose. The arrival rate for each trip purpose reaches a peak each day; however, the peak time varies among trip purposes. Figure 2 shows the normal distributions that were used for vehicle parking duration for those vehicles that arrived the first hour of each day. These distributions were truncated to provide realistic parking times (allowable range was from 2 min to 12 hours).

Definitions of Costs

As indicated previously, terminal capacity was optimized with the objective of minimizing total costs. By definition, the total cost is the sum of the cost of providing and maintaining the terminal, plus the cost of waiting for a parking space when the terminal is filled to capacity at the time of an arrival. Mathematically, the objective function may be represented as

$$TC = (FC) + (VC)(CAP) + \sum_{i} (VT)_i(WT)_i$$

where

TC = total cost,
FC = fixed terminal cost,
VC = variable terminal cost,
CAP = terminal capacity,
VT = value of waiting time by trip purpose,
WT = total waiting time by trip purpose, and
i = trip purpose.

Figure 1. Mean arrivals by trip purpose and by hour of day.

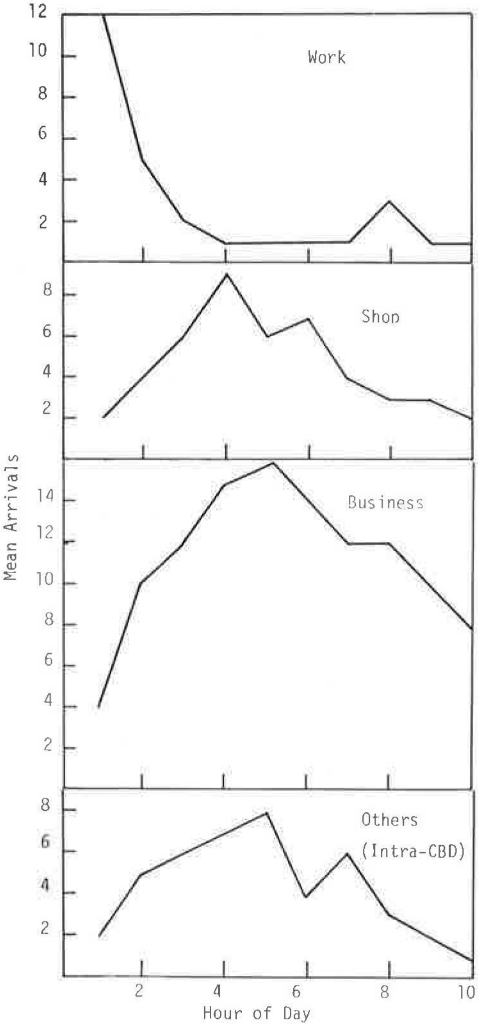


Figure 2. Vehicle parking duration (in minutes) for first hour of day.

