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PUBLICATION

ELEVATOR TRAFFIC SIMULATION PROCEDURE

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ABSTRACT

Passenger service level in an elevator system depends on the group control and cannot be calculated directly. With conventional control, waiting times and interval have a correlation in up-peak. With a destination control system (DC), interval and waiting times do not have a similar correlation as with conventional full collective control. Therefore, simulation has become important in determining passenger waiting times with DC. Passenger arrivals follow a Poisson distribution, and simulation results vary depending on the random seed number of the simulation. In this article, different simulation procedures and consistency of the simulation results are studied.

Keywords: Destination control, elevator, planning, simulation, traffic

1 INTRODUCTION

Two of the most used performance criteria in elevator planning are up-peak handling capacity (HC) and up-peak interval. HC is an important performance measure that shows how well the system can handle up-peak traffic. HC is calculated from well known formulas (Barney 1987). The formulas assume full collective control, where passengers can enter the first arriving elevator. Destination Control (DC) is different in that sense that the control system arranges passengers in the most appropriate cars using the destination information. This approach reduces the number of stops per round trip, travel per round trip and the round trip time, which, on the other hand, increases HC. Also passenger Time To Destination (TTD) becomes shorter. Equations for the round trip time and HC using DC were first introduced by Schröder (1990), and later by Sorsa et al. (2006). Interval is up-peak round trip time divided by the number of lifts in the group. Conventionally, passenger Waiting Times (WT) are much shorter than Interval when the arrival rate is below the HC. This happens when passengers can enter any car that leaves from the lobby. With DC, passenger waiting times can be longer than Interval. To be able to compare the performance of full collective control and DC, one should rather look at the passenger Waiting Times and Times to Destination than Interval. Interval is just an intermediate result to find out waiting times, but with simulations waiting times can be analyzed without Interval. WT and TTD definitions were given by Barney (2005).

Simulations can be used to find out HC, i.e. the highest acceptable arrival rate with 80 % car load, or to study elevator performance with realistic building traffic patterns. Simulation practices were discussed in the CIBSE meeting in 2007 (Peters 2007a). DC has increased the need of simulation in elevator planning since conventional planning criteria cannot be applied with it. There are commercial elevator traffic simulators on the market as well as simulators of elevator companies and consultants. Each of them has their own procedures and ways to show the results. The aim of the meeting was find consensus or an industrial standard for how the simulation results should be utilized in elevator planning. Many questions were addressed but open questions still remain. This article seeks answers to some of those questions.

2 SIMULATION OF HANDLING CAPACITY

2.1 Determining of handling capacity

The traditional HC formula is based on a theoretical traffic situation where all arriving passengers travel from the lobby to upper floors. HC is defined as the number passengers or percentage of people that can be transported in an up-peak situation with 80 % car load. According to Western practice, HC should be higher than passenger arrival rate in daily traffic situations. Pure up-peak situations are rare in buildings although sometimes they may happen, e.g. after an evacuation when the emergency is over and all passengers return to the building. This is, however, an abnormal situation where all passengers enter the lobby at once, and waiting times become long.

Simulation can be used for determining the HC. Simulations and calculation formulas should give about the same HC with 80 % load factor. The problem is how to arrange 80 % car loads in simulation since elevators do not leave at even intervals as assumed in the up-peak calculation. One approach is to limit the maximum load to 80 %, to use a very intense arrival rate and to measure the throughput. Another, and better, approach is to limit the maximum load to 100 % and to find an arrival rate where the average car load is 80 %.

If we want more realism in up-peak simulations, a good rationale is the conflict between the rated load and the car floor areas. Fewer people may fit in a car than the number of passengers obtained from the rated load. If we for this reason limit the maximum number of people fitting in a car to 80%, and simulate random passenger arrivals, this would be the same as if we used a smaller rated load. With smaller load HC will be smaller and the results do not correspond to the calculated HC.

If in an up-peak simulation we allow cars to load up to 100% also an estimate of passenger waiting times is found. The random arrivals sometimes cause loads close to 100 % and on some round trips the load is below 80 %. The average car load factor becomes 80% at an arrival rate equal to HC, and passenger waiting times start to increase with arrival rates higher than HC.

