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The Application of Simulation to Traffic Design and Dispatcher Testing

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Abstract. Simulation is a popular traffic design tool, but there are many different ways in which it can be applied and the interpretation of results can be difficult. The relationship between round trip time calculations and simulation is explored, demonstrating consistency, but also highlighting why results can be very different. Simulation templates allow hypothetical and measured traffic patterns to be applied in the selection of lifts for new buildings, and in assessing the benefits of modernisation. The strengths and weaknesses of popular templates are discussed. Common misunderstandings are explained. Dispatcher testing can be approached in a similar way to traffic design, but success in sample traffic design simulations does not guarantee consistent performance across a range of traffic conditions and building configurations. A more comprehensive approach is proposed.

1. INTRODUCTION

Lift simulation models of varying sophistication have been written and applied since the early 1970s [1]. The continuing improvements in computer technology and software development tools make increasing complex and comprehensive simulation models feasible. In the late 1990s non-proprietary simulation software for modern operating system became available, making simulation popular and available to most lift companies and consultants. Lift simulation is a very powerful tool. However it is good practice to start all design exercises with a round trip time calculation [2].

With round trip calculations a single, average round trip is modelled. In simulation the whole process of passengers arriving at the landings, registering their landing calls, boarding the lifts when they arrive, registering their car calls and then alighting at their destination is modelled. Simulation calculates the performance for every call and every passenger.

Simulation can be used to model scenarios that cannot normally be analysed with the round trip time calculations, including:

i. Light (non-peak) traffic
ii. Changing levels of traffic, e.g. the increasing levels of traffic as the work start time approaches in an office building
iii. Mixed types of traffic, e.g. goods and passenger traffic using the same lifts
iv. Lifts in the same group with different speeds and sizes.

2. DESCRIBING TRAFFIC

With general analysis round trip calculations [3] the following may be analysed:

i. mixed traffic, defining a demand as a percentage of the building population, divided into incoming, outgoing and interfloor components
ii. entrance level bias to allow for car parking floors, restaurant floors and other utility floors

iii. arrival rate and destination probability tables, for traffic which cannot be described in simpler terms.

All these ways of describing traffic can all be applied in simulation. With round trip time calculations the assumption is that demand is constant; with simulation templates introducing a time element can be considered, see Figure 1. This paper considers constant and step templates; these are theoretical templates not based on real traffic in buildings. Finally templates derived from traffic surveys will be considered.

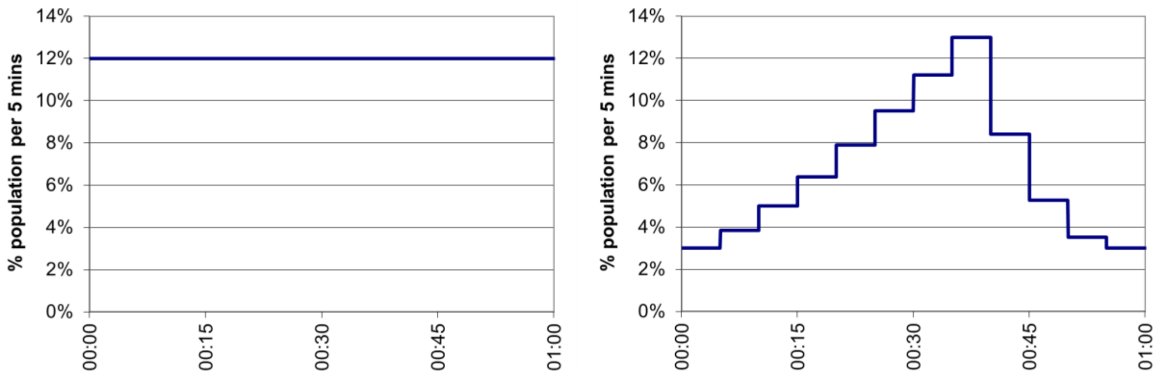


Figure 1 Demand may be constant or vary with time

3. CONSTANT TRAFFIC TEMPLATE

With a constant traffic template the premise is that if a system has a handling capacity of x%, it can sustain that demand indefinitely. This is directly analogous with the round trip time calculation.

Example 1 Simulation of up peak calculation

Perform a round trip time calculation and simulation for the parameters given in Table 1. Note that dwell times are included in the round trip time calculation. Run the simulation for 30 minutes ignoring the first and last five minutes to allow for start and end conditions. Apply a group collective algorithm with up-peak mode.

Table 1 Up peak calculation and simulation parameters

Rated speed	2.5 m/s	Passenger loading time per person	1.2 s
Acceleration	0.8 m/s²	Passenger unloading time per person	1.2 s
Jerk	1.6 m/s³	Number of floors above main entrance	14
Allowance for motor start delay	0.5 s	Total height of un-served floors in express zone	0 m
Levelling delay (s)	0 s	Floor heights (m)	Ground to Level 1, 5.0 m; other floors 3.8m
Number of lifts	5	Floor populations	48 for all floors
Lift capacity	1000 kg	Passenger mass	75 kg
Car area	2.4 m²	Area per person	0.21 m²
Advanced door opening time	0 s	Capacity factor by area	80 %
Door opening time	1.8 s	Capacity factor by mass	80 %
Door dwell time	2 s	Round trip time losses	5%
Door closing time	2.9 s		

Results are given in Table 2; in this case there is a close correlation between the up-peak calculation and simulation.

