Can Lift Traffic Simulators be Verifiable, Transparent, Repeatable and Reproducible?

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Abstract. A lift traffic design is carried out to determine the rated load, rated speed, number of lifts and number of other defining parameters of a lift installation, in order to meet the passenger demands made upon it. A calculation can be carried out using verifiable, transparent, reproducible and repeatable mathematical (statistical) theory. Should further information be required then a simulation is often carried out, but what is the veracity of the simulation results? This paper reviews the simulation results for the same project brief. The paper considers whether simulation results can be verifiable, transparent, reproducible and repeatable.

1 DEFINITIONS

Standards, whether British, European or International are required to be verifiable and secondly where calculations are included, they are required to be transparent, repeatable and reproducible.

Verifiable (able to be checked or demonstrated to be true, accurate), example:

> *Ventilation apertures shall be built or arranged in such a way that it is not possible to pass a straight rigid rod through the car walls from the inside.*

is not verifiable but:

> *Ventilation apertures shall be built or arranged in such a way that it is not possible to pass a straight rigid rod* ***10 mm in diameter*** *through the car walls from the inside.*

… is verifiable.

[Example from BS EN 81-20, 5.4.9.3.]

Transparent (easy to perceive or detect), example:

> *The values of acceleration and deceleration shall be calculated by applying a 10 Hz low-pass filter to the original un-weighted z-axis signal.*

is not transparent but:

> *The values of acceleration and deceleration shall be calculated by applying a 10 Hz low-pass filter to the original un-weighted z-axis signal ….* ***The 10 Hz low-pass filter shall be a 2-pole Butterworth filter*** *…*

… is transparent.

[Example BS ISO 18738:2003, 5.2.1]

Repeatable means:
A person carrying out a measurement, investigation or simulation can repeat the measurement, investigation or simulation and obtain the same results using the same simulator. There may be acceptable and understood random errors in the results.

For this paper it is assumed that each individual investigator can repeat their results.

Reproducible means:
A measurement, investigation or simulation is reproducible if when the measurement, investigation or simulation is repeated by another investigator using the same simulator or another simulator obtains the same results.

2 THE PROBLEM

Calculation and simulation methods are used to select lift systems to meet specified traffic design requirements and establish the main parameters of rated load, rated speed and number of lifts.

The calculation method

The calculation method takes the input parameters, applies a mathematical (statistically based) model and provides output results.

The mathematical model is represented by formulae and is defined precisely.

The calculation method is verifiable, transparent, repeatable and reproducible by the ordinary traffic designer.

The simulation method

The simulation method takes the input parameters, applies them to a simulator and provides output results.

The simulator runs a digital model. The details of how it operates are not fully known to the ordinary traffic designer.

A simulation should be repeatable by an ordinary traffic designer. But can the ordinary traffic designer confirm that the simulation method is verifiable, transparent and reproducible? The simulation method could be made more transparent if the simulator engine coding were available for review by the traffic designer. However, most designers would not have the skill or time to undertake this review.

This is why there are often different output results when using different simulators.

3 COMPUTER AIDED DESIGN OF LIFTS

The necessity for the computer aided design of lifts was foreseen by Jackson (1970) who wrote:

> *"a real need … is a computer program to simulate the likely performance of proposed lift systems . . . Different numbers, speeds and groups of lifts should be considered, as well as different control systems … the results would show designers the performance of several proposals . . . [and allow] . . . rational decisions".*

The computer simulation of engineering processes is particularly appropriate, where the study of the actual process is difficult or dangerous, too costly, would take too much time, or would be inconvenient. Existing lift systems fall into this category. In the case of a new lift, the installation does not even exist.

Digital computers are most suitable for the simulation of discrete (digital) systems, as their algorithms can be described by sets of logical equations. A lift system is a discrete system:

- Each passenger is a discrete entity.
- Each individual passenger arrival or departure are discrete events.
- Each floor is a discrete entity.
- Each lift is a discrete entity.
- Each lift car movement and door operation are discrete events.

