Lift Traffic Analysis for a Proposed Inner-City Development. A Comparison of the Lift Control Algorithms Considered

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Abstract. This account commences with an original enquiry regarding a proposed mixed development in Nottingham and the results presented to the client. The initial enquiry indicated the building will be subject to heavy mixed lunch time traffic. It was surprising to note the newest and most complex system, Hall Call Allocation, failed to satisfy the client's and the BCO traffic requirements [3]. This investigation set out to examine why one control system appeared to perform better under certain conditions. Alongside academic research, traditional mathematical calculations and simulations were used to explore and test the differences. This paper outlines and examines three generic group control systems and explores the basic concepts and differences of each system considered for the project. This investigation also briefly reviews calculation and simulation and the differences these make to the way the control algorithms are considered and treated.

The results of the various pre-design simulations, subsequent research and conclusions were somewhat unexpected. The differences were also surprisingly subtle.

This paper briefly follows the research of the "Technical Report" prepared in support of the author's application for C.Eng. registration earlier this year.

1 INTRODUCTION

This investigation originates from an on-going project - a Developer's and Architect's vision. The Report develops from the initial assessment and analysis Abbacas provided to a developer in 2016. It focuses on the different lift traffic performances provided by the various group control systems investigated.

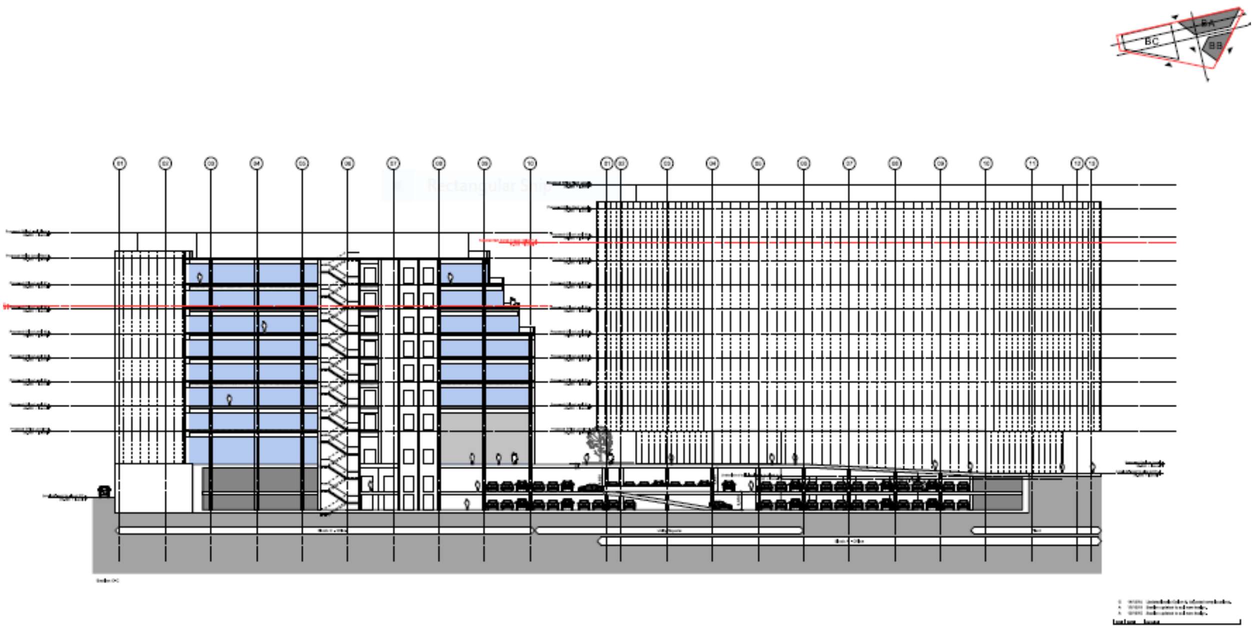


Figure 1 East Elevation of the proposed development

The proposed development presents a particularly challenging commission as it consists of three multi-storey blocks, each with different layouts, floor areas, floor numbers and various classes of accommodation and use, including: office, retail and hotel accommodation. Each block rises independently from a common area on the ground floor, with two car-parking levels below. This creates patterns of access, circulation and egress that are both complex and difficult to calculate.

There are a multitude of control systems in the market place, from the major lift manufacturers and independent controller manufacturers. Each comes with a claim of improving performance. Each one has it adherents and critics! This paper set out to briefly explore the differences between the group control systems and the reason for the difference in their responses and briefly follows the steps taken in the full Technical Report.

2 UNDERSTANDING PASSENGER MOVEMENT AND LIFT RESPONSES

There are several conditions of passenger traffic a lift control system must contend with.