Table 2 Result for comparison between round trip times and simulation

	up-peak calculation	*simulation*
Average up-peak interval	33.3 s (result)	33.3 s (result)
Percentage population served in up-peak five minutes	14 % (result)	14% (input)
Average no of passenger in car	10.4	Not calculated
Average waiting time	Not calculated	20.6 s

Example 2 Simulation demonstrating saturation

A lift group saturates when the demand exceeds the handling capacity. As the lifts cannot cope with the traffic, the longer the simulation runs, the longer the passenger waiting times become. Increasing queue lengths develop as the simulation progresses.

To demonstrate saturation, repeat the simulation in Example 1 with the demand increased from 14% to 15% and then to 16% of the building population requiring transportation in five minutes. Results are given in Table 3.

Table 3 Result for comparison between round trip times and simulation

Percentage population served in up-peak five minutes	14 %	15%	16%
Average waiting time	20.6 s	38.9 s	85.8 s
Average up-peak interval	33.3 s	33.8 s	34.3

Notice that with increasing demand the interval remains relatively stable. Up-peak interval is the time between lift departures from the entrance floor. For all three results the lifts are departing full from the ground floor. When the demand increases, a queue is forms. So, passengers have to wait more than one interval before they can board a lift. This is reflected in the rapidly increasing average waiting times and queue length.

Avoiding confusing simulation results with the constant traffic template

Round trip time calculations for office buildings are often carried out to establish the maximum handling capacity of a system. So, if a simulation is run based on a round trip time calculation it is likely that the simulation will be near or at the saturation point. If the simulation saturates, then results become unstable; a solution which was acceptable when analysed with a round trip time with simulation can present long queues and unacceptable waiting times. As the simulation is unstable, small changes in any parameter can have a large and sometimes counter-intuitive effect on results.

When comparing round trip time calculations with simulations, it is important to note:

i. often designers using round trip time calculation do not consider door dwell times
ii. round trip time calculations are based on averages and may be based on the assumption a car is loaded with say 9.9 persons; a simulation with multiple runs also yields an average, but in each simulation the maximum car load is an integer number of persons
iii. unless a round trip time inefficiency is used, round trip time calculations assume an ideal system with, for example, no bunching, no door re-openings or other “real life” delays.

4. THE STEP PROFILE

This template shown in Figure 2 starts with a low demand and increases constantly or, in increments of 1% every period. The demand can be pure up-peak, or any combination of mixed traffic. The premise of this approach is that the system's performance is tested across a range of traffic intensities.

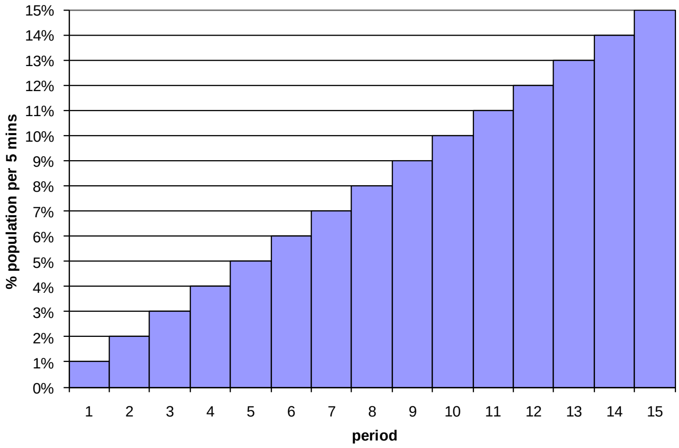


Figure 2 Passenger demand for step profile increasing by 1% every period

This presentation is useful as it highlights to the customer that the waiting time, loading, and other parameters are dependent on demand. A system that manages 12% of the design population in 5 minutes may be sufficient in most buildings. However, if it can transport a greater demand without saturating, it is more likely to manage, for example, if the building population exceeds the design population. The simulation should continue to at least 1% beyond the design value for passenger demand.

Example 3 Application of step profile

Repeat Example 2 with a step profile. Begin at 1% demand increasing traffic at 1% increments every 30 minutes up to a maximum of 16%. Results are given in Table 4.

Table 4 Quality of service results for increasing demand

Demand (% population per five minutes)	*Average Waiting Time (s)*	*Average Transit Time (s)*	*Average Time to Destination (s)*
1	0.0	25.9	26.0
2	0.1	29.8	29.9
3	0.1	31.4	31.4
4	0.1	33.8	33.9
5	0.5	37.8	38.3
6	0.7	43.4	44.2
7	1.2	48.5	49.7
8	1.8	53.2	55.0
9	2.7	57.6	60.3
10	4.1	64.1	68.2
11	4.8	67.9	72.8
12	9.7	72.4	82.1
13	12.6	75.3	88.0
14	21.6	79.1	100.8
15	83.4	80.1	163.5
16	183.2	67.3	250.5

When the demand exceeds the handling capacity (15%), the system becomes unstable. Up to this point the table provides a good indicator of how the system will perform across a range of traffic intensities. Note in the close correlation between the waiting times calculated with the constant traffic template and the step profile when the demand is 14%, see Table 5.

Table 5 Comparison of constant traffic template and step profile template.

	Constant traffic template	*Step profile template*
Average waiting time at 14% up peak demand	20.6 s	21.6 s

5. SIMULATION TEMPLATES DERIVED FROM TRAFFIC SURVEY

The templates presented in previous sections are not intended to represent actual passenger demand in buildings; they are tools to assist designers establish an appropriate design. The most authoritative position when predicting how a proposed lift installation will perform is to design applying evidence based research. Templates have been proposed which are intended to represent real traffic in actual buildings [4], [5], [1]. New design templates for offices were developed [2] to reflect the traffic in modern office buildings, see Figure 3. Each template represents one hour in twelve 5-minute periods.

