Elevator Planning and Analysis on the Web

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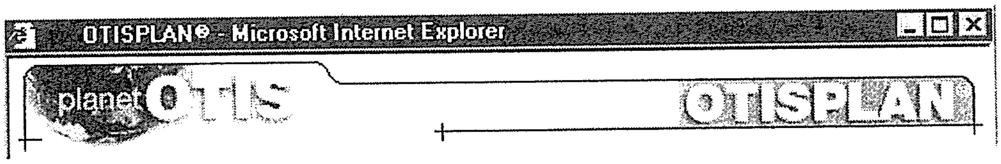
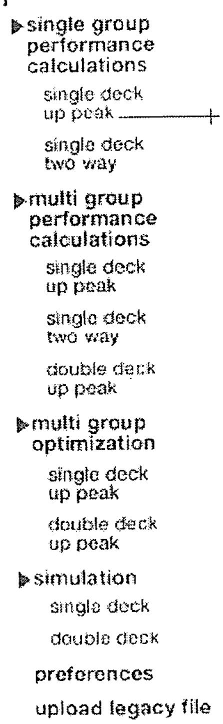
ABSTRACT

This paper discusses a set of recently developed on-line elevator planning tools used by Otis sales associates for most new equipment and modernization projects. These OTISPLAN® tools comprise three major applications: (1) ***single group performance*** tool for calculating up-peak round trip time, interval, and handling capacity, (2) ***multiple group optimization*** for determining good banking arrangements for tall buildings requiring two or more groups, and (3) ***dispatcher performance simulation*** for evaluating performance of individual Otis controllers against two-way and down peak traffic. The OTISPLAN tools represent an important part of a larger e*Business strategy. A demonstration of the Web site will be given as part of the presentation.

1. INTRODUCTION





A fundamental question often posed by a *developer* of a tall building is "How do I determine the number of elevators in my new building?" A fundamental question posed by an *owner* of an existing building with aging elevators is "If I modernize with your equipment, what level of performance improvement can I expect?" When these questions are directed to Otis, the sales associate now has access to OTISPLAN® analysis tools via the Internet.

The OTISPLAN tools comprise three major applications: (1) **single group performance** tool for calculating up-peak round trip time, interval, and handling capacity, (2) **multiple group optimization** for determining good banking arrangements for tall buildings requiring two or more groups, and (3) **dispatcher performance simulation** for evaluating performance of individual OTIS® controllers against two-way and down peak traffic. These planning tools on the Web have been developed to accommodate not only traditional single deck elevators but also double deck systems.

2. BACKGROUND

The issue of "how many elevators?" is directly related to the level of service that is required. Traditional industry metrics of performance are ***quality*** and ***quantity*** of service. The interval, and handling capacity are time-honored metrics of performance known to all elevator planners as explained below.

Quality of service is equated to the frequency that loaded cars depart from the lobby in the up direction. The interval between car departures affects passenger waiting time. Industry standards often call for an interval of 30 seconds or less between car departures. In a well-balanced system, this will provide waiting time for individual passengers in the range of 15 to 18 seconds.

Quantity of service is equated to the number of people that the group of elevators can move away from the main lobby. The handling capacity of a group of elevators is most often expressed as a percentage of the population of the floors served by the group that the elevators can carry away from the main lobby during the heaviest five minute period during morning up peak. Industry standards often call for handling capacity to be at least 12% of the population in the heaviest five-minute period.

For 50 or more years now, elevator planners have been calculating performance of a group of elevators with essentially the same method. An average round trip time of an elevator was postulated with a full load of passengers leaving the lobby, the car would make stops to let the passengers off at the various upper floors, and the car would return empty to the lobby, completing the round trip. Standard formulas for interval (the round trip time divided by the number of cars) and handling capacity would be invoked. In many cases, two planners doing the same calculations would come up with different answers, if ever so slightly different, because the assumptions and approximations made in the determination of round trip time would be different. A common belief in this methodology was that Up Peak traffic was the most severe traffic situation that the group would have to handle. Therefore, the model of round trip was calculated as if all passengers were traveling from the lobby to the upper floors.