Apart from being idle, there are four basic traffic conditions a lift system may experience:

2.1 Light Random Traffic – balanced interfloor

No dominant direction of travel. Light demand – less than 3 x passengers for each available car [11].

Generally found between peak periods, it normally consists of a relatively equal number of up and down journeys to the main and intermediate floors. Several cars may be parked or unused.

This is of no concern to the lift designer, as it places little demand on the control system.

2.2 Up Peak – uppeak

The dominant direction of travel is upwards. Heavy demand - Cars are over 50% of capacity [11]

A typical uppeak can be found at start of work period. It is characterised by a gradual build-up of passengers to a maximum demand with a sharp decline. Whilst the whole period may last 30 - 60 minutes, it is common practice to size the lift group system on the busiest 5 minutes of the peak [2,9]

2.3 Down Peak – dnpeak

The dominant direction of travel is downwards. Heavy demand - Cars are over 50% of capacity [11]

A typical dnpeak can be found at the end of the work period. It is characterised by a steeper build-up of passengers to an uppeak demand and lasts a little longer, so 10 minutes is normally applied to this peak [1,2].

2.4 Mixed Peak –lunchpeak

No real dominant direction of travel. Heavy demand - Cars are over 50% of capacity [11]

Traffic flows in both directions to intermediate floors with common welfare & social facilities as well as the main floors. Unlike the other peak conditions, this may last for a couple of hours with more than one peak flow, in both directions, to deal with.

This has proved to be the hardest condition to predict and accommodate.

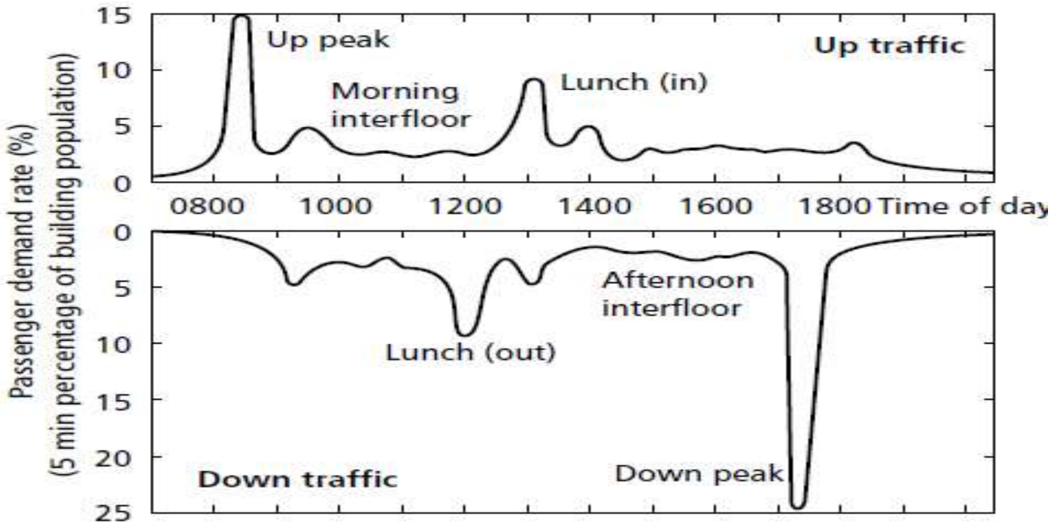


Figure 2 A classical view of passenger traffic in an office block (courtesy of CIBSE Guide D:2015)

3 BASICS OF TRAFFIC ANALYSIS

Understanding the basics of passenger movement and traffic analysis is essential, irrespective of the method used, whether it be an analytical mathematical or computer simulation.

There isn't enough time or space to go through the details and mathematics here, except to mention one equation, and this is the Round Trip Time. The RTT consists of many elements of a hypothetical average journey of a single lift car; starting from the main floor, where persons enter the building and distribute an average number of passengers (P) in one trip to a probable numbers of floors (S) up to the highest probable floor (H) and returning (non-stop) to the main floor (MT) [1,5]. This underpins all traffic calculations.

The RTT calculation contains all the elements in the theoretical trip as displayed in this graph. The RTT was originally expressed by Barney & Dos Santos in 1975.