Digital computer simulation programs can be either event based, ie: the model is updated every time something happens, or time based, ie: the model is updated at regular intervals. A lift system is relatively sparse in the number of events that occur, compared to some engineering systems. Most lift system events do not require immediate action, and some events initiate identical actions, making it efficient to service them at the same time. It is therefore better to select the time-based method, with an update interval chosen to contain a statistically significantly number of events.

Engineering design involves the appreciation of shape, form and relative values; thus the graphical presentation of data allows the designer to appreciate a design quickly. The process of computer aided design (CAD) is to input data, carry out an application (APP), eg: a simulation, receive output data to consider and, if necessary, repeat the process with new input data.

4 TESTING SIMULATIONS

During the course of work on the revision of ISO 4190-6: 1984, *Passenger lifts to be installed in residential buildings* to create ISO/FDIS 8100-32, *Planning and selection of passenger lifts to be installed in office, hotel and residential buildings* it was decided to complement the calculation method with a simulation method. Doubts were expressed to the veracity of results obtained by simulation. As the group comprised traffic specialists with different experiences and skill sets, this presented the writer with a unique opportunity. The writer asked the group members to investigate the problem by running simulations to the same project brief with the same input data and report in the same output format.

The investigation was to run nine simulations at one percent point steps of passenger demand from 8% to 16% for an office building with low and high zones. The uppeak and midday traffic patterns were to be considered. There were 36 simulations to be carried out by each investigator.

Table 1 shows the lift traffic design criteria. Table 2 is the project brief and shows the building and lift data. Table 3 reports the uppeak results and Table 4 reports the midday results in the data format required from the simulations.

Table 1: Lift traffic design criteria

Type of Building:	Office building	
Uppeak traffic:	100 % incoming	
Midday traffic:	40 % incoming, 40 % outgoing, 20 % inter-floor	
Design criteria:	**Uppeak**	**Midday**
Required handling capacity:	12 %	11 %
Required average waiting time	30 s	40 s

5 THE RESULTS

Six sets of results were sent to the writer and anonymised. Only the writer and the investigators will recognise the results. The six data sets were identified as Series 1, Series 2, Series 3, Series 4, Series 5 and Series 6. The example values shown in Tables 3 and 4 are from Series 2.

The results were from three major manufacturers, three consultants and carried out on three software platforms. Two simulations were carried out by the same investigator using two different simulators. Four of the sets of results were made using the same platform.

The results were tabulated on a spreadsheet and graphed as shown in Figures 1 and 2.

6 SUMMARY OF RESULTS

Table 5: Summary of passenger average waiting times (AWT) in seconds.

Traffic type	Rise	Required Demand	Required AWT	Series 1	Series 2	Series 3	Series 4	Series 5	Series 6
Uppeak	Low	12%	30s	9.1	7.5	5.0	5.2	13.5	7.7
Uppeak	High	12%	30s	19.6	8.1	10.0	6.8	34.0	16.5
Midday	Low	11%	40s	15.8	21.8	23.2	23.3	23.8	19.1
Midday	High	11%	40s	20.3	24.2	25.0	26.0	31.0	26.1

The results obtained are assumed to have been **repeatable** by each individual investigator.

All the simulations return different values so the all the simulators fail to provide **reproducible** results, see Table 5.

The results for Series 5 are significantly different to the other series.

The four sets of results from the same platform (Series 2, 3, 4, 6) returned different results. This indicates different interpretations of set up parameters made by the investigator or a tailoring of the simulation engine.

7 WHY ARE THE RESULTS DIFFERENT?

Each investigator was provided with the design criteria (Table 1) and the building and lift data (Table 2) and asked to report to a standard template (Tables 3 and 4).

Although the data in Table 2 is all that the calculation method requires the data specified in Table 2 is not sufficient for the simulation method.