The OTISPLAN tools provide a user-friendly calculator for round trip time, interval, and handling capacity for a single group of elevators.

The task of determining good elevatoring arrangements for buildings requiring more than one group of elevators provided planners with a computational challenge. These buildings commonly had 20 or more floors. Simply put, there were so many combinations of cars, speeds, capacities, and floors-served that planners were limited by time in the number of combinations that they could evaluate.

The OTISPLAN tools provide an easy-to-use computational procedure to evaluate all combinations of elevatoring and report the best ones for consideration.

As passenger traffic profiles changed over the years, elevator planners began to realize that very often noontime traffic was a more difficult situation for the elevators to handle than was up peak. The initial approach to deal with two-way traffic involved modifications to the round trip time calculation to account for stops for up and down hall calls above the lobby, and this allowed a more realistic calculation of interval.

However, in the era after terminal-to-terminal dispatch systems, it was recognized that cars did not always return to the lobby during two-way traffic as they did for up peak. In fact, the dispatching logic embedded in the controller did things like command a down traveling car to turn around before reaching the lobby. Also, cars would park above the lobby when not needed by passenger demand. Finally, the importance of better dispatching logic was recognized as the elevator suppliers competed to develop control schemes that provided better performance not only in the up peak but also at other times of the day.

But there was one problem. *Even as modified for two-way traffic, the calculation formulas for round trip time could not differentiate the performance of various dispatchers.*

The OTISPLAN tools meet this problem directly by providing access to complex event based simulation models that enable the user to evaluate dispatcher performance in a way that distinguishes one dispatcher from another. The user can predict performance of a variety of Otis dispatchers as a group of elevators respond to a wide range of traffic conditions. This part of the OTISPLAN tools is exceptionally useful for modernization where the customer demands an estimate of the degree of performance improvement with his modernized elevators.

3. SINGLE GROUP PERFORMANCE

As an example, let us say that we have a proposed building with 35 floors above the lobby. Without regard for elevatoring considerations, the developer has specified that the first 13 floors must be served by one low-rise group of cars. The total population of these floors is expected to be 1,225. The requirements for up peak performance are that the interval must be 30 seconds or less, and the handling capacity must be 12% population per 5-minutes or greater. The OTISPLAN Single Group Performance Tool can be used to determine the number, speed, and capacity of the elevators needed to meet the required performance.

The following copy of the Web page from the Single Group Performance tool shows that five elevators are needed to meet the required performance. In the Web application, the user enters the building information in the fields in lower portion of the page, and the performance calculations are displayed at the top, much like a numerical calculator.

Because the calculations are nearly instantaneous, the user can evaluate many combinations of input parameters in a small amount of time. For example, an experienced user might wish to determine if four higher speed cars (e.g., 4 cars at 4.0 mps) would meet the requirements.

An important concept that is often overlooked is the **Up car loading** parameter. This specifies the number of passengers that are on the elevator for the average trip. The example shows a car capacity of 1350 kgs, for which some 19 passengers would constitute a full load. However, the **Up car loading** in this example is 10 people per car. The user of OTISPLAN must recognize the culture of the building and the traffic arrival patterns. **Up car loading** should be the number of people who would (not could) board the car. Also, **Up car loading** should not be greater than the number of people who would arrive to the system in a single interval.