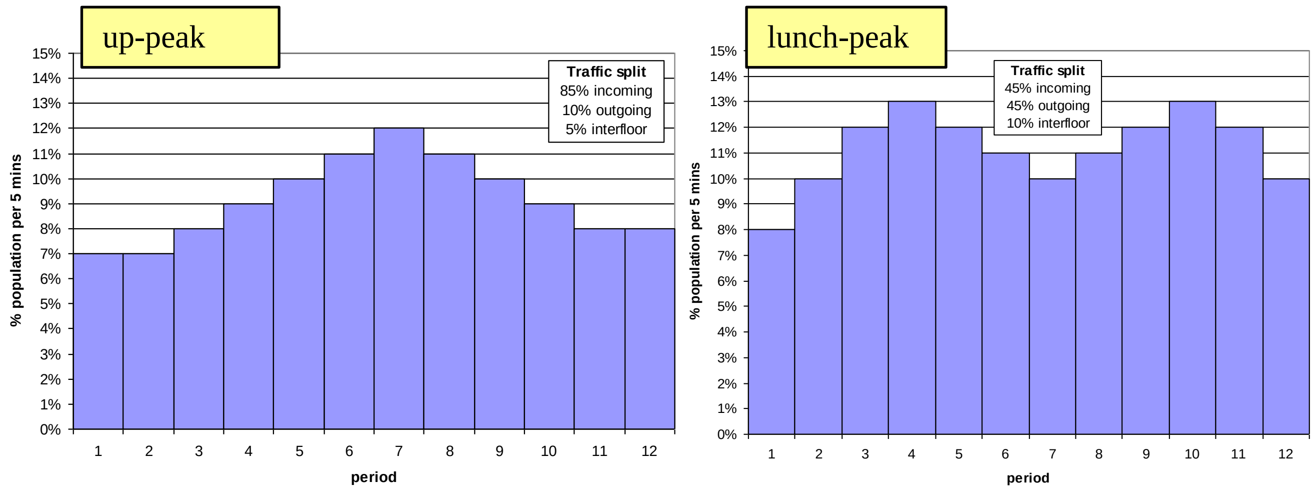
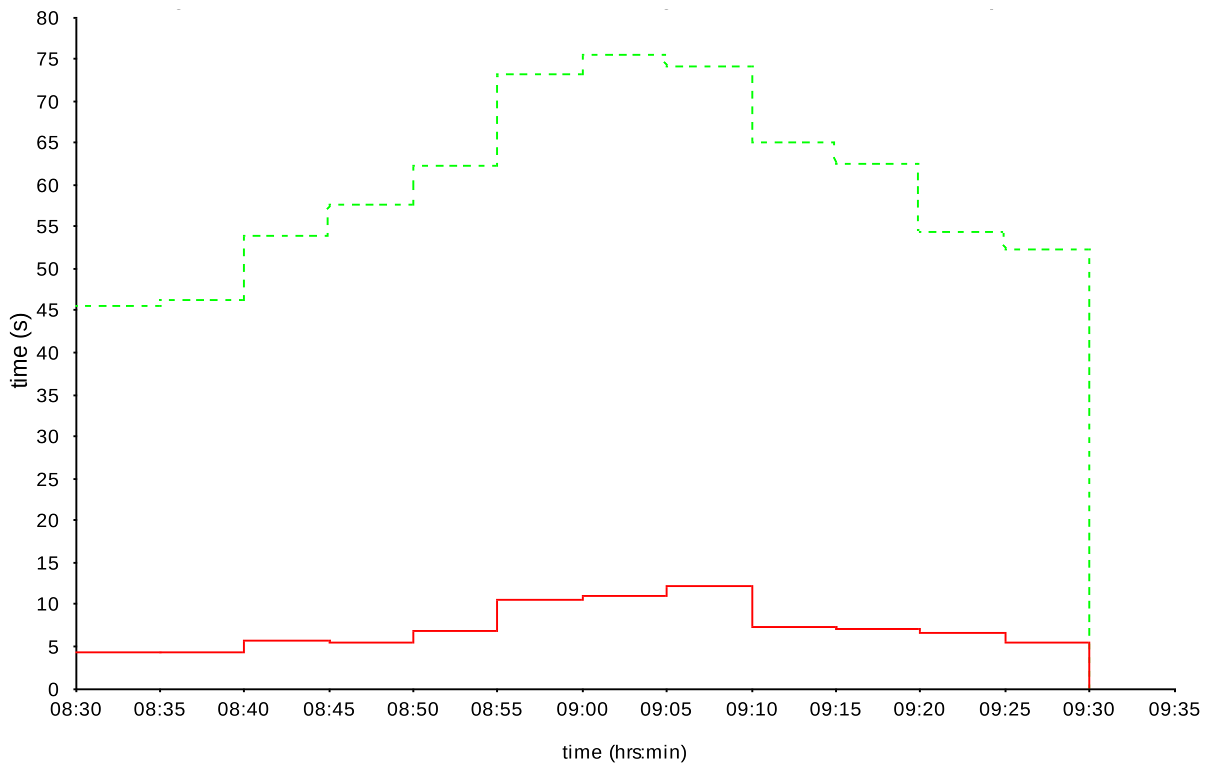