In simulations the average car load factor will be 80% at the passenger arrival rate of calculated handling capacity if cars are allowed to fill up to 100%. Or conversely, handling capacity can be found from the passenger arrival rate where average load factor is 80%. Even though HC is defined for the up-peak situation only, there is no reason why HC could not be generalized to cover other traffic situations as well. Then a few new definitions are needed:

- Round Trip Time: Time from moment car starts up to the next time it starts up after two reversals
- Handling Capacity (HC): the number of passengers or percentage of population an elevator group can transport in five minutes on average with 80 % car load factor
- Car Load Factor (CLF): The maximum load during the round trip of elevator

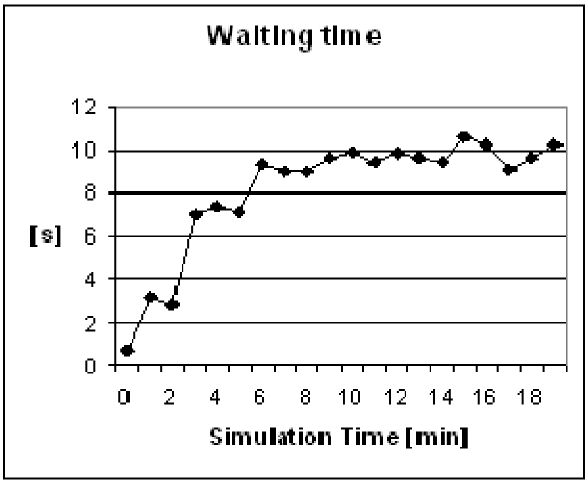
2.2 Effect of initial transient

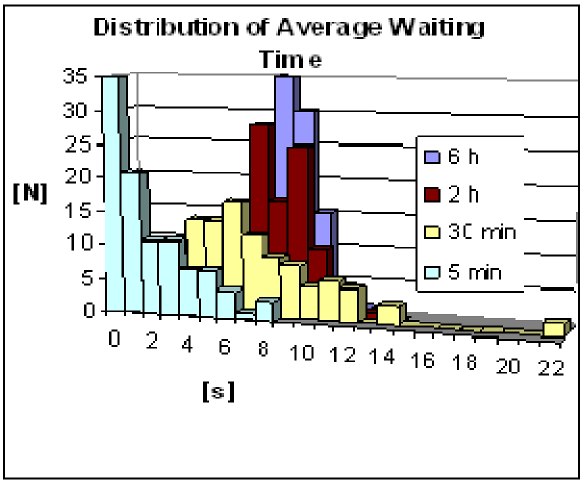
In the beginning of simulation the system has no passengers and the elevators are vacant. In the first minutes of simulation, the number of passengers in the system increases and also WT and TTD increase. When a constant traffic flow goes through the system during the simulation the system will eventually reach a steady state. Since the passenger arrivals follow a Poisson distribution, the state is steady only in a statistical sense, which means that the distributions of results do not change in time. In the beginning of simulation there is a transient or warm-up period that causes bias in the results. The effect of bias is small, when the simulation time is long, but the accuracy is better, if the initial part is removed from the results. The same applies to the transient at the end of the simulation after the last passenger has arrived.

Table 1. Test case

Entrance floor	0	Acceleration [m/s^2]	0.8
Populated floors	1-16, 18	Jerk [m/s^3]	1.2
Travel height [m]	72	Door closing [s]	3.1
Population	850	Door opening [s]	1.4
Number of elevators	5	Transfer time [s] in+out	2
Rated load [persons]	21	Start delay [s]	0.7
Rated speed [m/s]	3	Photocell delay [s]	0.9

The effect of initial transient was tested with the Building Traffic Simulator, BTS (Siikonen et al., 2001) in an up-peak traffic situation. The test case is shown in Table 1. A series of 1 000 simulations for 20 minutes were made using different seed numbers in passenger generation and one-minute averages were calculated. The result in Figure 1a shows that waiting time is short in the first few minutes of simulation. After 5 minutes, the results approach the steady state, and after 10 minutes no difference from steady state can be distinguished. Based on this case, it is justified to remove the first 5 minutes, or if high accuracy is necessary, the first 10 minutes can be removed.