OTISPLAN

single group performance (up peak)

Results

Round trip time:	**101.0**	**sec**	**High call reversal:**	**12.2**
Interval:	**20.2**	**sec**	**Up probable stops:**	**7.2**
Up handling capacity:	**12.2**	**%/5 min**		

Name: ELEVCON ASIA Low Rise

Floors above lobby:	13				
Lobby height:	4.0	m	Population per floor:	94	people
Average floor Height:	3.0	m	% counterflow:	0	%
Express zone height:	0	m	% interfloor:	0	%
Door time:	3.3	sec	Number of Cars:	5	
3.0 m flight time:	3.5	sec	Car Speed:	2.5	mps
Car acceleration:	1.00	m/sec/sec	Car capacity:	1350	kgs
High call reversal:	0		Up car loading:	10	people/car
Up probable stops:	0		Added trip time:	0	sec

4. MULTIGROUP OPTIMIZATION

The previous example calculation for round trip time, interval, and handling capacity was made for a single group of elevators in the low rise (note that express zone length was 0.0), but nothing was done about service to floors 14-35. The multiple group optimization tool of OTISPLAN can be used to develop good elevatoring solutions for the entire building.

Again, building-specific information is entered in a multiple tab format as shown below.

OTISPLAN

\- Open - Run - - - Help FAQ

building data | optimization constraints | printout options

optimization - single deck up peak

Name: ELEVCON ASIA 2001

Floors above lobby: 35

Average floor height: 3 m

Lobby height: 4 m

Equipment Data

Door Time:	3.3	sec
3.0m flight time:	3.5	sec
Car Acceleration:	1.00	m/sec/sec

Population Zones

	Start		End	Population
1	1	-	10	100
2	11	-	20	75
3	21	-	30	50
4	31	-	35	25
5		-		
6		-		
7		-		
8		-		

Once the building parameters have been properly specified, the user clicks Run. Then several alternative elevatoring solutions are displayed in tabular form. Each elevatoring solution generated by the Multi Group Optimization satisfies the requirements that have been specified (Handling Capacity ≥ 12% of the population per 5-minutes and Interval ≤ 30 seconds).

For this 35-story example building, the optimization identified four alternatives. The first solution has three groups of elevators, and the others have two groups. The first group listed among each alternative is the lower rise. The optimization also displays an estimate of core space required, and the solutions are listed in order of most efficient core utilization.

A click on the Riser Diagram link for any of the solutions will enable the user to create an Excel graphical display of the elevatoring for the entire building. This diagram can then be pasted into a proposal or presentation. The riser diagram below corresponds to the first elevatoring alternative.

Multigroup Elevator Optimization Program

Single Deck Up Peak

ELEVCON ASIA 2001

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No. Cars	Capacity	Speed	Floors Served	Car Loading	RTT	% HC	Interval	Core
5	1350	2.5	13	10	100.8	12.1	20.2	888
4	1350	4.0	13	10	117.0	12.4	29.3	958
4	1350	4.0	9	4	99.1	14.9	24.8	1089
3 Group(s) Totaling 13 cars - Riser Diagram							*TOTALS*	2935
6	1350	2.5	15	10	107.1	12.2	17.9	1108
6	1350	3.5	20	10	141.6	12.7	23.6	1961
2 Group(s) Totaling 12 cars - Riser Diagram							*TOTALS*	3070
7	1350	2.5	17	10	112.9	12.2	16.1	1535
5	1350	3.5	18	10	140.3	12.6	28.1	1678
2 Group(s) Totaling 12 cars - Riser Diagram							*TOTALS*	3213
8	1350	2.5	19	10	118.4	12.1	14.8	1822
5	1350	2.5	16	9	150.0	12.9	30.0	1605
2 Group(s) Totaling 13 cars - Riser Diagram							*TOTALS*	3427

Floor	Population			
35	25			X
34	25			X
33	25			X
32	25			X
31	25			X
30	50			X
29	50			X
28	50			X
27	50			X
26	50		X	X
25	50		X	
24	50		X	
23	50		X	
22	50		X	
21	50		X	
20	75		X	
19	75		X	
18	75		X	
17	75		X	
16	75		X	
15	75		X	
14	75		X	
13	75	X	X	
12	75	X		
11	75	X		
10	100	X		
9	100	X		
8	100	X		
7	100	X		
6	100	X		
5	100	X		
4	100	X		
3	100	X		
2	100	X		
1	100	X		
Lobby	0	X	X	X
		Low	Mid	High
	No of Cars	5	4	4
	Capacity (kgs)	1350	1350	1350
	Speed (mps)	2.5	4.0	4.0
	Floors Served	13	13	9
	Car Loading	10	10	4
	RTT	100.8	117	99.1
	UP (HC%)	12.1	12.4	14.9

The final column in the tabular output of elevatoring alternatives shows an estimate of core area required for this alternative. Core area is the floor space taken up by the hoistways and waiting areas as the elevators rise in the building. The solution with the least core area is listed first.