Figure 3 CIBSE modern office up-peak and lunch-peak traffic templates

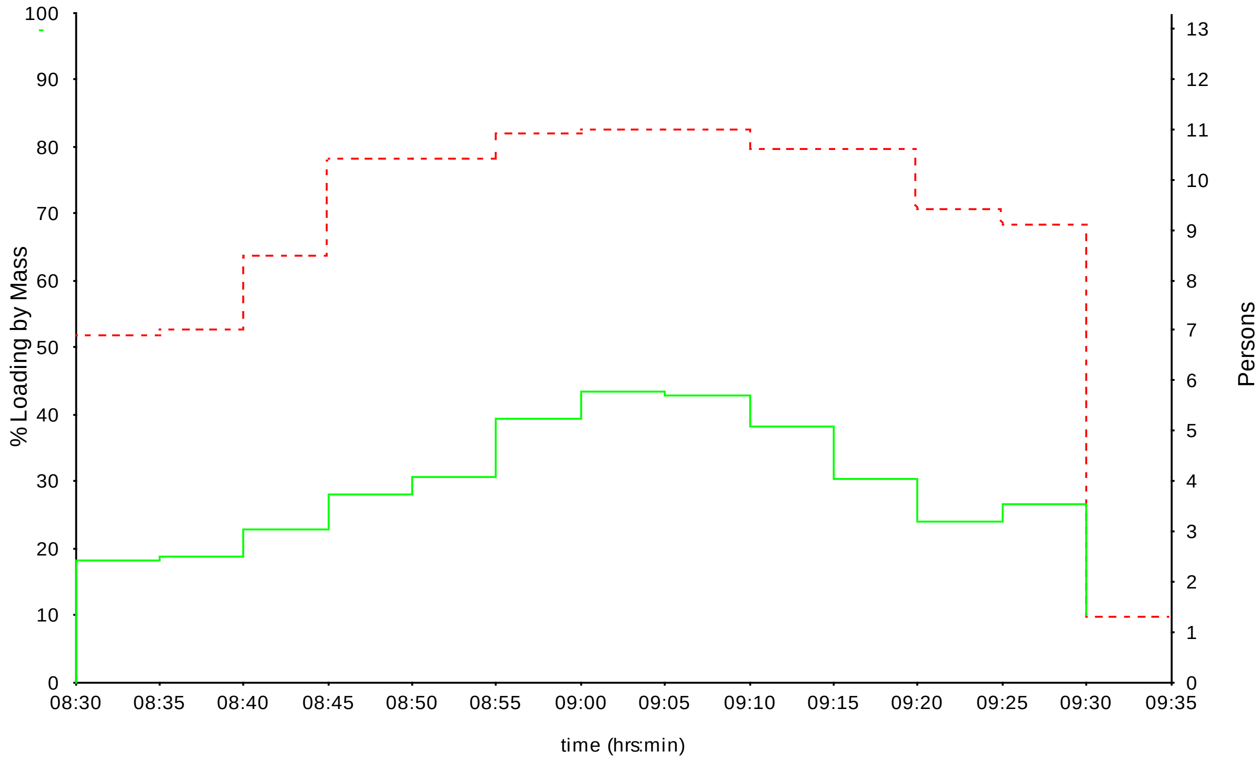
Example 4 Application of modern office templates

Repeat Example 1 in simulation applying the CIBSE modern office templates. Results for simulations based on the up-peak template are given in Figure 4 and Figure 5. Test against target requirements for prestigious city office [2]. The up-peak requirements are for average waiting time during the worst five minutes not to exceed 20 seconds; and for the average transit time not to exceed 80 seconds. These requirements are both met.



Worst Average Waiting Time during any 5 min period (s) 12.1
Worst Average Transit Time during any 5 min period (s) 64.5

Figure 4 Average waiting time (solid) and time to destination (dotted) applying CIBSE modern office up-peak template



Worst Average Capacity Factor by Area during any 5 min period (%) 50.5

Figure 5 Average (solid) and maximum (dotted) car loading on departure from home floor applying CIBSE modern office up-peak template

The up-peak loading requirements are for the capacity factor by area not to exceed 80%. This is met.

Results for the simulations based on the lunch-peak template are given in Figure 6.