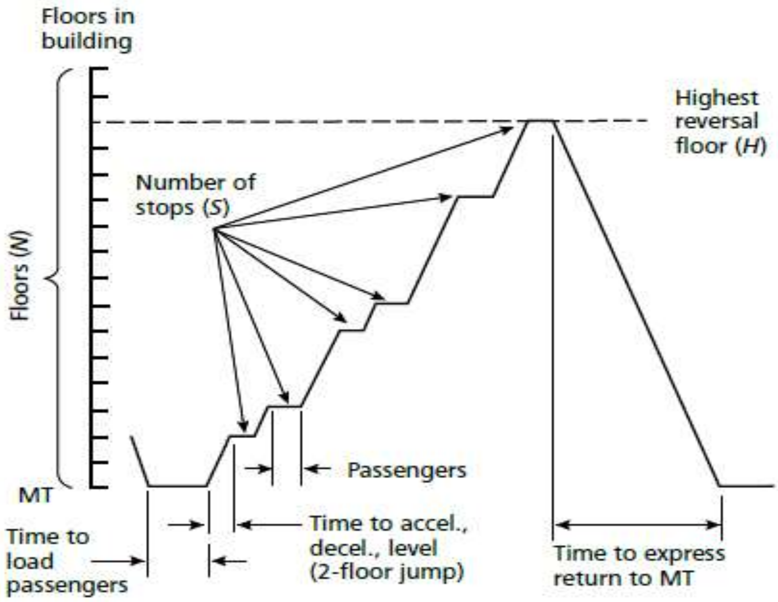


Figure 3 Round Trip Time in graphical form (courtesy of CIBSE Guide D 2015)

4 ANALYTICAL METHOD V SIMULATION

One of the steps of this journey was to review the methods of analysis and calculation. The simulation method highlighted the difference in control responses, but can the mathematics?

Whilst consistent, reliable and sophisticated, the basic manual calculations are simplistic and less flexible compared to the world of moving people. The standard calculations are based on a set of ideal conditions, using rectangular probability distribution; passengers arrive in a uniform rate, all travel up from the main floor, floor populations are proportional, floor heights uniform, etc. [4,6]

Simulation with its Poisson probability distribution, lends itself to more complex and multi-faceted situations with inter-floor traffic, differing floor populations, inconsistent floor heights, multiple access / egress floors and irregular passenger arrival [2].

Integers also play a part in the difference too; whereas calculation may use a decimal number (which creates part passengers), simulation only uses whole people [2].

The RTT is very useful when calculating the peak traffic conditions to or from the main floor. Although it can be extended to account for some of more complex situations; it cannot, however, handle them all. These conditions are better assessed with software driven iteration of General Analysis or Simulation, [8] both of which utilise Poisson passenger arrival.

Not only does having a good knowledge of the basic mathematics lead to a better understanding of the processes, but carrying out a manual calculation, allows a designer, to quickly establish which permutations are viable and worthy of further consideration before executing simulations [4]. It was clearly proven in this instance, as the manual calculations delivered a guide to "size" the lift systems and provided a starting point for the simulations.

The simulations fine-tuned the results, and in this instance, highlighted a variation between the different supervisory algorithms; a nuance overlooked by the mathematics!

The manual / spreadsheet method of calculation is by no means redundant as it provides the VT designer / specifier, as demonstrated in this project, with a quick assessment of the proposed system and a glimpse of the Quality of Service.

The analytical method also remains a good tool for projects with simple profiles, clearly defined peaks, undemanding inter-floor traffic and a single access floor. Due to the general size and design of buildings it is still well used in the UK.

Moreover, the mathematical method provides almost instant results, especially if executed in a spreadsheet; "what if" calculations are available with a single key press.

Unlike the mathematical method, a simulated solution takes time to deliver as the sequence needs to be repeated many times to achieve reasonably realistic results. The results are an average of all the simulated runs with each one based on a random seeding – the more simulations run, the more representative the resultant data will be [2].

5 REVIEWING THE CONTROL SYSTEMS

5.1 Conventional Group Control System – Next Car Available - NCA

The most modest of the 3 and in its simplest form is no more than a conventional Fully Collective Group Control System used on a simplex (one car) system, albeit interconnected with other lifts.

A lift car will be dispatched to the nearest hall call, in the direction it is travelling in, as long as it has capacity.

5.2 Estimated Time of Arrival - ETA

ETA is similar to the NCA (and to the passengers it appears identical) except the Hall Calls are prioritized, regarding the time a hall call has been registered. The supervisory group controller is constantly monitoring all hall calls and car positions; seeking the lowest Estimated Time of Arrival of a car answering a hall call.

5.3 Hall Call Allocation - HCA

A more sophisticated system that allocates cars and calls before passengers arrive at a lift car.

The group supervisory controller / dispatcher receives the passenger's intended designation from key pads (or encoded swipe cards) at each landing on arrival. The passenger is then directed to a lift car.

6 THE INVESTIGATION

After identifying and describing the different control systems, the next task was to compare their operation and performance. A simple method that was repeatable and could review all systems was required.

Following some detailed research, Dr Richard Peters explanation of the call degradation process in a Hall Call Allocation system [7] was selected to compare the effect of all three control systems.

6.1 Assessing the HCA

For this exercise, a simple algorithm, set to reduce Time to Destination only, was assumed.

Considering a 11-floor building (0 – 10) as in the chart below.

Two Hall Calls have been placed:

"A" is at level 6 wants to go to 2.