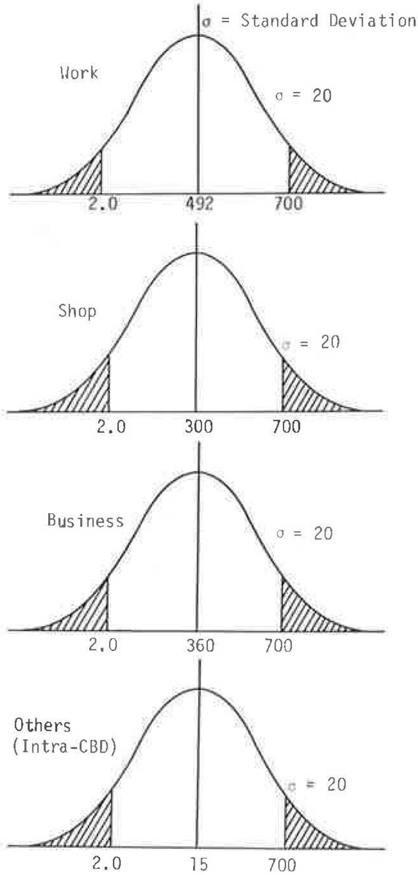
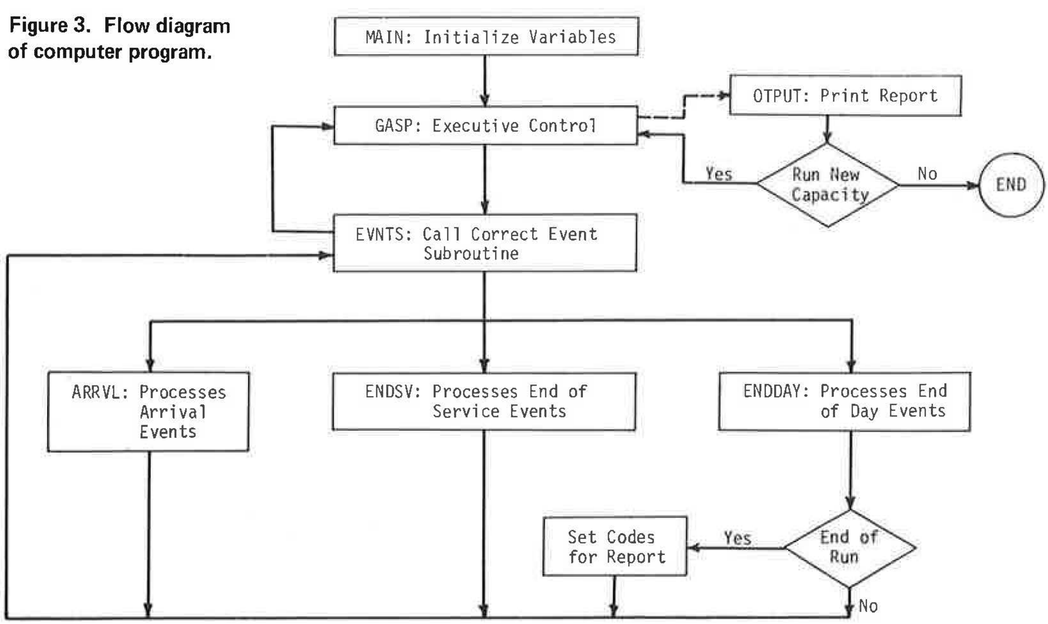


Figure 3. Flow diagram of computer program.



This study employed a fixed terminal cost of $20 per day and a variable cost of $0.46 per space per day, based on a previous study (14). The value of waiting time is a function of trip purpose because it is logical to assume, for instance, that a businessman will place a higher value on his time than a shopping housewife. The values assumed were $2.50, $2.00, $3.50, and $2.75 per hour for work, shop, business, and other trips respectively.

Simulation Program Description

Simulation techniques were applied to study the characteristics of the parking facility inasmuch as many important facets of the system may easily be described through simulation. Analytical procedures were not used to define the system because of the difficulties in problem formulation. The system never reaches a steady state, and the daily arrival rate is a nonhomogeneous Poisson process (nonstationary increments) due to the difference in hourly arrival rates.

It was felt that the discrete-event philosophy of simulation is most suitable to obtain the definition of the system under study. This simulation concept maintains that a system remains static until an event occurs that may cause a change in the state of the system. When an event occurs in the simulated time, only the effects of that particular type of event need be modeled. The GASP simulation language (6) was used because it provides an efficient means of discrete-event simulation.

GASP is essentially a set of FORTRAN-coded subroutines that provide necessary functions for simulations: executive control, gathering of statistics, generation of random numbers from a variety of probability distributions, dynamic storage of variables, and generation of reports. GASP maintains a file of events that will occur and will cause the appropriate subroutine to process an event when it occurs in simulated time. Only three types of events are necessary to model the terminal system: an arrival of a minicar at the facility, a departure from the facility, and an end-of-day event. At the occurrence time of an event, GASP removes the event attributes (or characteristics) from the event file, sets the code for the type of event (one of the attributes), and calls the appropriate subroutine to process the event.

As shown in Figure 3, the simulation program for this study consisted of a main program (that merely initializes values of variables and calls the GASP package), the EVNTS subroutine, the three event processing subroutines (ARRVL, ENDSV, and ENDDAY), and the OTPUT subroutine that provides a special report of the economic analysis for this problem. EVNTS merely calls the correct programmer-supplied subroutine to process that type of event.