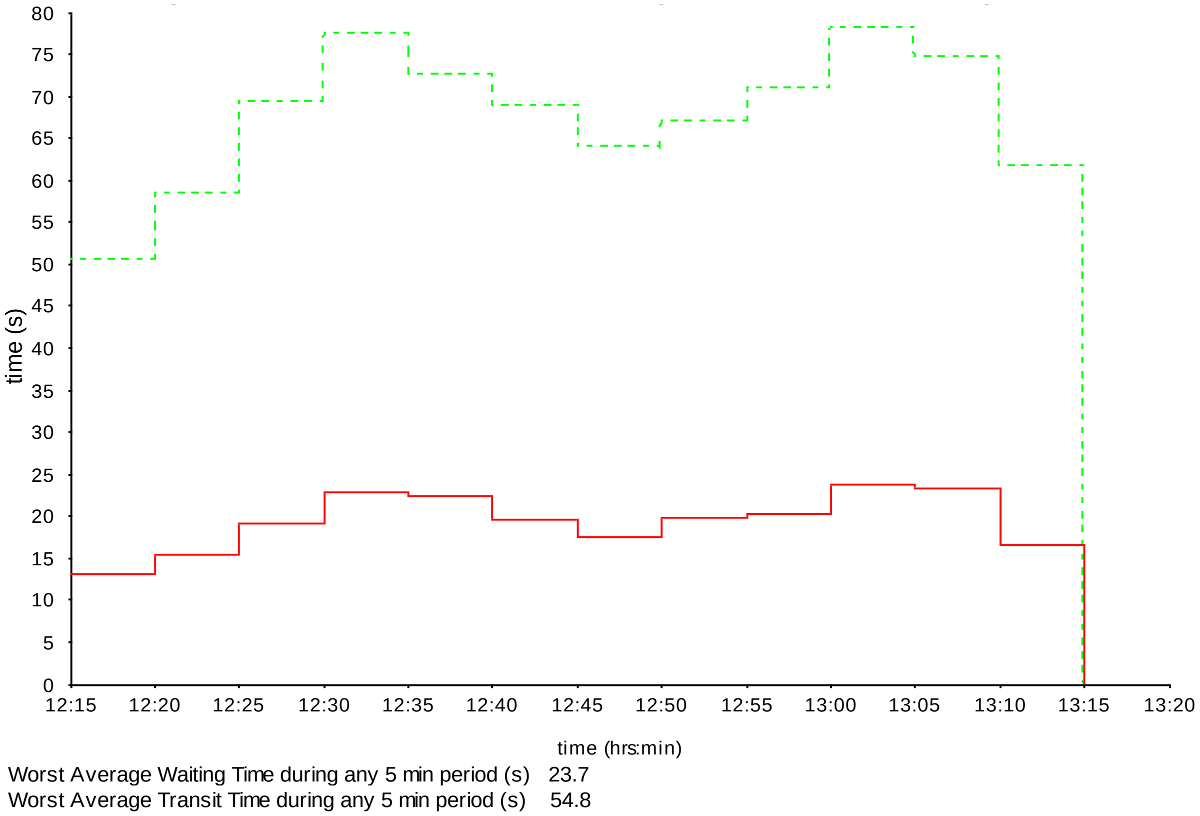


Figure 6 Average waiting time (solid) and time to destination (dotted) applying CIBSE modern office lunch-peak template

The lunch-peak requirements are for average waiting time during the worst five minutes not to exceed 30 seconds; and for the average transit time not to exceed 100 seconds. These requirements are both met. The lunch-peak loading requirements are for the capacity factor by area not to exceed 80%. This is met easily; loading during lunch is less critical as people are not all in the car at the same time; some in the car for the up trip, others for the down trip. Waiting times are typically longer as lifts stop for calls during both the up and down trips.

6. INTERVAL AND WAITING TIME

When clients and designers familiar with round trip time calculations first apply simulation, they sometime continue to use interval as a quality of service measure. This sometimes leads to confusion as interval does not always reflect quality of service.

Interval in an ideal system

Consider a lift system with an interval of 30 seconds. A lift departs the main entrance floor every 30 seconds as indicated in Figure 7. If people are arriving at a constant rate, the first passenger shown on the time line just misses the lift. He or she has to wait 30 seconds. The final passenger shown on the time line just catches the lift, so waits 0 seconds. The average passengers wait 15 seconds. So, in a perfect system the average waiting time is 15 seconds, or half the interval.

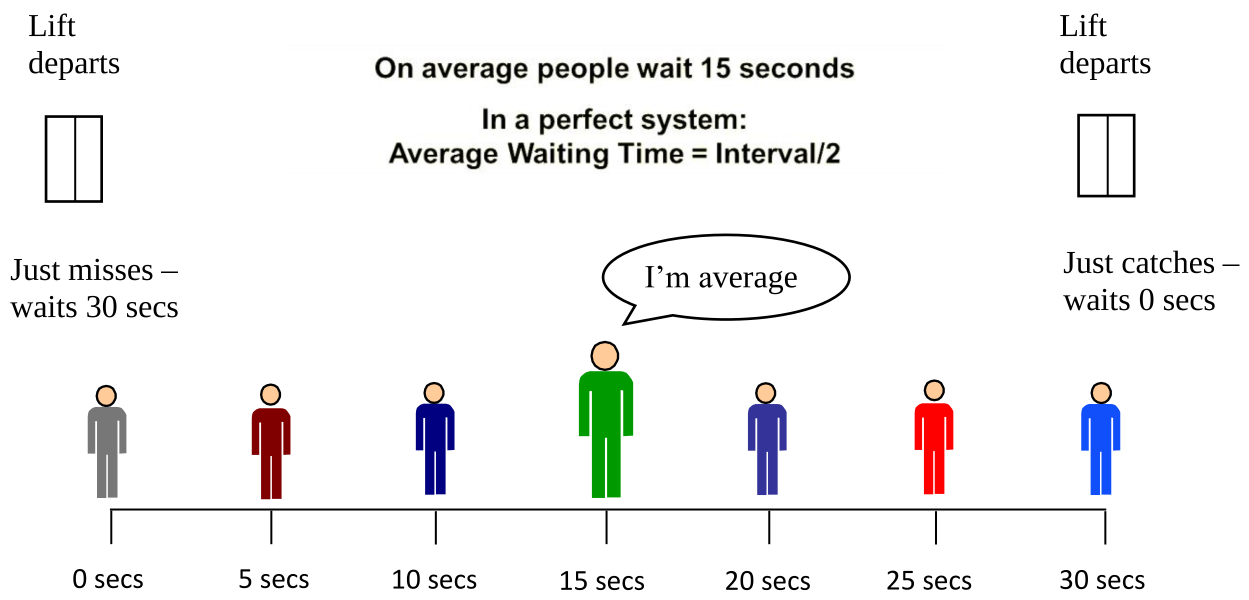


Figure 7 Comparing interval and waiting time

Interval across a range of traffic intensities

The scenario characterised in Figure 7 reflects our understanding of round trip time calculations. In the real word, and with more sophisticated simulation models, the relationship is not this simple. One way of investigating this is with a step profile. In Example 3 the up-peak demand increased by 1% every 30 minutes. Figure 8 shows the corresponding interval with increasing traffic demand.

