IMPORTANT ISSUES IN UP PEAK TRAFFIC HANDLING

Dr. Bruce A. Powell
Principal Research Engineer
Otis Elevator Company
Farmington, CT

ABSTRACT

The heavy influx of passenger traffic into a major office building at the start of business hours is commonly referred to as Up Peak. Unless the elevator dispatching logic takes special recognition of this traffic pattern, large queues of waiting passengers may develop in the main lobby. This paper will address this Up Peak traffic situation and will describe the Otis approach of the CHANNELING passenger traffic management option. It will focus on the effects of queuing and traffic handling capability of newer approaches as contrasted with traditional solutions.

INTRODUCTION

The morning influx of people into a major office building places a heavy load on the elevator system. Often, sizeable crowds of passengers queue up for elevator service in the main lobby of a building. This situation is called Up Peak, where the overwhelming majority of passengers board the elevators in the lobby and travel up to their destinations. Elevator systems are usually designed to recognize the occurrence of this situation not only in the initial design of the number and size of the elevators but also in the logic used in dispatching the elevators from the lobby floor.

The traditional approach to the handling of up peak traffic is to recommend that the number of elevators installed in a new building be sufficient to carry the expected influx of passengers without major delays and queuing. Additional steps are taken in the dispatching logic, such as expressing a car back to the lobby after it becomes empty. Whereas the method of "elevatoring" a building is fairly standard across the industry, the dispatching rules vary from one elevator company to another.

The Otis Channeling passenger traffic management option differs fundamentally from the traditional approach. It is widely acknowledged that a reduction in the number of stops contributes to efficiency of the group of elevators. The Channeling option takes maximum advantage of "coincident destinations" by directing passengers with similar destinations into the same car. This is done by restricting the number of floors served on any trip to a small subset of the total number of upper floors. This is in marked contrast to the traditional approach where all cars serve all floors. This approach has the obvious advantage of fewer stops per trip, which in turn leads to shorter round trip time, shorter interval, and a lower average turnaround floor.

This paper will discuss the handling of up peak traffic in general and the Otis Channeling option in particular. Detailed results of computer simulation experiments are presented to show the effects of the Channeling option on the important, observable parameters: round trip time, waiting time, service time, and queuing. It will be shown that the Channeling option offers a benefit to passengers in reduced service time and a benefit to the building in a more robust elevator system with capacity to handle heavier traffic due to increased building occupancy. In addition to a more robust system, the Channeling option offers the distinct possibility that under some circumstances, fewer and/or smaller elevators can be used.

CURRENT METHODOLOGY

In the planning for a new building, the "elevatoring" calculations are usually based on morning up peak traffic. Typically, the recommended number of cars must meet performance requirements such as

INTERVAL $\leq$ 30 seconds
CARRYING CAPABILITY $\geq$ 12% Population/5-minutes
ROUND TRIP TIME $\leq$ 150 seconds

The degree to which a solution meets these requirements is based largely on a mathematical estimation calculation of the round trip time of an average elevator carrying a given load during up peak. All elevator contractors and consultants have methods to estimate round trip time, interval, and handling capability which are based largely on the same assumptions discussed in References [1], [2], and [3].

Consider a hypothetical building with 12 floors above the lobby, with each floor having a population of 100 people. With a moderately heavy load of 13 people, a round trip would be expected to make approximately 8 stops and require 130 seconds. This round trip time calculation assumes accepted parameter values for car speed, floor height, door times, boarding rates, etc. The standard methods of elevatoring can be used to show that a total of five elevators are required to satisfy the up peak requirements listed above. This implies that a group of five elevators will be able to smoothly move people away from the lobby as fast as they arrive in the morning up peak time period. To complete the elevatoring analysis, an improved method is to take the recommended five car group and also estimate waiting times under two additional and distinctly different traffic periods: (a) evening down peak and (b) two-way noon period. These additional analyses were carried out for this building, and the result was that the five car group performed satisfactorily, answering all hall calls in an average of 18 seconds under heavy traffic intensity.

The above up peak result based on round trip time calculations implies that the group of five elevators will operate as specified under the following conditions:

* People arrive at a steady rate 12% of the population per five minutes.

o Elevators are maintained on a regular schedule of one departure every 130/5 or 26 seconds.

o Each elevator is loaded to the same number of passengers (in this case, 13).

o No interfloor or counterflow traffic occurs.

o All elevators are in service 100% of the time.