Subroutine ARRVL processes all possible changes to the state of the system by an arrival at the terminal. The hour of day of the arrival is calculated, and the total demand variable is incremented by one. The next arrival event is then generated and stored in the event file to occur at some later time. Because the number of arrivals is Poisson-distributed, the time between arrivals is exponentially distributed (5) with a mean equal to the reciprocal of the associated Poisson mean. The appropriate Poisson mean is determined by the hour of the arrival; this value, along with the seasonal and yearly adjustment factors, is used to generate an exponential random deviation that represents the interarrival time. This value is added to the current arrival time and represents the time at which the next arrival will occur. This event time, along with the arrival code, is stored in the event file. The current arrival is then processed. The trip purpose is randomly generated based on the mix assigned for that hour of day; the parking duration for this vehicle is generated as a random deviation from the appropriate normal distribution as described previously. A check is then made to determine if the facility is currently filled to capacity. If a parking space is available, the number of parked vehicles is incremented by one (adding the vehicle to the lot), and an end-of-service event characterized by the time of occurrence (current time plus duration) and the end-of-service code is stored in the event file. Then ARRVL returns to GASP, which causes the next event to be processed. If the facility is full at the time of the current arrival, the attributes of this arrival (arrival time, trip purpose, and duration) are stored in a queue file, and ARRVL returns to GASP.

Subroutine ENDSV is entered to process the removal of a vehicle from the terminal. The total number of parked vehicles is decremented by one, and the number of departures for the current hour of day is incremented. A check is then made to determine if a vehicle is in the queue. If no vehicles are waiting to enter the facility, ENDSV returns to GASP. If there is a queue, the vehicle that arrived first is removed from the queue file, and an end-of-service event is created and stored in the event file. Statistics are then gathered on the time this vehicle waited in queue, and ENDSV returns to GASP for further processing.

Subroutine ENDDAY is entered at the end of each day (every 10 hours). All vehicles in the facility at that time are departed, and queues are emptied if there is a queue at that time. Various daily statistics are then collected by using appropriate GASP subroutines. The first arrival event for the next day and the next end-of-day event are generated and stored in the event file. Other system variables are initialized to start the next day. A check is then made; and, if the simulation run has not completed 250 days (weekdays per year only), ENDDAY returns to GASP to process the next day. If 250 days have been simulated, several codes are reset to cause GASP to print reports.

After GASP prints standard reports, subroutine OTPUT is called to generate a report on the economic evaluation for the terminal. Terminal capacity by year of the life cycle is then incremented, and a sequential run is initiated to simulate the revised terminal capacity. This procedure is used to evaluate the total cost function over a wide range of terminal capacities and years within the life cycle.

SINGLE-YEAR CAPACITY ANALYSIS

A previous study (15) indicated that each terminal should serve a diamond-shaped service area to minimize average walking distance along the rectilinear walking paths found in most cities. Because the minicar transit system must consist of a network of terminals to provide service to urban travelers, the capacity of each terminal depends on the vehicle storage demand generated within the bounded service area. The level of (attracted) demand used in this study represents the part of the total available demand in the service area that is attracted to the minicar transit system. As indicated previously, four trip purposes were assumed in this study. For the intra-CBD trips, total arrivals may be different from total departures, with each customer using only one-way service to or from a terminal. For simplicity, all purposes were handled the same by assuming that the arrival of a vehicle triggered the departure of some vehicle at some future time. It could be assumed that these two processes are independent. The advantage gained in using this approach is that input to the facility equals output.

SINGLE-YEAR SIMULATION

This section describes the important results of simulating demand for a period of 1 year. Various characteristics of the system were defined by the results and the optimum terminal capacity was determined. For each capacity tested, the simulation period covered 250, 10-hour weekdays or the equivalent of 1 year of operation.

The total number of arrivals per hour appears fairly uniform because the input data were arbitrarily selected. The trip purpose mix within the total is, however, quite different from hour to hour as seen in Figure 1. The total number of departures per hour is high during the last half of the day, reaching a peak during the evening rush hour, as expected. This represents a large number of vehicles entering the traffic stream during peak congestion time, and the capacity of the bordering streets should be checked to ensure that it is adequate to handle this increased traffic volume. Figure 4 shows these relationships.

The average number of parked vehicles at the end of each day was found to be about nine. As expected, no units were in the queue at the end of each day. In an actual case, some may park overnight; or, in the minicar system, redistribution at night may cause some vehicles to be in the facility at the beginning of the next day. These vehicles, however, would not affect the waiting times incurred if they depart the facility early the next day before the facility is filled to capacity.

Figure 4. Mean arrivals and departures by hour of day at optimum capacity.