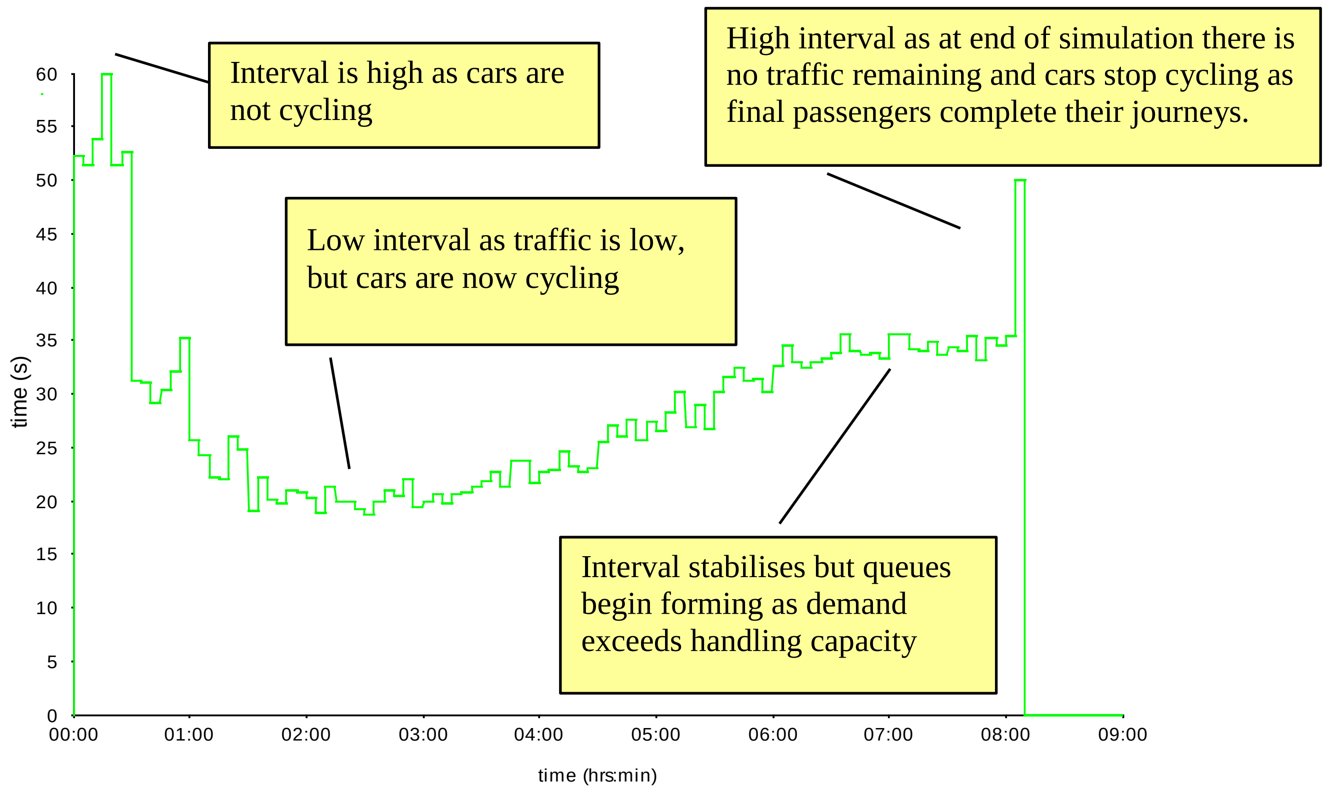


Figure 8 Interval for increasing traffic demand

For the same demand profile, consider the plot of waiting time (and time to destination) as given in Figure 9.

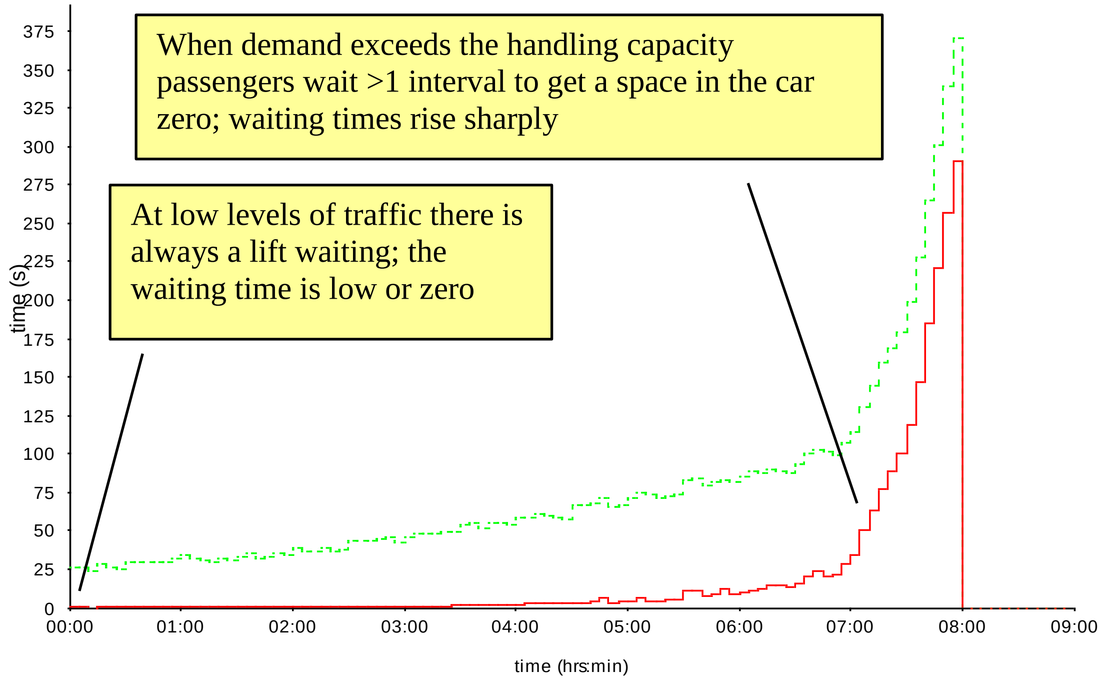


Figure 9 Average waiting time (solid) and time to destination (dotted) for increasing traffic demand

The idealised interval to waiting time relationship seen in Figure 7 only occurs just before the simulation saturates. Average waiting time proves the better measure of quality of service.