(a) (b)

Figure 1. Effect of initial transient (a) and effect of the length of the simulation time (b)

2.3 Effect of simulation time

Simulation time must be longer than the initial transient. In addition, there should be enough data, such that the calculated averages do not have too much deviation. Figure 1b shows average waiting times of single 5-minute, 30-minute, 2-hour and 6-hour simulations. The number of iterations (also called replications) is 100 in each histogram. The initial transient is not removed from the distributions in order to see the effect of the transient. Therefore, the distribution for 5-minute simulations is clearly biased. Its average WT is below 3 s while the others have average WT close to 8 s. The deviation of waiting time decreases as the simulation time becomes longer.

2.4 Serial simulation

Passenger traffic in simulations can be generated using the arrival rate and three traffic components: incoming, outgoing and inter-floor. Arrival rate is usually given as percentage of population in five minutes and the three components are percentages of total traffic. Passenger arrival rate can be constant, it can be increased continuously (ramp profile) or stepwise as shown in Figure 2, or it can follow a typical daily traffic pattern. Greater accuracy is achieved by using a larger number of simulations or longer simulation time. According to Law and Kelton (2000), the deviance of results is inversely proportional to the square root of iterations (replications); thus we get an accuracy of one more decimal by making 100 times more iterations. Computation time sets limits to the simulation time and to the number of iterations.

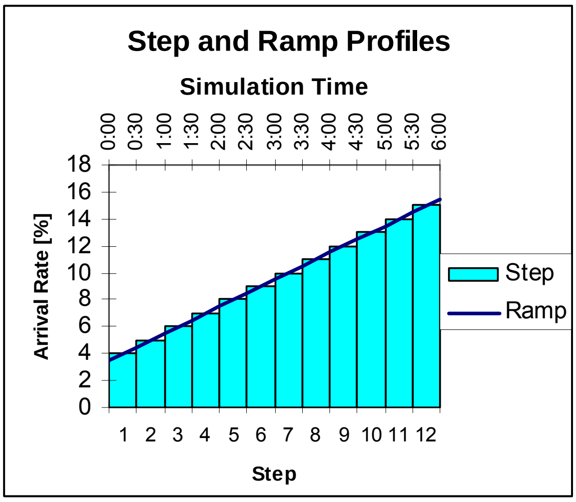


Figure 2. Ramp and stepwise arrival rate profiles

2.4.1 Stepwise profile

In the stepwise profile, the system is usually empty in the beginning of the simulation. There is a transient in the beginning of the simulation before the results are stabilized. A defined time, e.g. 30 minutes, is simulated with a fixed, constant passenger arrival rate. All arrived passengers are served first before a new simulation with higher arrival rate starts. A series of simulations can be made starting from a certain arrival rate and stepwise increasing the arrival rate ending at an arrival rate close to the HC.

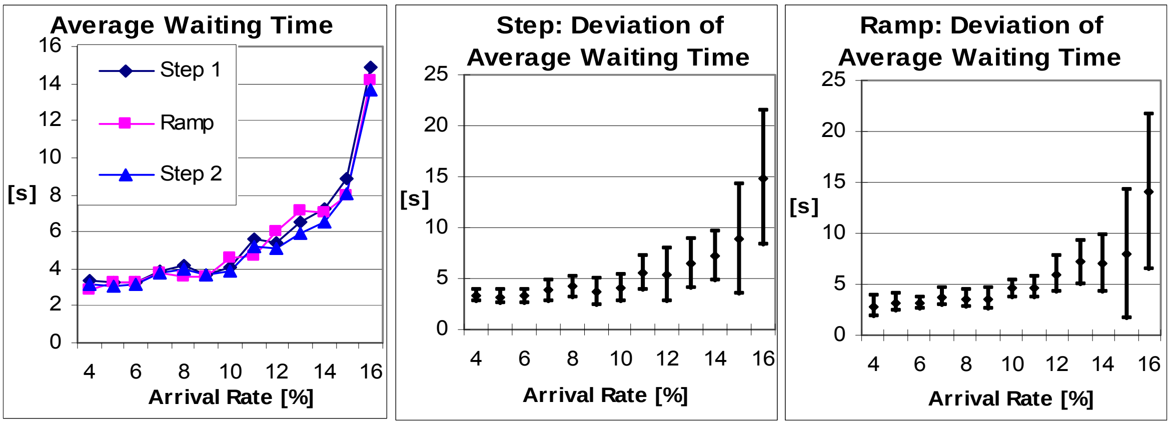
2.4.2 Ramp profile

Ramp profile is not a constant traffic situation but the arrival rate increases slowly. If the increment is too fast, the effect of initial transient is visible in the simulation results. If the arrival rate changes slowly enough, the results are essentially the same as with a constant arrival rate. More accuracy is achieved by making several iterations and calculating the average of all simulations.