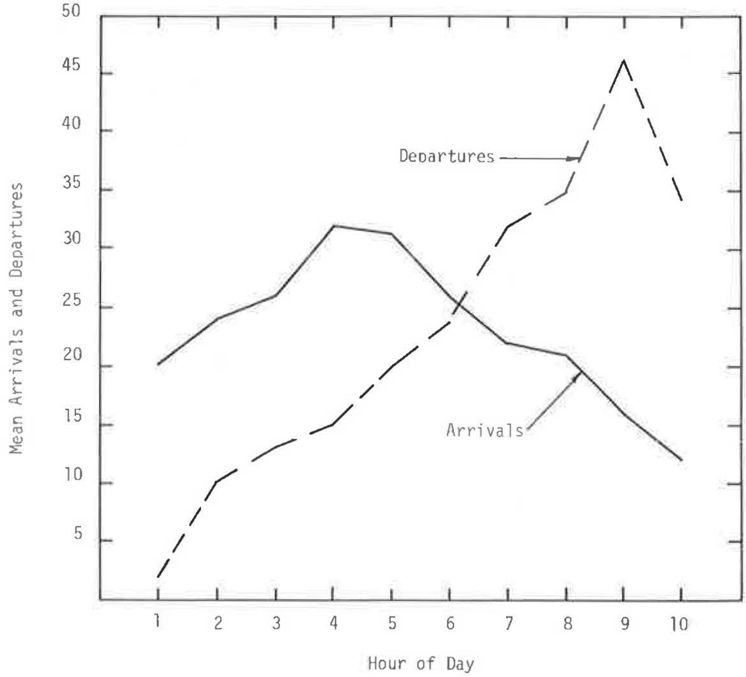
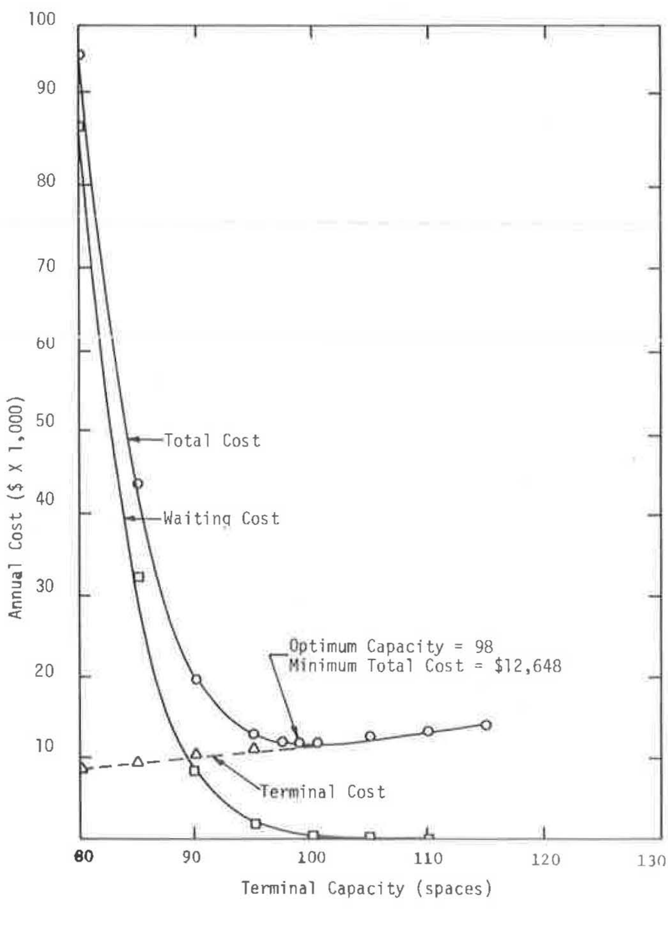


Figure 5. Annual cost versus capacity (1-year analysis).



Peak accumulation of parked vehicles is, of course, a function of the capacity and increases as capacity increases. The average peak accumulation is somewhat lower than the capacity because the peak accumulation will not fill the facility on some days. The expected time of day that peak accumulation was experienced was approximately 1:00 to 2:00 p.m., which corresponds well with results from studies of automobile parking facilities.

Figure 5 shows the expected costs (on an annual basis) as a function of facility capacity. It is seen that small changes in capacity (below optimum) have a large effect on the waiting cost. For the demand rates assumed, minimum total cost occurred at a capacity of 98 spaces. Beyond this capacity, total costs again increase due to increasing facility costs, whereas waiting costs (practically) reduce to zero. For very large capacities, total cost equals facility cost and increases linearly. Table 1 gives the values of the various costs for several capacities. Total cost per year at optimal capacity is \$12,648, waiting cost is \$298, and facility cost is \$12,350.