Investigator settings

There are many variations possible that the investigator can set including:

- Did the investigator run one simulation or several and take an average?
- Did each investigator run a constant simulation for each of the nine demand values from 8% to 16% or did they run a stepped simulation across the range?
- Dwell times are not defined and different values can be selected. Often a simulator enters default values.
- How many door recycles, as the result of multiple landing calls, are permitted? Often a simulator enters default values.
- Did the investigator allow stair traffic?
- Were passenger numbers determined by area or by weight to determine maximum lift car capacity?
- Was a factor added to allow for "running out of sequence" (bunching)?
- Is the main terminal given extra attractiveness to park there?

There are other input parameters in most simulators and the investigator can set them to their experience.

Controller settings

The control algorithm used is defined as full collective. The meaning of this algorithm is understood, but:

- In uppeak, does the simulator bring all cars to the main terminal floor, when empty?
- On arrival at the main terminal floor do the doors open immediately or wait?
- Is there a load detector operating to bring lift cars to the main terminal?

  Series 2, 3 and 4 have an improvement in waiting times near to 13.5% demand. Could this be the effect of a switching algorithm?

Simulator settings

The simulator "engine" has a number of factors generally unknown to the designer, including:

- Is the simulation event based or time based?
- To what accuracy is data measured?
- Is the data kept to the maximum accuracy or rounded?
- How is the Poisson arrival process carried out?
- Does the arrival process force exactly the current number of passengers to arrive in each 5-minute period?
- If the passenger arrival rate is a decimal number does the simulator round up or down?
- How are destination calls determined?
- What is the pre-simulation period until data is gathered (start effect)?
- If passengers are still not disembarked at their destination is their waiting and travel times included (finish effect)?

There are other simulation parameters that are not defined and that the investigator may not be aware of.

Output setting

The output module can also present data in different ways, including:

- Is the average passenger waiting times gathered as an average per 5-minute period or are they an average over the whole period?
- Have the values been rounded?
- For midday simulations are the averages for one floor?
- For midday simulations are the averages for all floors?
- Is there any result filtering?

The report module often has advanced processing features that at are not defined.

Thus, the internal workings of the simulator engine are **not transparent** to the designer. The simulator designer will know all the features, but usually will not be the user.

8 ARE THE SIMULATION RESULTS BAD?

The graphs show similar shapes. Table 5 shows there is no best simulator.

All except Series 5 follow a similar shape for uppeak traffic and all follow a similar shape for midday traffic.

The right-hand graphs show the results to a smaller time range. The design criteria for average waiting times (AWT) for the passenger demand values of 12% in uppeak (except Series 5) and 11% in midday traffic for both rises are easily achieved. Why?

A calculation for uppeak traffic shows that six 2000 kg lifts can provide:

Low Rise *%POP* = 14.3% /5 min	UPPINT = 27.3	AWT = 23.2	CF = 80%
High Rise *%POP* = 13.6% /5 min	UPPINT = 28.7	AWT = 24.4	CF = 80%

Both rise installations are over lifted. This is why at the uppeak design criteria value of 12% the performance is so good, as the cars are only 57% loaded (CF).

Different conclusions would be drawn if, for example, the uppeak design criteria were set at the 14.3% full handling capability.

Taking low rise passenger demand at 14.3% (marked with a "snowflake" on Figure 1 (B)). Examining Figure 1 (B) shows the AWT results are all less than 30 seconds (except Series 5), but show a range of AWT of approximately 5 s – 25 s.

The values obtained are better than required so does it matter there is a range?

It is possible in a tender situation that a client receiving simulation results from suppliers and consultants would favour the lower values, other matters being considered. So, there might be a competitive advantage.

Calculations show that the low rise could be served by either five, 2000 kg lifts or six, 1350 kg lifts.

Calculations show, for the high-rise installation, that six, 1600 kg lifts would be suitable.