Any departure from the above conditions will affect the accuracy of the result to the extent that the prediction could not be observed in an actual building. In fact, these conditions rarely are met. Passenger traffic intensity is often below 12% for any given five minute period and can easily reach 16% during the heaviest five minutes of up peak. It is difficult to control the departures of elevators to an exact interval of 26 seconds. The load on a car often reaches 20 people and just as often (during the start and end of the rush hour) is less than 13. Interfloor and counterflow traffic exists during up peak, albeit at low levels of intensity. Finally, from time to time, an elevator must be removed from service for maintenance.

Given these complications, the method of elevatoring based solely on solutions determined from the round trip time and interval is inadequate and incomplete. These solutions should be used as a starting point to the planning of an elevator system, with the next step being the use of detailed simulation modeling of the events involving the interaction of passenger traffic with the elevators.

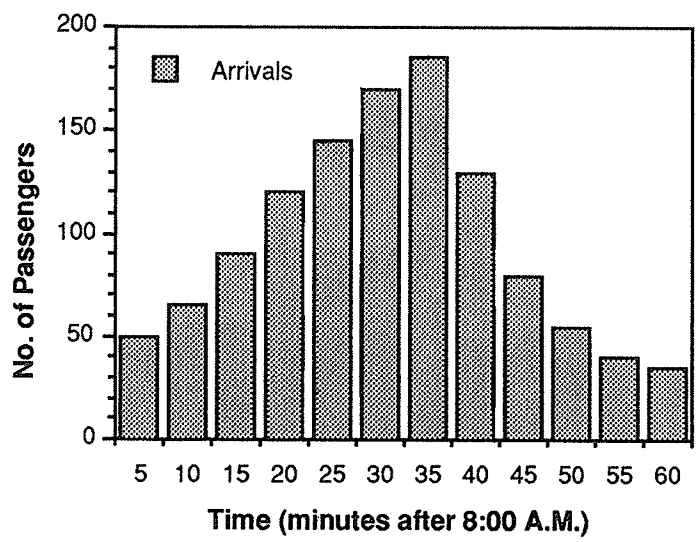

Figure 1. Up Peak Passenger Traffic Profile

SIMULATION MODELING FOR UP PEAK TRAFFIC

Observations of existing high-rise buildings show that the morning influx of passengers typically lasts for about one hour. Traffic starts gradually at low levels of intensity (approximately 3-4%), builds up to a peak (as high as 16% in single purpose office buildings), and then gradually decreases. Over a one hour period, most of the occupants of the building have used the elevator to reach their offices. A traffic profile of a typical up peak that begins at 8:00 A.M. is shown in Figure 1, with the number of people arriving to the hypothetical building in each five minutes of the hour indicated.

If a building such as this example building were designed to handle 12% traffic but the peak traffic turned out to be 16%, the round trip time analysis no longer applies. During the first 10 minutes of the one hour period, the traffic intensity is light and considerably less than 12%. Therefore, the cars will be very lightly loaded and will consequently make round trips in much less than 130 seconds. Conversely, during the most intense five minutes, the cars will be fully loaded and the round trips will exceed 130 seconds. The five car group designed to handle 12% traffic would be overloaded during the heaviest period, and a queue of people waiting for the elevators would form in the lobby. The critical issue is how large this queue becomes and what, if any, adverse effects this overload has on the service time of the people at the end of the queue.

In order to study the dynamic behavior of the queue length, Otis makes extensive use of the simulation software called OTISPLAN. Within the simulation software, an engineer has access to a powerful computerized procedure which realistically models the major events related to the elevator system. The simulation and statistical analysis of a one hour up peak period requires a matter of a few seconds of elapsed time on a mainframe computer. A schematic representation of the approach is shown as Figure 2.