2.5 Comparison of ramp and stepwise methods

Different simulation procedures in the ramp and stepwise methods may cause differences in the results. Comparing individual passengers in simulations is not meaningful. For this reason we calculate average values to get one to one correspondence between the results. The initial transient period is removed before averaging. The results of ramp stepwise methods are compared by making two kinds of simulation tests for pure incoming traffic

- 30-minute stepwise simulations for 13 arrival rates: 4, 5, …, 16 % of population in five minutes
- 6-hour ramp simulation where the first arrival rate is 4 % and the last is 16 %. Half-hour averages are taken from the results



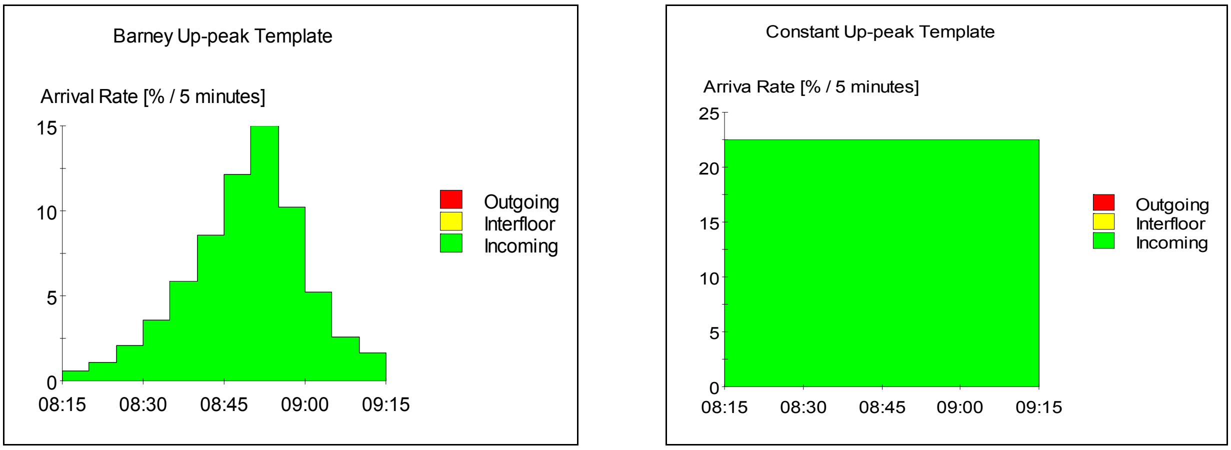
(a) (b) (c)

Figure 3. Waiting times with stepwise method without (Step 1) and with (Step 2) transient and ramp method (a), and waiting time deviations of step (b) and ramp (c) methods

The process was iterated four times to get standard deviations. Figure 3a shows waiting times with three methods: using the step method with and without initial transients and using the ramp method. The results are averages of four simulations. The difference between the methods is quite small. The step method without initial transient gives longest waiting times, 0.2 s longer than the ramp method and 0.4 s longer than the step method with initial transient. Figures 3b and 3c show averages and 90% confidence intervals for average waiting time for a single simulation. The confidence interval is about the same in both stepwise method (without transient) and ramp method. This is quite natural, since simulation time per data point is 30 minutes in both cases. The confidence interval gets quite large, when the arrival rate is close to the HC where it is necessary to simulate a longer time than 30 minutes or more than just one simulation to get good accuracy.