Other difficulties with interval

Non-peak traffic With low demand, the interval in simulation becomes high as cars are not being dispatched regularly from the main entrance floor; sometimes they are sitting idle, see the start of Figure 8. It is generally accepted [6] that for low traffic scenarios such as residential buildings, simulation is the better tool, and waiting time should be used in preference to interval.

Multiple entrance floors Interval is a measure of the time between lift departures from the main entrance floor. With multiple entrance floors, not every lift stops at the main entrance floor on every round trip. This causes high intervals; again interval falls down as a measure of quality of service.

Destination Control With destination control passengers are allocated to a specific car, so they do not take the next car to depart. So, even if the interval is 20 seconds, it may be two or three intervals until the car allocated to a passenger departs. Some early presentations of destination control reported excellent intervals, which were potentially misleading; the interval does not correlate with quality of service with these systems.

Discussion

Interval is a very useful measure of quality of service in the context of round trip time calculations. In simulation it is an interesting result, but can be confusing without a clear understanding of what is being measured. If simulation is required, but the design criteria specified is interval, it is advisable to target an equivalent average waiting time. Barney suggests that the relationship is a function of loading [1] , as also demonstrated in this paper. Strakosch [5] suggests the relationship is approximately 60%, which is consistent with the author's simulations at traffic levels marginally below the saturation point. Therefore, for example, a target interval of 30 s could be interpreted as a target average waiting time of 18 s.

7. TRAFFIC CONTROL SYSTEM TESTING

Most traffic control systems have strengths and weaknesses; the step profile is a good way of testing dispatching strategies, which do not necessarily perform consistently across a range of traffic intensities and traffic split (incoming, outgoing, interfloor).

Example 5 Testing traffic control system performance across a range of traffic intensities

Weaknesses in the management of outgoing traffic can often be observed in buildings where people are attending a large meeting or event with a fixed end time.

Repeat Example 3 with 100% outgoing traffic. Run the simulation with a group collective dispatcher with and without the application of a down peak algorithm.

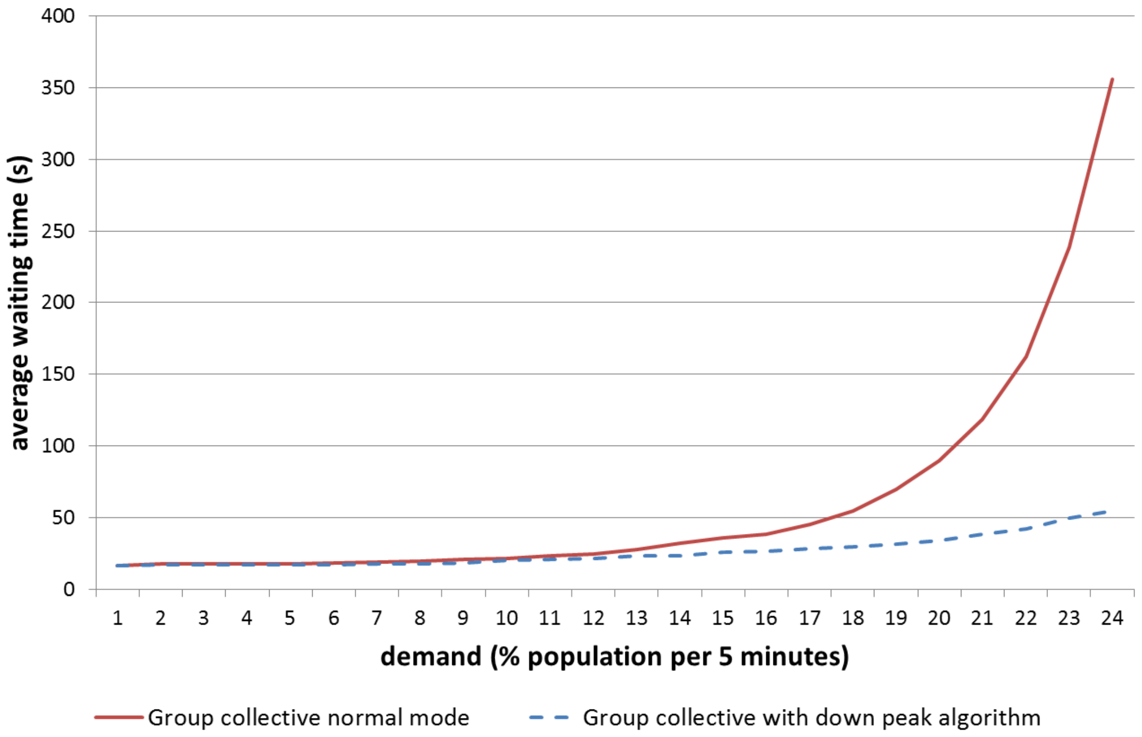


Figure 10 Comparison of average passenger waiting times across a range of passenger demands

The group collective algorithm is based on allocating the “nearest car”, which is a simple, but effective way of minimising system response time. This strategy works reasonably until demand exceeds handling capacity. At this point, a lack of handling capacity is the problem. The down peak algorithm [1] reduces the average number of stops per round trip, which reduces the round trip time and increases the handling capacity. The increased handling capacity results in lower waiting times.