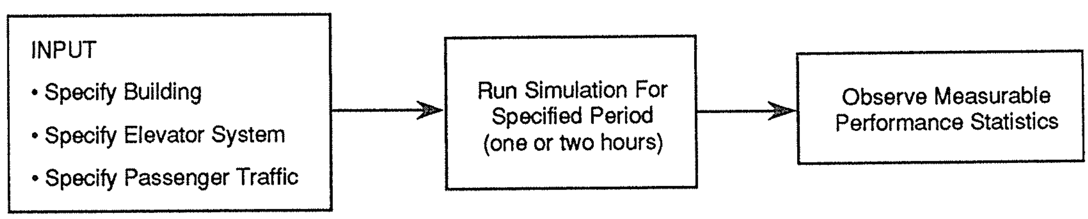

Figure 2. Simulation

These major events include the arrival of passengers, car loading/unloading at floors, car starts and car stops. Being event-based, this simulation model records a history called an "event calendar" over a one or two hour period of time. The time of occurrence of each major event is recorded on the calendar. At the end of a simulation, the engineer can observe a detailed, second-by-second view of what has happened. These observations include waiting times of each individual passenger, times and floor position of the starts and stops of each car, and the sizes of the queues at each floor. A graphical representation of the calendar is shown in Figure 3 (next page), in which the unit of time is one second. The arrivals of passengers at the lobby are shown on the time axis. The simulation records the events for each car in the group. Only the events of Car 1 are shown in Figure 3.

Of critical importance during up peak is the number of people still waiting in the queue when a car departs from the lobby with a load of passengers. A departing car leaving people behind is a sign that, at least for the moment, the system is not able to keep up with the incoming traffic. In order to carefully study this measure of elevator system performance, a special car loading module was added to the simulation which models the real-world behavior of people boarding a car. Because observations have shown that people often refuse to enter even a moderately crowded car, even though it is not at full capacity, the simulation model calculates a maximum car load each time that a car returns to the lobby and begins the boarding process for its next trip. This number is not always the same, being generated statistically based on Monte Carlo sampling. This particular aspect of the simulation provides a more realistic view of events during up peak than would be obtained if the load were always the same number, as is the case in the round trip calculation formulas.

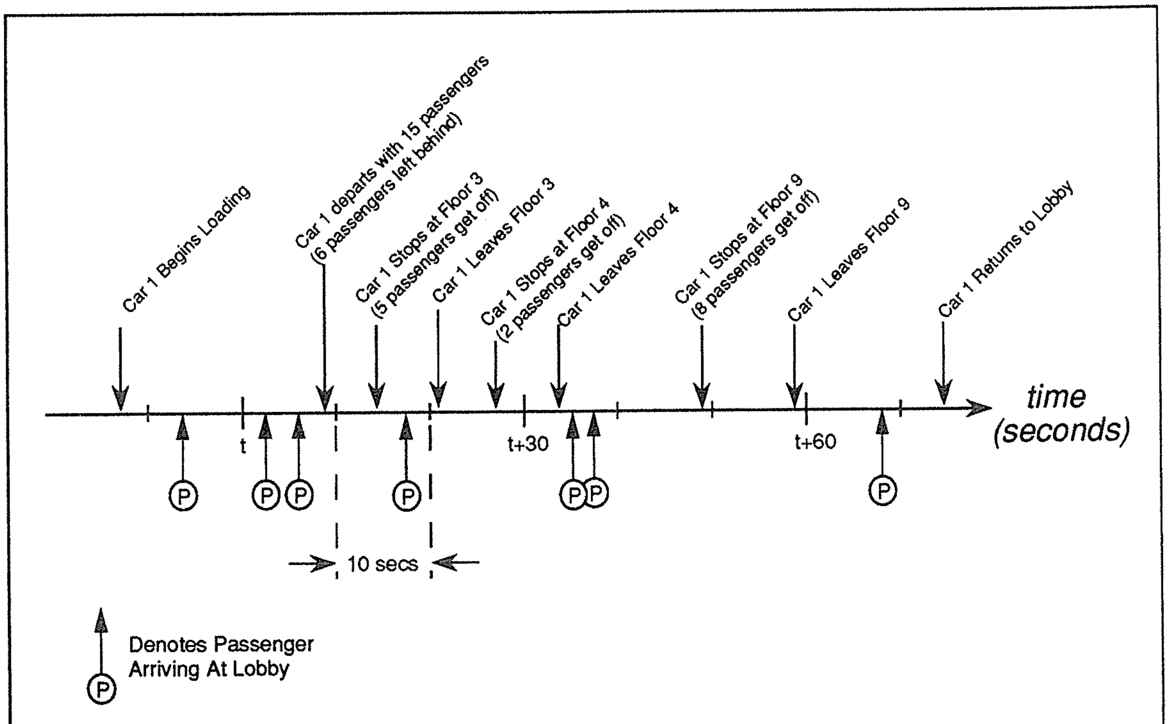

Figure 3. Segment of Event Calendar

Figure 4 (next page) shows the growth of the average queue length over a one hour up peak situation. It can be observed that during the 10 minute time period from 8:35 A.M. to 8:45 A.M., the average number of people left waiting in the queue is between 8 and 9. This is a tolerable situation, given that it only lasts for a short time.