3 SIMULATION OF TYPICAL TRAFFIC PATTERNS

3.1 Up-peak simulation



(a) **(b)**

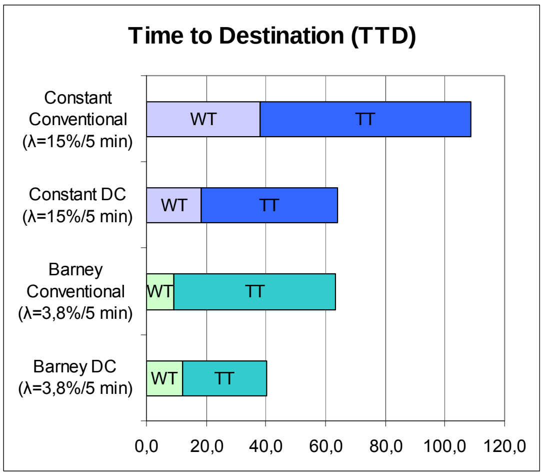
Figure 4. Peaked (a) and constant (b) passenger arrival profiles in up-peak

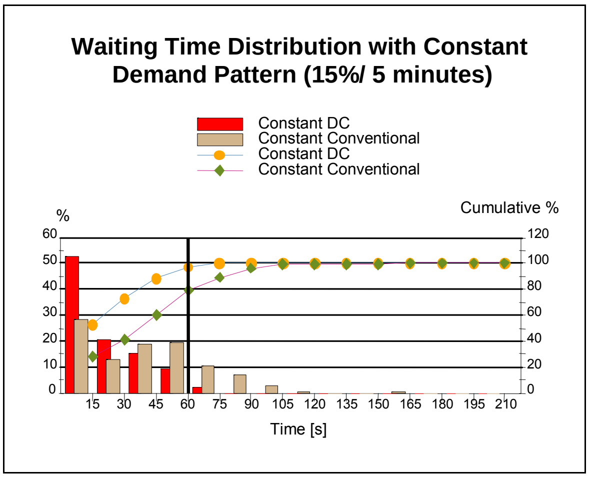
Morning up-peak traffic is a critical traffic situation in office buildings. For this reason performance requirements are often specified for an up-peak situation and elevator configurations are compared in an up-peak situation. Simulations make it possible to assess more performance measures than calculations and enable comparison of different control systems.

Pure incoming traffic at a constant arrival rate, e.g. 15% of the population in five minutes, is a basic simulation case (Figure 4b). The system will reach a steady-state unless HC is exceeded. It is advisable to remove initial and end transients, as with the step profile.

Non-constant up-peak arrival profiles can be simulated as well. Figure 4a shows a one-hour up-peak template by Barney (Peters 2007b), which is scaled so that the highest peak is the required up-peak HC. The hourly average arrival rate is only about a quarter of the peak arrival rate. Therefore, if the peak arrival rate in Barney's profile is the same as the arrival rate in the constant profile, the results are better with Barney's profile.

Full collective control with up and down call buttons, and DC control were simulated for constant and Barney profiles for one hour (Figure 4). DC allocates a passenger call immediately to an elevator which, during light incoming traffic, can produce longer passenger Waiting Times than conventional control with continuous call allocation. On the other hand, passenger Transit Times (TT) and Times to Destination will be shorter with DC (see Figure 5a). In Figure 5b passenger waiting time distribution and cumulative waiting times (axis on the right) are shown for conventional and DC systems.





(a) **(b)**

Figure 5. Average TTD for Barney and constant profiles with full collective control and DC (a) and waiting time distribution with constant profile using full collective control and DC (b)

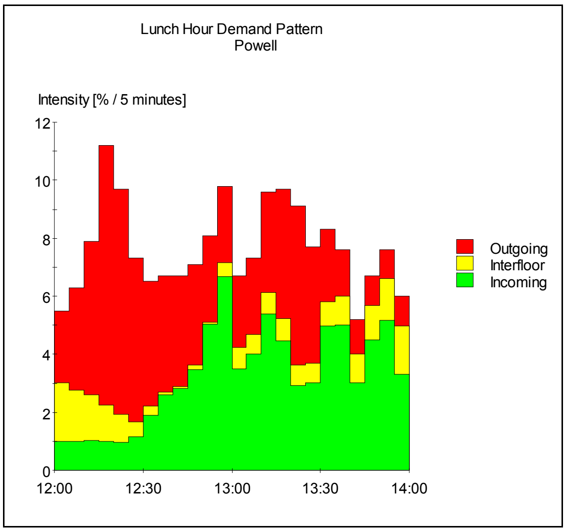
3.2 Lunch hour traffic simulations

During mixed lunch-hour period, traffic is often heaviest in office buildings. In the beginning of the lunch hour, outgoing traffic is dominant and the percentage of incoming traffic increases towards the end of the lunch hour. Inter-floor traffic is heavier in a single-tenant than in a multi-tenant office building. Working times of the companies, culture, habits of employees, and locations of restaurants cause differences in lunch-hour traffic in every country and building. Lunch-hour traffic patterns have been suggested by Powell and by Barney (Barney 2003). In the following, three traffic profiles are compared:

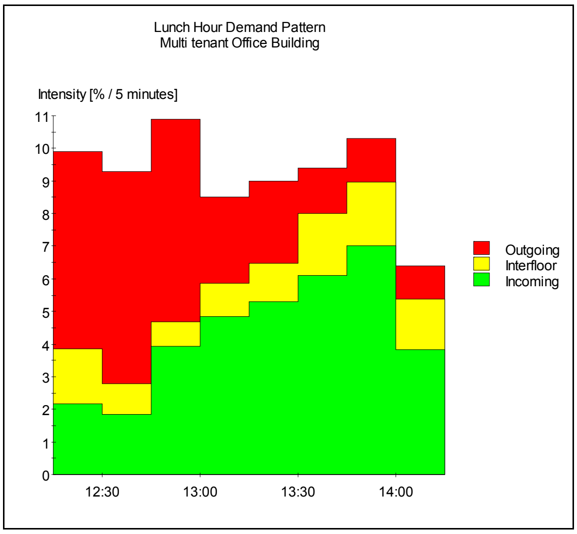
- two-hour lunch-time profile by Powell (Peters 2007b)
- lunch-time of one-day multi-tenant office profile by Siikonen
- lunch-time of one-day single-tenant office profile by Siikonen

Table 2. Portions of Incoming (In), Outgoing (Out) and Inter-floor (Int) traffic components and arrival rate (Arr) in single and multi-tenant lunch-hour profile

Siikonen multi-tenant (6b)					Siikonen single-tenant (6c)				
Time	**In**	**Out**	**Inter**	**Arr**	**Time**	**In**	**Out**	**Inter**	**Arr**
12:00	20	59	21	9.6	12:00	14	56	30	9.6
12:15	22	61	17	9.9	12:15	11	58	31	14.2
12:30	20	70	10	9.3	12:30	11	43	46	12.5
12:45	36	57	7	10.9	12:45	13	44	43	12.6
13:00	57	31	12	8.5	13:00	16	34	50	11.1
13:15	59	28	13	9	13:15	23	29	48	11.5
13:30	65	15	20	9.4	13:30	35	22	43	11.4
13:45	68	13	19	10.3	13:45	33	19	48	11



(a)



(b)

Figure 6. Lunch Hour demand patterns (a) Powell (b) Siikonen multi-tenant (BTS)

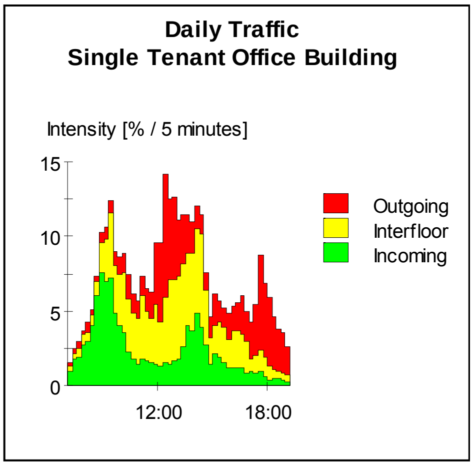
The case in Table 1 is used in the simulations. A series of simulations is performed for each profile to determine the accuracy of the simulation. Passenger arrival profiles are defined in Table 2 and Figure 6. Table 3 shows the average service times and their standard deviations for the two-hour simulations. Average WT and TTD are the shortest for the Powell profile where the average passenger arrival rate is the lowest. When we compare the averages of traffic profiles, we notice that the differences in average WT and TTD values are much bigger than the standard deviations. This means that the chosen traffic pattern has much more impact on the simulated WT and TTD than the simulation method.