Example 6 Example of traffic control system collapse in saturation

It is well understood that destination control boosts up-peak handling capacity. However some destination control installations perform poorly where the demand exceeds the boosted handling capacity.

This is easiest to illustrate by extending Example 3 and plotting passenger transfer (people who have loaded the lifts) with demand. Figure 11 shows up-peak demand increasing to a point where it exceeds the handling capacity of a conventional system (in this case approximately 14%). Queues will be forming, but the system still delivers 14% handling capacity. The up-peak handling capacity of the sample destination control system is greater (in this case approximately 17%). However when the demand exceeds the boosted handling capacity the system manages saturation poorly, and its handling capacity drops to approximately 10%.

This collapse in handling capacity has been observed in real buildings. It happens because the dispatcher concept does not consider the saturation scenario. There are a number of ways of to address this.

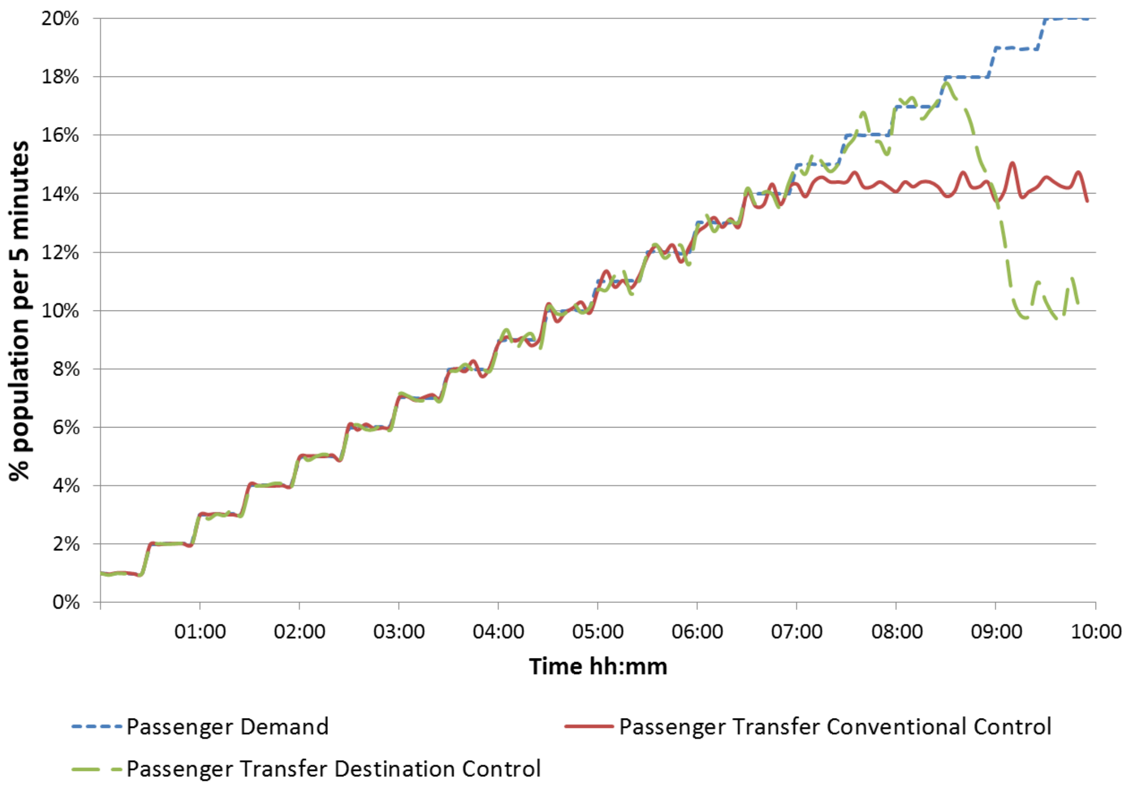


Figure 11 Increasing demand followed by passenger transfer until handling capacity reached, showing subsequent collapse of handling capacity in some cases

For comprehensive testing, the designer should consider all recognised traffic conditions (up-peak, lunch-peak, and down-peak). Scenarios should include multiple entrance floors and special floors such as restaurant and conference levels.

8. OTHER CONSIDERATIONS

Multiple runs

In most cases it is best to carry out multiple (typically ten) simulation runs. This provides a greater sample size with which to generate results that are statistically significant.

Multiple runs can be achieved by using different random number seeds with the same arrival rates and destination probabilities. The demand is the same, but passengers are arriving at slightly different times. It can be helpful to think of this as modelling different days of the week, Monday, Tuesday, Wednesday, etc. Results can then be averaged for all the simulations.

Without multiple simulations, the chance element in simulation means that changing a parameter, such as speed or door operating times can sometimes lead to performance results getting worse when it would be expected for them to improve (or vice versa). For example, if doors times are changed to be slightly slower, in one simulation a passenger may catch a lift which they otherwise would have missed. This may impact results in one simulation run, but if multiple simulations are performed the advantage of the improved door times will be demonstrated.

The smaller the variation, the greater number of simulations will be required. For example, if door times are improved by 0.1s, it may be necessary to run fifty simulations to demonstrate that average waiting time is also improved, if only by a fraction of a second.

9. DISCUSSION

Simulation is a powerful tool which overcomes the limitations of round trip time calculations. However it introduces many complexities to do with real operation, which are not captured in round trip models. Simulations applying a constant traffic template are useful for understanding the relationship between round trip time calculations and simulation; result correlate well if the input assumptions are consistent. Simulations with the step profile provide a better understanding of how lift systems perform across a range of traffic intensities. Simulations based on traffic surveys provide more realistic estimates of how planned lift installations will operate, and the basis for a better assessment of the value of different technologies.

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