In addition to the queue lengths, the simulation report shows waiting times, service times, and round trip times. Waiting time begins when a passenger joins the queue and is completed when the passenger boards an elevator. The service time of a passenger begins at same instant and ends when the passenger deboards.

For the example building, the following results were obtained:

Average Waiting Time = 15.3 seconds per passenger

Average Service Time = 74 seconds per passenger

Average Round Trip = 111 seconds per elevator-trip

These results are specific to the five car group serving 12 upper floors with a total population of 1200. Results would be different, for example, if 12 floors comprised a high rise bank (floors L,14-25 instead of L,1-12) or if higher speed cars with shorter dwell times were used.

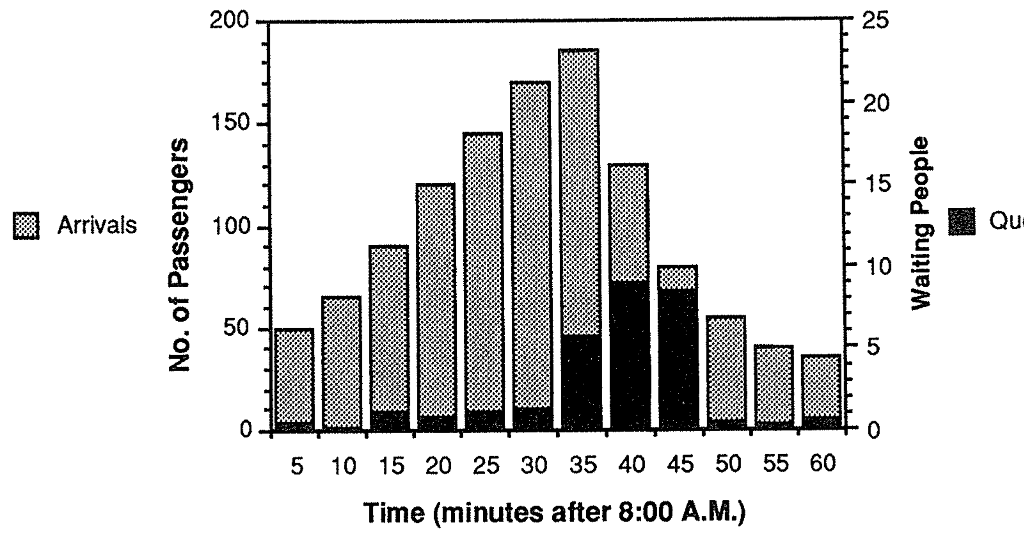

Figure 4. Queue Length - Normal Up Peak Operation
Five Car Group

These statistics were generated from the simulation and differ somewhat from the round trip time calculations. For example, the calculated value of round trip time (130 seconds) differs from the 111 seconds observed from the simulation. The difference is easily explained. The value of 111 seconds reflects the entire one hour period, during the beginning and end of which the traffic was much lighter than at the peak and round trips were much shorter than average.

OTIS CHANNELING

In the Elevonic 411 elevator control system, Otis has introduced an option called CHANNELING which is designed to alleviate lobby congestion during heavy up peak traffic periods. The key technical features of the Channeling option are described in Reference [4]. Elevators make fewer stops per round trip, with the result that cars return to the lobby faster. With reference to the example building, the floors above the lobby currently being served by five cars would be divided into four groups of contiguous floors: Sector A (floors 1-3), Sector B (4-6), Sector C (7-9), and Sector D (10-12). The Lobby is often referred to as Floor 0. As an elevator returns to the lobby during an up peak period, it is assigned to service one of the sectors. Passengers can easily determine which floors each car is serving by checking the Information Display System screens located next to or above each elevator entrance. Figure 5 shows an example of the display. The same car will not necessarily serve the same sector on successive trips, and care is taken to ensure that each sector will receive equal service by the assignment of sectors in a "round robin" manner.