9 CAN A SIMULATION BE MADE MORE VERIFIABLE?

The definition of all simulator parameters is a huge job, if at all possible. The parameters mentioned above are some. But do all simulators have these features anyway?

Could a benchmark be developed to certify a simulator?

Yes, it could, but simulator designers could still tune their simulators to pass the test.

10 CONCLUSIONS

The calculation method is verifiable, transparent, repeatable and reproducible.

The simulation method is not verifiable, transparent or reproducible, but is repeatable.

Simulators could be made more verifiable by defining more parameters. There is a risk, however, that defeat algorithms are inserted to ensure a successful compliance.

11 SIDENOTE

Both the proposed low- and high-rise lift installations are over lifted. This is clear from the simulations. But the simulations give no clear idea as to a more appropriate selection. The calculation method does this instantly.

Peters (2019) recommends: *"… it is good practice to start all design exercises with a round trip time calculation. …Simulation is complex and it is easy for less experienced practitioners to make mistakes, a round trip calculation may alert the practitioner of a possible error"*

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BIOGRAPHICAL DETAILS

Dr Gina Barney Principal of Gina Barney Associates, Honorary English Editor of Elevatori, Member of the Chartered Institution of Building Services Engineers (CIBSE) Lifts Group Committee, Member of the British Standards Institution (BSI) Lift Committees, UK expert to ISO committee ISO/TC178/WG6/SG5 revising ISO 8100-32 Planning and selection of passenger lifts to be installed in office, hotel and residential buildings and ISO/TC178/WG10 Energy efficiency of lifts and escalators. Liveryman of the Worshipful Company of Engineers and a Freeman of the City of London. Dr Barney is the author of over 120 papers and is the author, co-author or editor of over 20 books. She has the degrees of BSc, MSc and PhD and the professional qualifications of CEng, FIEE, HonFCIBSE and Eur.Ing. Trustee of three charities and member of several Sedbergh organisations and a volunteer Area Lead for Broadband for the Rural North (B4RN) installing 1Gbps full fibre in the Rawthey Valley. For relaxation (sic) she dances ballroom, Latin, sequence and Scottish country, with gardening and dog walking and goes on cruises.

Table 2: Project brief (building and lift data)

Parameter	Low Rise	High Rise
Population	1232 persons	1232 persons
Lift group control	Full collective	Full collective
Maximum passenger capacity	20	20
Rated load	2000 kg	2000 kg
Average interfloor distance	3.75 m	3.75 m
Express-Zone	--	52.5 m
Number of served floors	14	14
Number of lifts	6	6
Rated speed	2.5 m/s	5.0m/s
Acceleration / Deceleration	1.0 m/s^2	1.0 m/s^2
Jerk	1.0 m/s^3	1.0 m/s^3
Door type	1speed CO	1speed CO
Door width	1100 mm	1100 mm
Flight time	5.0 s	5.0 s
Door closing delay time	0.0 s	0.0 s
Door opening time	2.0 s	2.0 s
Door closing time	2.4 s	2.4 s
Door pre-opening time	0.0 s	0.0 s
Start delay	0.6 s	0.6s
Performance time	10.0 s	10.0 s
Single passenger transfer time	1.0 s	1.0 s

Table 3: Passenger average waiting times for uppeak traffic (series 2)

Demand (times in seconds)	Low Rise	High Rise
Avg. waiting time at 8 % passenger demand	1.7	3.5
Avg. waiting time at 9 % passenger demand	2.1	4.3
Avg. waiting time at 10 % passenger demand	3.5	6.1
Avg. waiting time at 11 % passenger demand	3.6	8.2
Avg. waiting time at 12 % passenger demand	7.5	8.1
Avg. waiting time at 13 % passenger demand	5.2	12.0
Avg. waiting time at 14 % passenger demand	6.0	24.6
Avg. waiting time at 15 % passenger demand	33.8	314.0
Avg. waiting time at 16 % passenger demand	267.0	603.0

Table 4: Passenger average waiting times for midday traffic (series 2)