The total daily demand is described by a mean of 236 vehicles and a standard deviation of 28 (minimum = 168, maximum = 317). This is perhaps low for an actual facility, but demand rates were selected to lower required computer storage space for this study while indicating important system characteristics. The turnover rate averaged 2.41 per day with a minimum of 1.71 and a maximum of 3.23.

At this optimum capacity, 533 vehicles out of a total of 59,004 arrivals waited. The probability that an arrival will wait was therefore 0.009. The expected waiting time of those that waited was 12.5 min. Waiting occurred only on 19 days out of 250 (7.6 percent). The total waiting time was 110.6 hours with the following breakdown: workers, 6.1 hours; shoppers, 23.3 hours; business, 17.2 hours; and others, 64 hours.

Waiting time followed a negative exponential form with only a few vehicles waiting longer times. Figure 6 shows the resulting relative frequency distribution of waiting time. As capacity was increased, the maximum number of units in the queue decreased but at a decreasing rate. This appears reasonable inasmuch as it was shown that, if a vehicle waits in a queue, it will probably wait only a short time. Each increment in capacity, therefore, included a "smaller increment" of queue. Although it may be economical with respect to the parking facility total cost to incur some waiting, there are additional practical factors that must be considered. First, not everyone will wait for a space to become available; balking and reneging may occur even though a customer is supposed to use a given terminal. Consideration of this effect would be included in an expanded study that would include the impact of these changes on neighboring terminals. Second, there must be adequate physical space for the queue of vehicles to build. This might be in the traffic lanes within the facility or along adjacent streets. Under the assumptions of this study, the maximum number of vehicles in queue at one time was 27, the average number was 0.0441, and the standard deviation was 0.7393. The length of the queue is thus seen to be a problem on only a few days during the year. A capacity of 110 was required to eliminate all waiting; this would require investment in 12 additional spaces in the facility.

To study the profit potential of the facility, we assumed that a portion of the minicar rental cost would be allocated to the facility. A value of \$0.35 was used for all vehicles, inasmuch as duration will not affect this fee structure for the minicar operated on a fleet parking basis. The profit analysis indicated that profits are lowered as the capacity is increased (profit = \$8,300 at capacity of 98). The optimization criterion, therefore, is seen to be an important factor in the analysis. It is conjectured that optimum capacity based on maximizing profit would be equal to the minimum peak daily demand because the facility would have a maximum utilization at that point. Capacities greater than this would result in unused spaces at least some of the day. However, this neglects ill will caused by inadequate size and, practically, may not be optimal.

DETERMINATION OF OPTIMUM LIFE-CYCLE CAPACITY

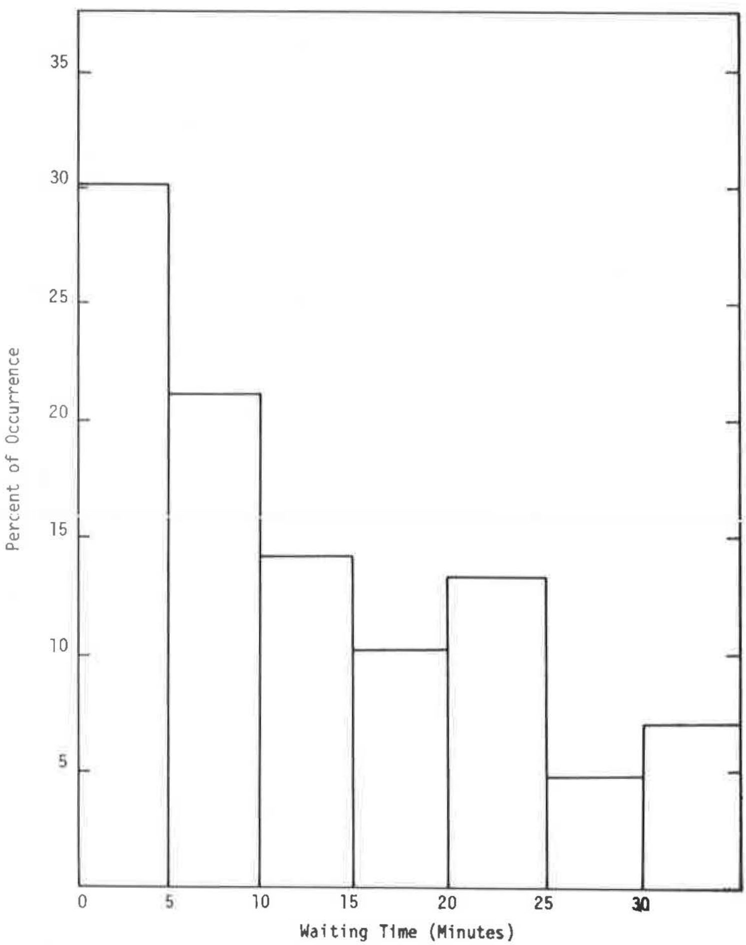
The preceding section determined the optimum capacity of a facility by using the demand characteristics of a 1-year period. Realistically, a terminal must be of optimum capacity over its entire life cycle, so the demand must be accurately projected

Table 1. Data for single-year analysis.