Figure 5. CHANNELING Sector Display

Under the Channeling mode of operation, cars usually load all of the people waiting to travel to the assigned sector, rarely leaving a queue behind. This phenomenon is illustrated in Figure 6, which is a portion of the typical simulation results. It depicts Car 3 returning to the lobby, being assigned to Sector D (the top three floors), loading all six passengers waiting to go to those floors, and departing. This sequence of events occurred during an intense period of the one hour simulation. Notice that the five passengers waiting for the elevator at the time of the car's landing were able to board the car, along with an additional passenger who arrived just after the car landed at the lobby. Notice also that during the boarding of Car 3, several passengers joined the queue to wait for cars serving other sectors.

```
CAR C3 RETURNS TO LOBBY  time =  2512.5  lobby queue =  22
C3    dest floor:  1  2  3  4  5  6  7  8  9 10 11 12
C3         queue:  3  2  3  2  1  1  3  1  1  2  2  1

pass_enter_car_3:  tnow = 2514.0  arrtime = 2470.2  (O/D) = 0 11  wgt = 61.4  wait_time = 43.8 sec
pass_enter_car_3:  tnow = 2515.6  arrtime = 2475.1  (O/D) = 0 10  wgt = 48.6  wait_time = 40.5 sec
pass_enter_car_3:  tnow = 2517.0  arrtime = 2478.0  (O/D) = 0 11  wgt = 68.6  wait_time = 39.0 sec
pass_enter_car_3:  tnow = 2519.1  arrtime = 2486.7  (O/D) = 0 10  wgt = 49.5  wait_time = 32.4 sec
pass_enter_car_3:  tnow = 2520.0  arrtime = 2490.8  (O/D) = 0 12  wgt = 59.5  wait_time = 29.2 sec
pass_enter_car_3:  tnow = 2521.9  arrtime = 2514.9  (O/D) = 0 10  wgt = 79.1  wait_time =  7.0 sec

CAR C3 LEAVES LOBBY       time =  2526.0  load =  6  lobby queue =  21

C3   dest floor:   1  2  3  4  5  6  7  8  9 10 11 12
C3     carcalls:   0  0  0  0  0  0  0  0  0  1  1  1
          queue:   4  3  3  2  2  1  4  1  1  0  0  0
```

Figure 6. Partial Results From Simulation (Car 3 Serving Sector D)

The simulation was used to compare the performance of the group of five elevators with the Channeling mode against the normal up peak operation. The identical traffic profile of Figure 1 was used. The following table summarizes the results.

	Normal Up Peak	CHANNELING
Average Waiting Time	15.3	18.3
Average Service Time	74	55
Average Round Trip	111	79

As the table shows, for this case where traffic exceeded the planned intensity for part of the one hour period, the waiting time increases by three seconds when the Channeling mode is applied. However, the service time is reduced by some 25% to 55 seconds. In addition to these statistics, Figure 7 below shows that the queue lengths under the Channeling mode are comparable to the queues with Normal Up Peak.

The Channeling option is intended to operate during a heavy morning rush hour. The fundamental rule of operation is that the Channeling mode is to be activated only when needed, which requires the elevator system to sense an influx of passengers. As currently implemented, a clock period -- typically between 8:00 A.M. and 9:00 A.M. - during which the heavy rush of passengers is expected is stored in the control software. During operation, the system begins the day in normal mode and switches into up peak mode at 8:00 A.M. Then, when the system recognizes a significant increase in the level of incoming traffic, it activates the Channeling option. One way to detect such an increase is to sense the departure of heavily loaded cars from the lobby. The Channeling mode normally remains active until the end of the clock period, although deactivation can be customized to each building. In Figure 7, the Channeling mode was activated at approximately 8:18 A.M.