Demand (times in seconds)	Low Rise	High Rise
Avg. waiting time at 8 % passenger demand	12.7	18.7
Avg. waiting time at 9 % passenger demand	14.9	19.5
Avg. waiting time at 10 % passenger demand	18.4	22.6
Avg. waiting time at 11 % passenger demand	21.8	24.2
Avg. waiting time at 12 % passenger demand	23.6	28.3
Avg. waiting time at 13 % passenger demand	24.9	29.1
Avg. waiting time at 14 % passenger demand	29.5	29.2
Avg. waiting time at 15 % passenger demand	35.7	37.0
Avg. waiting time at 16 % passenger demand	35.7	45.9

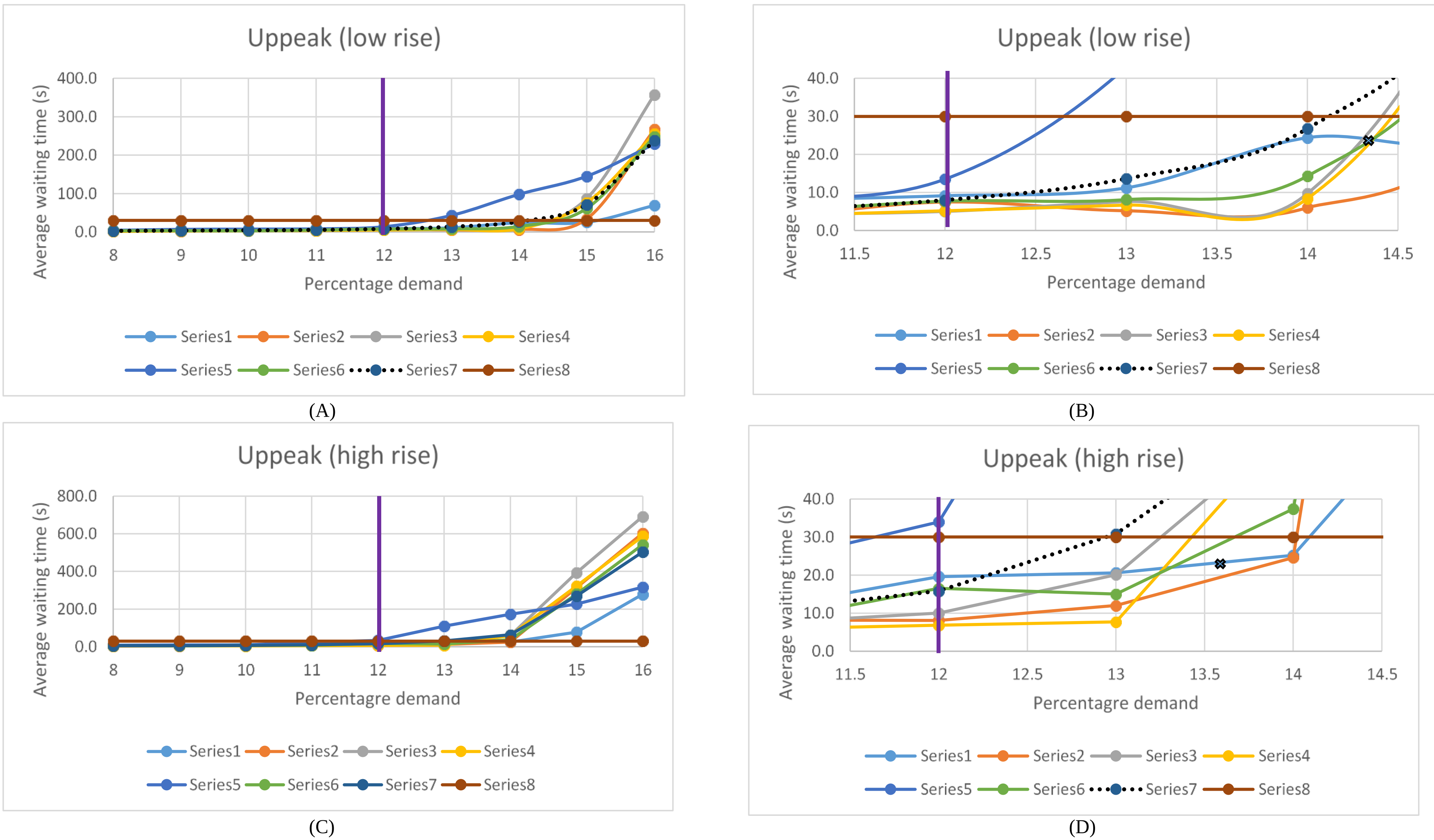
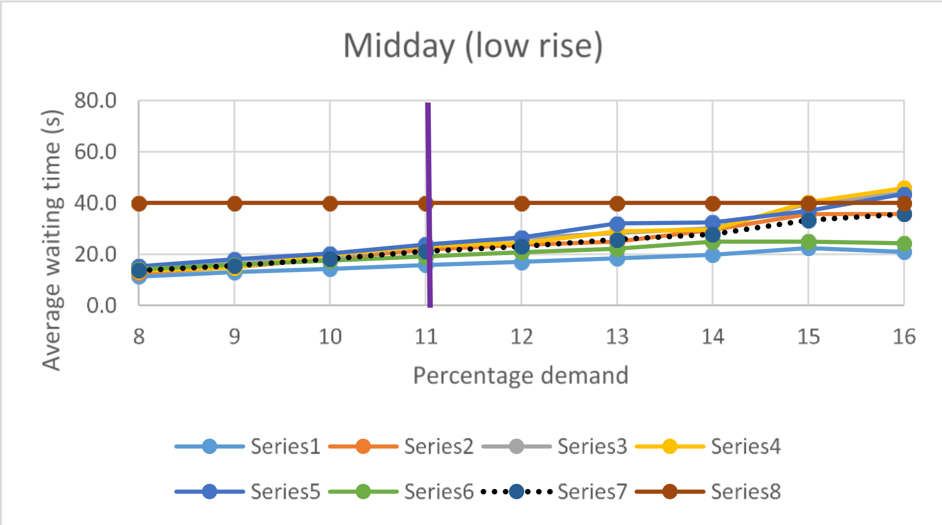
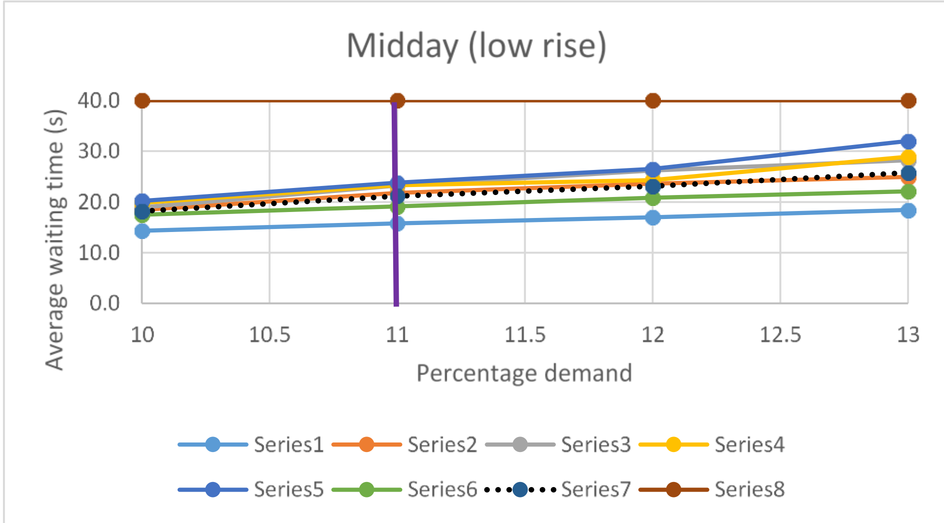