Capacity	Waiting Cost ($)	Terminal Cost[a] ($)	Total Cost[b] ($)	Wait Time (hour)	No. of Days Waiting Occurred	Maximum Queue Length	No. of Waiting Vehicles
60	87,298	9,500	96,798	32,016	245	120	27,053
70	32,750	10,250	43,000	12,015	199	87	16,080
80	8,852	11,000	19,852	3,264	125	61	7,096
90	1,627	11,750	13,378	602	54	40	2,012
94	736	12,050	12,786	272	32	35	1,065
95	591	12,125	12,716	219	28	33	898
96	468	12,200	12,668	174	26	31	775
97	375	12,275	12,650	139	23	29	635
98[c]	298	12,350	12,648	111	19	27	533
99	238	12,425	12,663	88	16	24	455
100	188	12,500	12,688	70	13	22	385
101	145	12,575	12,720	54	11	20	344
110	2.6	13,250	13,252	0.9	3	6	22
120	0	14,000	14,000	0	0	0	0
130	0	14,750	14,750	0	0	0	0

[a]Including $5,000 fixed cost. [b]Decision variable. [c]Optimum capacity.

Figure 6. Waiting time distribution.



over the life cycle to determine optimal life-cycle capacity. A yearly adjustment factor was applied to the demand rates, and the simulation period was extended over the life cycle of the system to determine optimum life-cycle capacity.

Although a unique optimum capacity may exist for each year's demand, yearly changes in terminal capacity may not be practical so that a fixed capacity must, in many cases, be used over the system life cycle. The optimal life-cycle capacity is the capacity that minimizes the present worth of the total cost over all years.

Several additional factors could be considered in this life-cycle analysis. The demand mix may change over future years as well as the variance of parking duration. The local economy (inflation, recession, and the like) must be evaluated over the future years. Inflation, for instance, would increase the value of waiting time as well as terminal operating costs. Accurate predictions are mandatory to finding the optimal solution.

The computer program developed during this study was used for this life-cycle analysis. It was assumed that the demand rate would increase by 6 percent per year (compound), while terminal fixed costs would remain constant at $5,000 per year and all other costs (waiting, terminal variable, and parking costs) would increase by 5 percent per year (compound). The trip-purpose mix within the total and the parking duration were assumed to remain the same as used previously. These are relatively simple assumptions concerning future changes but indicate quite drastic differences in the results. The terminal life cycle was assumed to be 10 years. Each capacity examined was simulated for each of the 10 years under the appropriate demand and cost structure. The present worth of the costs for each of the 10 years for each capacity was found, and the objective became that of finding the capacity that minimized the present worth total cost over the life cycle. Figure 7 shows this present worth function for various capacities and indicates that the optimum capacity under these assumptions was 146 spaces. Total cost increases rapidly for capacities less than optimum because of increased waiting time. Capacities greater than optimum reduce waiting and increase the level of service but at the expense of increased investment and terminal operating cost.

Data given in Table 2 show some interesting results for this optimum capacity. No waiting occurred for the first 5 years, but the waiting incurred in years 9 and 10 may be prohibitive. Profit was greater than terminal cost only in the last 4 years. This indicates that a better scheme than having a fixed capacity over the life cycle may be found. However, in many cases, a variable capacity may not be feasible, particularly with respect to land availability. Dynamic programming could be used to determine the optimum variable capacity program although it would prove to be an expensive method of analysis. Alternately, a constrained objective function could be employed to determine the optimum, minimum total cost capacity that would allow no more than a predetermined maximum number in a queue or a maximum amount of waiting time or both.

CONCLUSIONS AND RECOMMENDATIONS

The criteria on which the worth of the system is evaluated are principally economic in nature. That is, the "best" choice of a parking facility capacity for a given demand is simply the configuration that achieves the lowest cost solution in light of the economic trade-offs that are characteristic of such problems. The theoretical considerations should be basically incorporated into any practical application. If we are to illustrate the optimization concept, we should generalize the solution method by determining the capacity of an actual facility so that the method can be examined from both theoretical and practical levels.