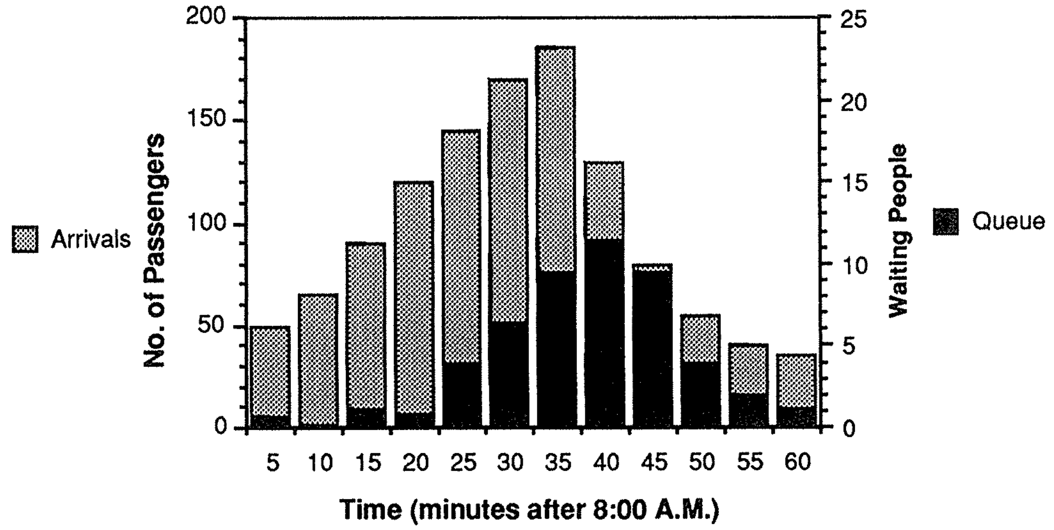

Figure 7. Queue Length - CHANNELING
Five Car Group

For any particular application, the mechanism that activates the Channeling mode can be customized to meet building requirements. In addition to the method just discussed, it can be activated and deactivated at specific clock times. The Channeling mode can also be controlled remotely with an electronic elevator monitoring system. In its most sophisticated implementation, the Channeling option can be made to be dynamic by varying the number of sectors and the floors within each sector as a real-time response both to sudden changes in passenger traffic and to passenger behavior learned from history.

SENSITIVITY TO INTERFLOOR AND COUNTERFLOW TRAFFIC

The passenger traffic profile of Figure 1 contains only passengers traveling up from the lobby. In most buildings, however, the morning rush hour usually includes some counterflow and interfloor traffic. A small number of people use the elevators to go from their floor of residence to the lobby, counter to the predominant direction of traffic. An equally small number of people often travel from one upper floor to another. Both counterflow and interfloor traffic serve to increase the round trip of an average car.

The traditional calculation methods can be modified to account for this increased time with the addition of a constant number of seconds. For example, two extra stops for the counterflow and interfloor traffic would be expected, resulting in a additional 20 seconds in the round trip time. There are two problems with such an approach. First, the value of such a term is at best an exercise in estimation and will vary with the elevator habits of the occupants. Second, even if the extent of this extra traffic is known, the extra time is most definitely a function of the elevator dispatching logic, which differs dramatically from one elevator company to another.

For these reasons, it is again appropriate to use simulation modeling to evaluate the effect of the extra traffic. The passenger traffic profile of Figure 1 was augmented to include additional passengers divided evenly between counterflow and interfloor. The following results were observed.

	Normal Up Peak	CHANNELING
Average Waiting Time (all passengers)	32.5	23.8
Average Waiting Time (lobby passengers only)	29.2	23.0
Average Service Time (all passengers)	89	58
Average Round Trip	129	89

In this case, the waiting times for passengers at the lobby is lower with the Channeling mode than with normal up peak. This advantage of the Channeling mode for lobby passengers is more dramatic than the previous situation in which there was assumed to be no counterflow and interfloor traffic. There are some very clear reasons for this result, beyond the specific handling of upper floor hall calls by the dispatcher. First, under normal up peak the elevators will be more heavily loaded in the up direction, leading to bypassed calls. Second, with respect to down hall calls with three floors in a sector, the probability of a car call coinciding with the floor of a hall call is higher under the Channeling mode, thus making the response to down hall calls more efficient.

SENSITIVITY TO INCREASED TRAFFIC VOLUME AND CAR OUT OF SERVICE

Finally, the Channeling option shows up most favorably when traffic is intensely heavy in relation to the number of elevators. This situation can provide the building owner with two distinct advantages. First, the Channeling™ option allows for growth in the traffic volume which might occur when the building population changes. Second, the Channeling option is more robust and flexible in the event of a car being out of service for maintenance or otherwise.