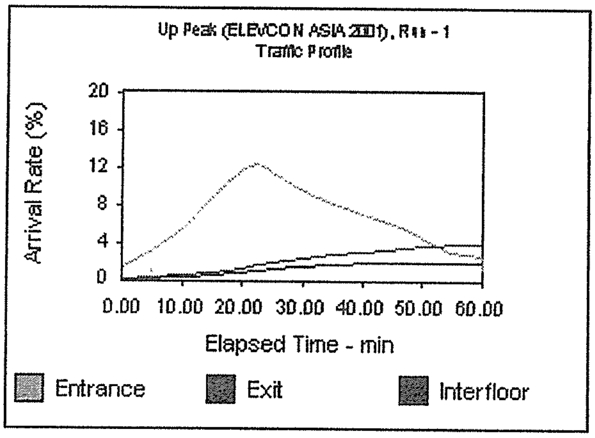
It is important to emphasize that the basis for these alternative elevatoring solutions is the simple single group formulas for calculating the time for the average round trip, interval and handling capacity under morning up peak traffic conditions.

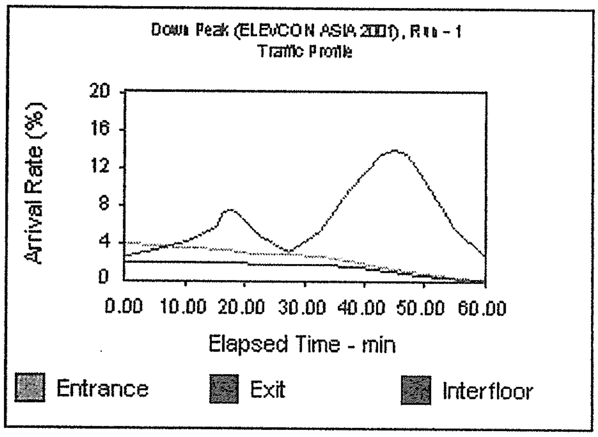
5. DISPATCHER PERFORMANCE SIMULATION

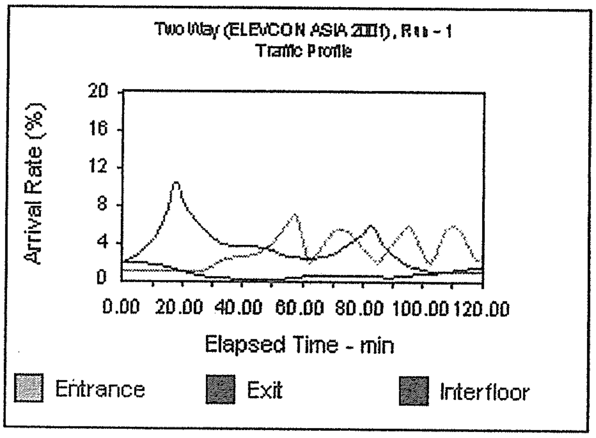
The Single Group Performance calculator and its extension to the Multiple Group Optimization elevatoring program are good for initial planning. However, these applications have two serious limitations.

First, the round trip time that forms the basis of the performance calculations is based on the model of Up Peak traffic in an office building. It has been recognized for some time now that two-way traffic at noontime is often a more severe test of the elevators than up peak. In fact, performance reports for hall call waiting times from job sites will often show that waiting times are longest during the hours of 11:30 A.M. to 1:30 P.M.

The figures below show that there are significant differences in both the intensity and the general shape of the arrival patterns for passenger traffic. The morning up peak profile is shown with heavy counterflow and interfloor traffic. Down Peak profiles can be customized to reflect staggered quitting times. And Two Way traffic can describe the various waves of passengers going to lunch and returning.