Figure 1: Uppeak results *Note: Series 7 (dotted line) is the simple average of the results. Series 8 (solid) line are datum values.* **– (A) & (C) from 8% to 16% (B) & (D) from 11.5% to 14.5% for 12% demand – shows <30 s average passenger waiting time**



(A)



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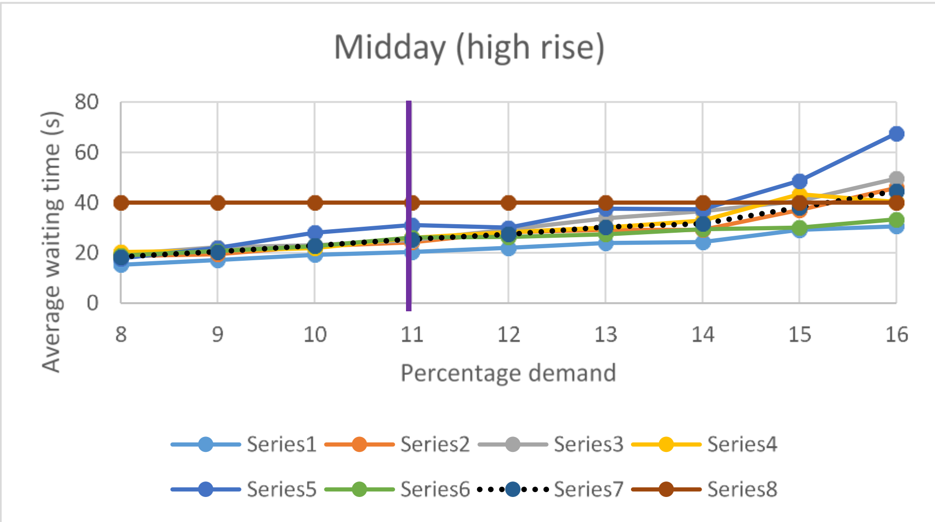
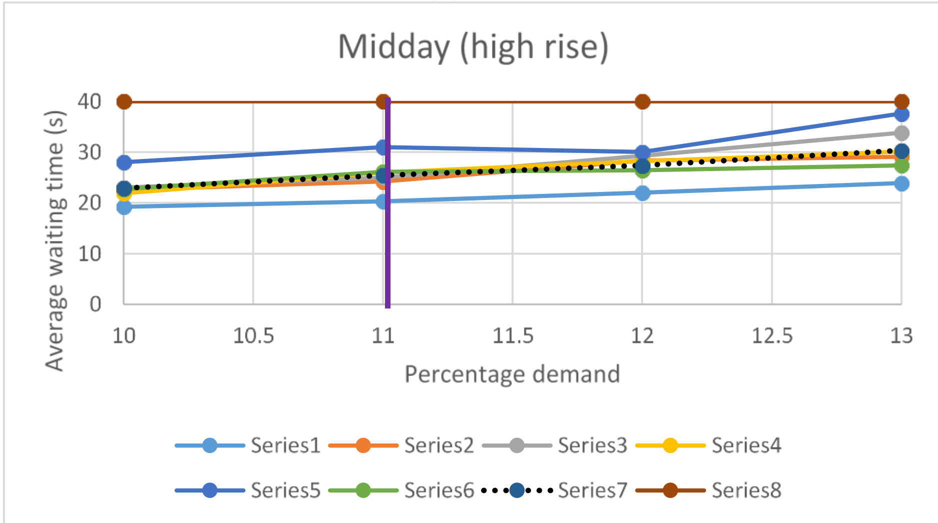


(C)



(D)

Figure 2: Midday results *Note: Series 7 (dotted line) is the simple average of the results. Series 8 (solid) line are datum values.*

– (A) & (C) from 8% to 16% (B) & (D) from 10.0%to 13% for 11% demand – shows <40 s average passenger waiting time