The implication of this "car out of service" situation is particularly dramatic. The example building was planned with five elevators in mind, and the simulation results shown earlier demonstrate some significant yet modest benefits to the Channeling option. As an additional experiment, the passenger traffic profile (without counterflow and interfloor traffic) was run with four elevators, simulating one car being out of service. The results are shown below. It can be easily observed that elevator response deteriorates for operation under normal up peak.

	Normal Up Peak	CHANNELING (3 Sectors)
Average Waiting Time	125.0	37.0
Average Service Time	188	81
Average Round Trip	144	107

The average waiting time of 125 seconds for the normal up peak operating mode case results from the buildup of very large queues as the traffic intensity increases. In fact, Figure 8 shows that the average number of people in the lobby in during the five minute period when queuing is greatest is some 88 people. During this time period, people had to wait for approximately four departures before boarding a car. With the Channeling mode, this average queue length during the same time period never exceeded 13 people, which is approximately one car load. The solid curve in Figure 8 represents the queue length with normal up peak operation and the dashed curve is for the Channeling mode.

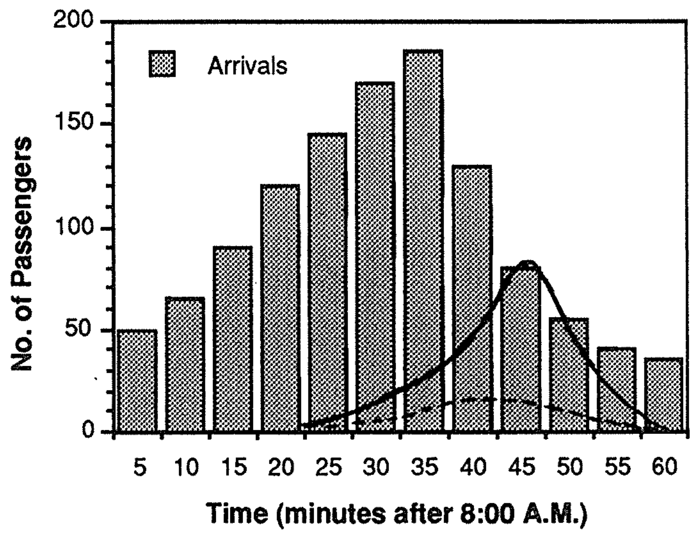

Figure 8. Queue Length - Four Car Group
Normal Up Peak Operation vs. CHANNELING

CONCLUSION

Two main ideas have been presented in this paper. First, detailed event-based simulation modeling is recommended as an additional step in the planning of an elevator system. The benefit of simulation is its ability to validate an elevatoring solution determined from the round trip time calculation method and modify the solution if necessary. With this procedure, the effects of counterflow and interfloor traffic can be measured. Also, the merits of special up peak traffic handling options such as the Channeling option can be evaluated with respect to the dynamic nature of the formation of queues.

Second, the Channeling option has been shown to provide a significant advantage in handling morning up peak passenger traffic. It was demonstrated through computer simulation that service time for an average passenger was reduced by 25% in a case with no counterflow and interfloor passengers. The advantage is even greater when the traffic is heavy in relation to the number of elevators and when hall calls above the lobby occur. Not only is the service time for all passengers reduced in excess of the 25% but also the queuing at the lobby is much less severe. These results show that the Channeling option assures continued good elevator response in the event of growth in building occupancy and provides a measure of protection for a car being temporarily out of service. Finally, the Channeling option has proved to be an attractive option in modernizing under-elevatored or over-populated buildings.

REFERENCES

[1] Barney, G. C., and S. M. dos Santos, Elevator Traffic Analysis Design and Control, Peter Peregrinus Ltd., London, 1985 (second edition).

[2] Powell, B. A., "Elevator Banking for High Rise Buildings," Transportation Science, Vol. 9, No. 3, 1975.

[3] Strakosch, G. C., Vertical Transportation: Elevators and Escalators, Wiley, 1983 (second edition).

[4] Bittar, J., and K. Thangavelu, "Contiguous Floor Channeling With Up Hall Call Elevator Dispatching," U.S. Patent 4,792,019, December 20, 1988.