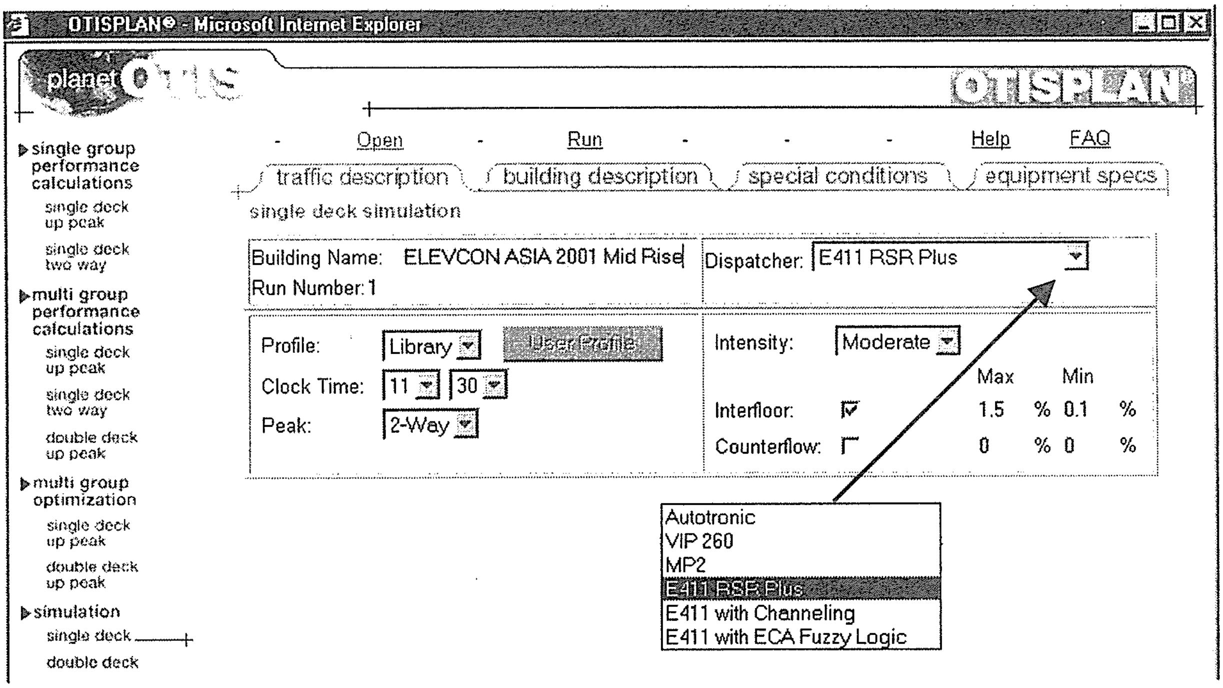




The second limitation of the single group performance calculations is that the determination of round trip time is ***independent*** of dispatcher logic. Elevator suppliers can verify that the microprocessor-based dispatcher logic of 2001, for example, yields better performance (i.e., shorter waiting times) than the relay logic of the 1950's. However, the interval and handling capacity calculations do not show this improvement because the clever dispatcher rules are not included in the formulas.

The OTISPLAN tools provide access to complex event-based simulation models that can be used to overcome the limitations of the simple round trip calculations. While the calculations, by definition, determine the time of the ***average*** round trip, the simulation models determine the time of ***every*** round trip. Thus, when the dispatcher logic parks a car at a strategic floor in anticipation of imminent arrival of passengers, for example, the more efficient performance is accounted for and reported in the performance results.

As with the other applications, the simulation begins with the specification of building and passenger traffic parameters. Notice that several OTIS dispatchers may be chosen for performance evaluation.



Once the input parameters are specified, the simulation is run for a one or two hour time period. For example, since the typical noontime scenario in a building lasts two hours, the OTISPLAN simulates two hours of operation. When a simulation has finished, an *html* page of performance results for this set of parameters is created and made available for insertion into reports and proposals.