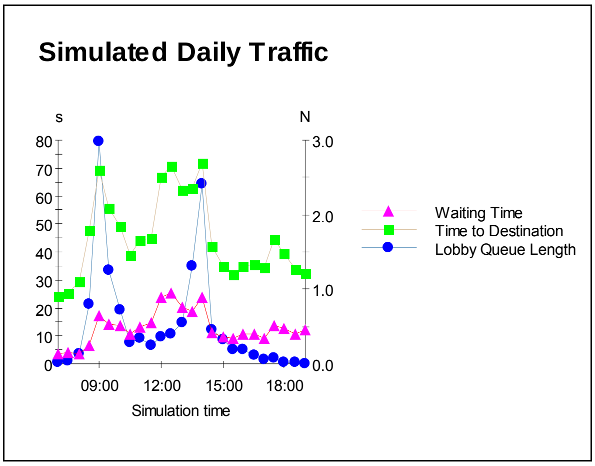
Table 3. Averages of lunch hour traffic simulations

Profile	**Powell 6a**		**Multi-tenant 6b**		**Single-tenant 6c**	
Average arrival rate [%/5min]	7.7 %		9.6 %		11.7 %	
Performance measure	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
Waiting time [s]	12	0.5	16	0.6	28	1.0
Time to destination [s]	48	0.9	58	1.0	78	1.4
Load factor [%]	14	0.3	19	0.4	27	0.6

3.3 Daily traffic simulations

Daily traffic profiles are based on real daily traffic in office buildings. The pattern of Figure 7a was measured from an office building in Paris (Siikonen et al. 1991). The daily traffic pattern is simulated to determine the service level and to find out how the elevator group can handle traffic peaks during the day. Usually WT and TTD are studied, but also other features such as passenger queuing in the lobby (Figure 7b). Also the number of round trips, number of starts, and energy consumption during the day and year are interesting figures.





(a) **(b)**

Figure 7. Typical daily traffic profile for a single-tenant office building (a) and the simulation results for full collective control (b)

4 PERFORMANCE CRITERIA

The performance measures are related either to elevator performance or passenger service level. WT and TTD are good criteria for passenger service level. To be able to judge how good the service level of the elevator group is, there should be criteria for it. In an elevator group with an efficient control system waiting time distribution roughly follows exponential distribution

$$Ft = \exp(-t/Tav) \qquad (1)$$

where Tav is the average waiting time and Ft shows the fraction of waiting times that exceed time t. Waiting time recommendations are shown in Table 4. Time to destination follows Gamma distribution, and the limits in Table 5 were specified according to it. These recommendations are valid in all types of buildings for the daily traffic, and also for one peak hour and a 15-minute peak period. In practice, service level parameters can be checked from the BMS or elevator monitoring systems.

Table 4. Passenger waiting time recommendation where walking time is not included

Service level	Average waiting time	% of passengers served within		
	(s)	**30 s**	**60 s**	**90 s**
Excellent	< 20	75%	95%	99%
Good	20 – 30	65%	85%	95%
Satisfactory	30 – 40	50%	75%	90%
Acceptable	40 – 60	40%	60%	75%

Table 5. Passenger time to destination recommendation where walking time is not included

Service level	Average time to destination	% of passengers served within		
	(s)	**90 s**	**120 s**	**150 s**
Excellent	< 80	70%	85%	95%
Good	80 – 100	40%	75%	90%
Satisfactory	100 – 120	15%	50%	80%
Acceptable	120 - 150	5%	20%	55%

5 CONCLUSION

In this article, simulation procedures and their accuracy were compared. In determining Handling Capacity, the choice of whether to use the ramp or stepwise method does not have much effect on the results as long as the simulation time is long enough. The initial transient decreases the average value of waiting time, especially in short simulations. If about 5 – 10 minutes are removed from the beginning of the simulation, the results become quite stable. If the simulation is run until all passengers are served, also the transient after the last passenger arrival should be removed. The accuracy of waiting time improves, if the simulation time is made longer or the number of iterations is increased. If only one iteration is performed, the simulation time should be at least 30 minutes long. If the arrival rate is close to Handling Capacity, a longer simulation time or more iterations are needed.

A general way to compare the efficiency of alternative elevator arrangements is to show average passenger waiting times and times to destination at a desired arrival rate. Constant or typical traffic profiles can be simulated to make the comparison. The same demand pattern should then be used for all alternatives with a proper arrival rate.

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BIOGRAPHICAL DETAILS

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