The discrete-event simulation model developed by this study is a good method to determine the optimum capacity of minicar terminals and to analyze the effects of waiting with respect to users and the terminal area. The model provides a great deal of detailed information about the terminal system. Changes or additions to the program can be made easily to provide additional information that may be required for a particular application. The objective of other studies may be to maximize profits and determine return on investment rather than minimize costs, but the computer processing

Figure 7. Life cycle capacity costs.

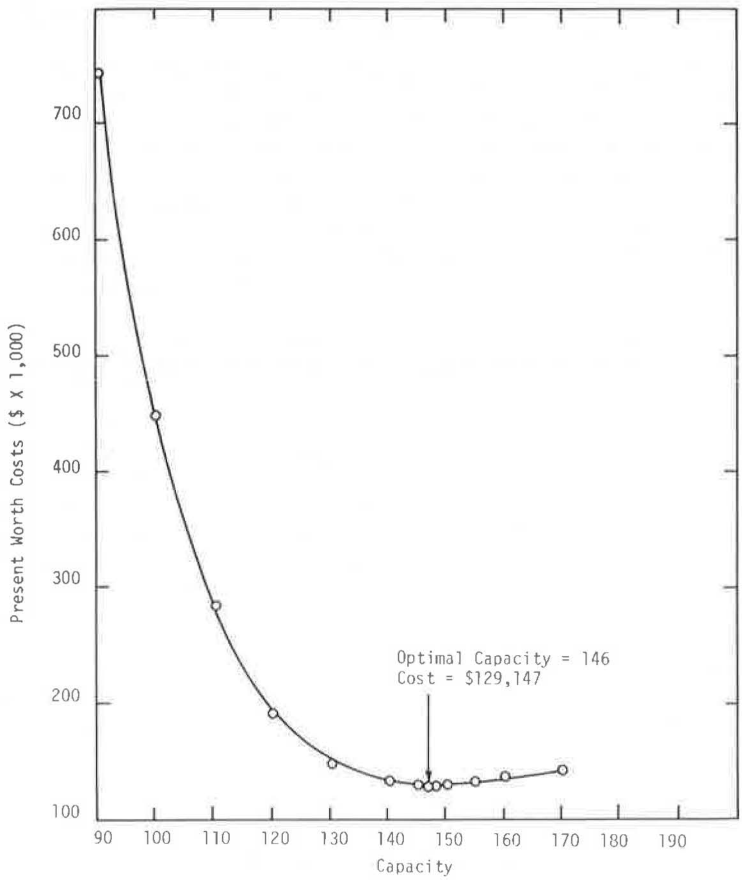


Table 2. Life cycle analysis—optimal capacity.

Year	Waiting Cost ($)	Terminal: Fixed Cost ($)	Terminal: Variable Cost ($)	Terminal: Total Cost ($)	Total Costs	No. of Days Waiting Occurred	No. of Waiting Vehicles	Maximum in Queue	Total Demand	Profit (disc.)	Waiting Time (min): Average	Waiting Time (min): Maximum
1	0	4,630	10,139	14,769	14,769	0	0	0	59,004	4,350	0	0
2	0	4,287	9,857	14,144	14,144	0	0	0	62,121	5,680	0	0
3	0	3,969	9,583	13,553	13,553	0	0	0	66,415	7,270	0	0
4	0	3,675	9,317	12,992	12,992	0	0	0	70,676	8,730	0	0
5	0	3,403	9,058	12,461	12,461	0	0	0	75,542	10,300	0	0
6	1.20	3,151	8,807	11,958	11,959	1	12	4	80,139	11,620	2.8	4.6
7	66.3	2,917	8,562	11,480	11,546	8	241	17	84,545	12,840	7.9	22
8	275	2,701	8,324	11,026	11,301	15	808	26	89,919	14,200	10	37
9	2,309	2,501	8,093	10,594	12,904	38	2,839	83	95,566	15,560	24.3	82
10	2,316	2,316	7,868	10,184	13,548	73	5,036	97	100,510	16,550	20.6	104
Total					129,147					107,100		

would remain basically the same. The most important factor in applying the model is to predict accurately the demand structure to be serviced. Although discussion of prediction models is beyond the scope of this paper, suffice it to say that the true stochastic nature of demand must be adequately predicted to obtain meaningful results.