The OTISPLAN simulation monitors and reports every important measure of performance. The three main performance metrics are (1) Hall Call Registration Time, (2) Passenger Wait Time, and (3) Passenger Service Time. **Hall Call Registration** is the time that elapses between registration of a hall call and the arrival of the elevator. This really is the *waiting time of the hall call*. The **Passenger Wait Time** is the waiting time of individual simulated passengers and is different from call registration. Passenger waiting time considers the waiting time of all passengers. Passengers arriving to board a car that has been called by an earlier-arriving passenger will wait less than the passenger who registered the hall call. While the waiting time of the first passenger is equal to the hall call registration time, the waiting time of subsequently arriving passengers will be shorter. The **Passenger Service**

Time is the time that the passenger spends getting to his floor of destination. It includes both waiting time in the hallway and time spent riding the elevator to his/her destination floor. The OTISPLAN summary page prominently displays the average times for each of these metrics.

But averages do not tell the entire story. Especially when dealing with metrics based on waiting times, it is the very long waits that get passengers upset. Therefore, the OTISPLAN tools display a histogram and cumulative distribution of the most commonly measured performance variable, Hall Call Registration Time. Also, the distributions of the three main performance metrics are displayed in tabular form.

webOTISPLAN

Elevator Dispatcher Evaluation Simulation

ELEVCON ASIA 2001 Mid Rise, Run 1

Single Deck Version ***E411 RSR Plus***

Simulation Run Time, min **120**

Total floors including basement **14**

Number of Cars **4** Population **850**

Rise (lobby plus floors above), m **79**

Car capacity, kgs **1350** Speed, mps **4**

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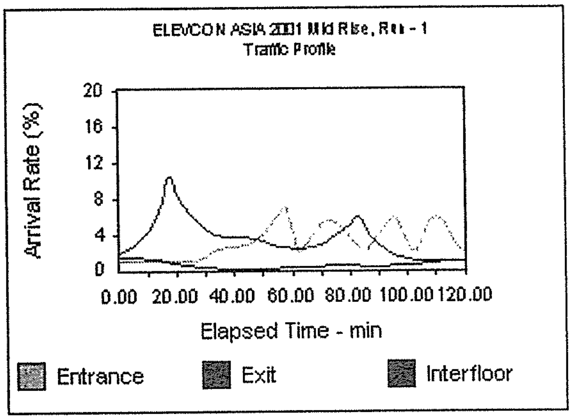
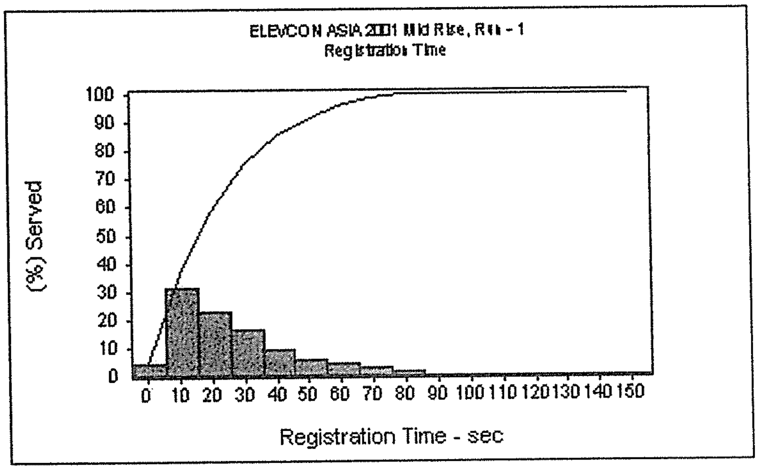


Average Times:

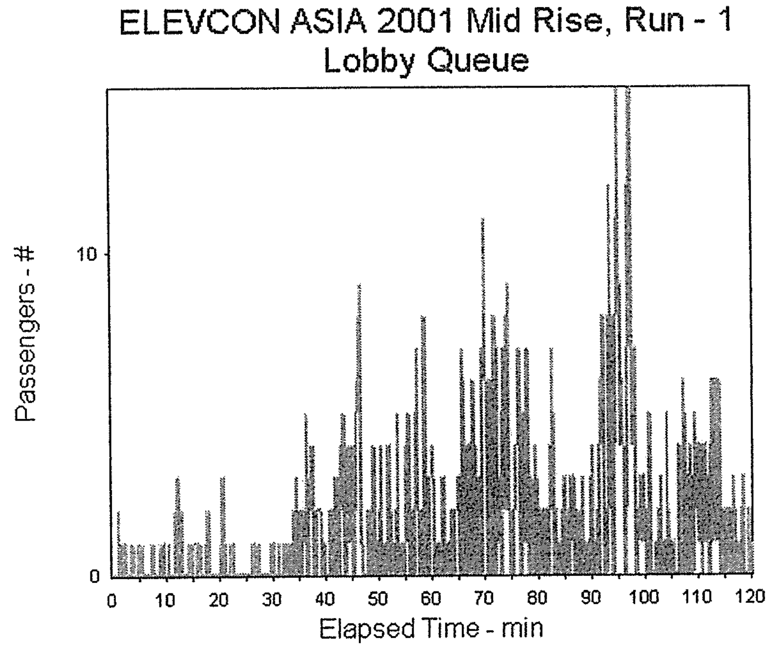
Call Registration:	**20.65**
Passenger Wait:	**15.73**
Passenger Service:	**61.98**
Round Trip Time:	**108.43**



REGISTRATION TIME, SEC Upper Limit	% Hall Calls	WAITING TIME, SEC Upper Limit	% Pass.	SERVICE TIME, SEC Upper Limit	% Pass.
0.0	4.4	0.0	22.1	0.0	0.0
10.0	36.0	10.0	50.0	20.0	1.3
20.0	59.1	20.0	68.9	40.0	22.9
30.0	75.3	30.0	81.6	60.0	54.0
40.0	84.7	40.0	89.4	80.0	77.2
50.0	90.7	50.0	94.0	100.0	89.9
60.0	95.2	60.0	97.0	120.0	97.4
70.0	98.1	70.0	99.0	140.0	99.0
80.0	99.7	80.0	99.9	160.0	99.9
90.0	100.0	90.0	100.0	180.0	100.0
100.0	100.0	100.0	100.0	200.0	100.0

The OTISPLAN simulation application provides a variety of performance measures displayed in graphical form. The distribution of hall call registration times was shown on the previous page with the summary report. A graph showing the degree of crowding in the lobby is valuable in the planning process for handling capacity. Lobby Queue shown below displays the number of passengers waiting in the lobby at any particular time during the simulation. If the simulated elevator system were unable to handle this traffic, the graph would display a steadily growing queue, rather than the normal filling and emptying of the lobby waiting area. This Lobby Queue is most important during Up Peak traffic and is not available with the simple calculations of Single Group Performance.

Only a very few seconds of computational time is required to perform simulations for a typical scenario of building parameters and passenger traffic conditions. Because this time is so small, the user often is motivated to simulate many combinations of parameters.



6. CONCLUSION

The deployment of the OTISPLAN traffic analysis tools on the Web is less than two years old. However, already the easy access to the tools has resulted in improved training and higher skill level of sales associates. To date, the OTISPLAN tools are an important part of the overall strategy for e*Business and are currently being used by more than 300 sales associates around the world.

7. BIOGRAPHY

Bruce A. Powell is an Otis Technical Fellow at Otis Elevator Company's Engineering Center in Farmington, CT, USA. He and his team are responsible for the application of advanced technology to the dispatching of elevators. He earned a BS in Mathematics from Denison University and an MS and Ph.D. in Operations Research from Case Western Reserve University. He has spent more than 30 years applying mathematical optimization and simulation to elevator systems and has numerous publications and some 34 issued patents.