It was also shown that optimization to maximize profits gave a very different solution than optimizing to minimize total costs. It is evident that the minimum-cost solution is superior because it provides for a larger terminal and thus a higher level of service to customers. In an actual application, it may be desirable to find the optimum capacity without studying the cost function over a wide range. The Fibonnaci search procedure (10) may be incorporated into the computer program to do this economically. This search technique guarantees that the optimal solution would be found in a minimum amount of computer processing time.

In an actual minicar system, an imbalance may exist between the daily arrival and departure rates at a given terminal. This would necessitate the redistribution of minicars sometime during the day or night to ensure the best distribution of vehicles throughout the system. An extension of this study, therefore, should include the possibility of having to wait for an available minicar at departure time and the redistribution interaction among terminals in the minicar network.

ACKNOWLEDGMENTS

This research was performed, in part, under a project supported by the National Science Foundation. The research contract was awarded to the Civil Engineering Department of Virginia Polytechnic Institute and State University.

REFERENCES

1. Altman, M., et al. Minicar Transit System: Feasibility Study, Books 1 and 2. Univ. of Pennsylvania, Philadelphia, 1968.
2. Baerwald, J. E., ed. Traffic Engineering Handbook. Institute of Traffic Engineers, 1965, pp. 459-500.
3. Capobianco, M. F. Using Probabilities to Compare Parking Disciplines. Traffic Quarterly, Vol. 22, No. 1, Jan. 1968, pp. 137-144.
4. Kole, C. P. Real-Time Parking Control. Traffic Engineering, April 1967, pp. 36-38.
5. Parzen, E. Stochastic Processes. Holden-Day, San Francisco, 1967, p. 118.
6. Pritskan, A. A. B., and Kiviat, P. J. Simulation With GASP. Prentice-Hall, Englewood Cliffs, N. J., 1968.
7. Schulman, L. L., and Stout, R. W. A Parking Study Through the Use of Origin-Destination Data. Highway Research Record 317, 1970, pp. 14-29.
8. Vuchic, V. R., ed. Minicar Transit System, Final Report. Univ. of Pennsylvania, Philadelphia, 1970.
9. Parking in the City Center. Wilbur Smith and Assoc., New Haven, Conn., 1965.
10. Wilde, D. J., and Beightler, C. S. Foundation of Optimization. Prentice-Hall, Englewood Cliffs, N. J., 1967.
11. Wilhelm, W. E. Determination of the Number, Location, and Capacity of Terminals in a Network. Virginia Polytechnic Institute, Master's thesis, 1970.
12. Wohl, M. A Methodology for Forecasting Peak and Off-Peak Travel Volumes. Highway Research Record 322, 1970, pp. 183-219.
13. Yu, J. C. A Parametric Analysis of Fleet Parking Terminal Capacity. Highway Research Record 317, 1970, pp. 30-39.
14. Yu, J. C., and Wilhelm, W. E. Optimization of Urban Transportation Terminal Network. Highway Research Record 348, 1971, pp. 94-108.
15. Yu, J. C., and Wilhelm, W. E. Optimal Location Patterns of Urban Transportation Terminals. Presented at the Joint Transportation Engineering Conference, Chicago, Oct. 1970.

SPONSORSHIP OF THIS RECORD

GROUP 1—TRANSPORTATION SYSTEMS PLANNING AND ADMINISTRATION
Charles V. Wootan, Texas A&M University, chairman

Committee on Transportation Information Systems and Data Requirements
Robert E. Barraclough, Information Systems Consultant, chairman
Ben Alexander, Geoffrey J. H. Brown, Henry W. Bruck, Edward N. Dodson, Kenneth J. Dueker, David J. Dunlap, Gideon Hashimshony, George T. Lathrop, Joseph M. Manning, Alfred J. Marston, Peter S. Parsonson, Albin Pearson, Alan E. Pisarski, Sydney R. Robertson, George N. Sarames, Arthur B. Sosslau, D. L. Wieman, J. E. Wright

Task Force on Application of Economic Analysis to Transportation Problems
Robley Winfrey, consulting civil engineer, chairman
James B. Chiles, Paul J. Claffey, Donald O. Covault, Dan G. Haney, Herbert Mohring, Roger G. Noll, Clarkson H. Oglesby, Jan De Weille

James A. Scott and Kenneth E. Cook, Highway Research Board staff

The sponsor is identified by a footnote on the first page of each report.