"E" is at level 5 descending to 0.

Car 1 is leaving level 10 with B, who is going to 8.

Car 2 is passing level 9 with C who is going to 5.

Car 3 is filling with 6 delegates on level 8 who are heading for level 1.

Car 4 is leaving level 4 with D who is going to 10

Table 1 Floors, passengers, car positions and hall calls

Flr	Hall Call (1)	Car 1	Car 2	Car 3	Car 4	Hall Call (2)
Direction		Down	Down	Down	Up	
10		B to 8				
9			C to 5			
8				6 pers to 1		
7						
6	A-to 2 s	☜ 20s	☜ 15s	☜ 10s		
5		25s ☞	20s ☞	15s ☞		E to 0
4					D to Top	
3						
2						
1						
0						

Each cell is equal to a floor level and represents 5 seconds transit time.

Passenger's journeys are not isolated; passengers affect each other. The effect on passenger's journeys are accounted for in the HCA calculation. This is known as the System Degradation Factor (SDF).

For clarity of this exercise, the SDF has been broken in to 2 sub components of inconvenience that passengers may experience within a journey:

- SDF1 - picking up other passengers.
- SDF2 - dropping off other passengers.

The HCA algorithm also includes the estimated time to the selected floor (TT) into its analysis.

Each possible journey is expressed as the Total Time Cost (TTC).

The TTC equals ETA + TT + SDF 1 + SDF2 and is expressed in seconds.

Table 2 Breakdown of Hall Call Allocation elements and times

Estimated Response Times in Seconds									
	Car 1			Car 2			Car 3		
Picking up	A	(A+E)	E	A	(A+E)	E	A	(A+E)	E
ETA	20	25	25	15	20	20	10	10	15
Transit	20	35*	25	20	35*	25	20	35*	25
SDF1 - Pick up	0	20	0	10	20	10	60	130	60
SDF2 - Drop off	10	10	10	10	10	0	60	130	60
TTC	50	90	60	55	85	55	150	305	160

*If A + E were travelling together in the same lift car the total transit time will be reduced. In this instance by 10 seconds (2 x 5s floors 4 to 3).

Table 3 The Total Time Cost of each car and effect on the intended passengers

For A to travel from 6 to 2:	For E to travel from 5 to 0:
Car 4 – not applicable as it has no effect.	Car 4 – not applicable as it has no effect.
Car 3 – 10 + 20 + 120 = 150 s.	Car 3 – 15 + 25 + 120 = 160 s.
Car 2 – 15 + 20 + 20 = 55 s.	Car 2 – 20 + 25 + 10 = 55 s.
Car 1 – 20 +20 + 10 = 50 s.	Car 1 – 25 +25 + 10 = 60 s.

6.2 The Decision

With the lowest Total Time Cost, of 50s, the Despatcher allocates Car 1 to collect A.

Car 2 has the lowest Total Time Cost, of 55s, and will be dispatched to collect E.

6.3 Assessing the Total Time Cost of the three systems

Applying the HCA analysis to the other systems.

Although the NCA and ETA do not assess the total time effect of their algorithms, the process of answering hall calls does affect the response and journey times.

The NCA despatcher makes no account of time and only looks for the nearest car in its direction.

The ETA despatcher only accounts for the Estimated Time of Arrival.

To compare we need to apply the SDF and TT to the ETA and the SDF, TT and ETA to the NCA.

Table 4 Expressing the TTC of each control system

	Pick up A – Travel from 6 to 2		Pick up E – Travel from 5 to 0	
	Car	**TTC**	**Car**	**TTC**
NCA	Car 3	10+20+30+60+60=150s	Car 3	15+25+40+60+60=160s
ETA	Car 3	10+20+30+60+60=150s	Car 3	15+25+40+60+60=160s
HCA	Car 1	20+20+0+10=50	Car 2	20+25+10+0=55

From the table 4 we note:

To pick up A:

- With the lowest arrival time, the ETA will also select car 3. SDF = 150s
- As it is the nearest car above, the NCA will select car 3. SDF = 150s
- With the lowest calculated TTC, the HCA selects car 1. SDF = 50s.

To pick up E:

- With the lowest arrival time, the ETA will also select car 3. SDF = 160s
- As it is the nearest car above, the NCA will select car 3. SDF = 160s
- With the lowest calculated TTC, the HCA selects car 2. SDF = 55s.

In both instances the HCA is beneficial to its passengers.

Although this is very simplistic, it clearly demonstrates the efficacy of the HCA system.

So, why doesn't the HCA surpass the other systems in all conditions?

7 A CLOSER ANALYSIS – USING SIMULATION

Considering Peters [7] example again. Running Step Profile simulations on the most onerous of the buildings, Block C, provided a more detailed view of what was actually happening.

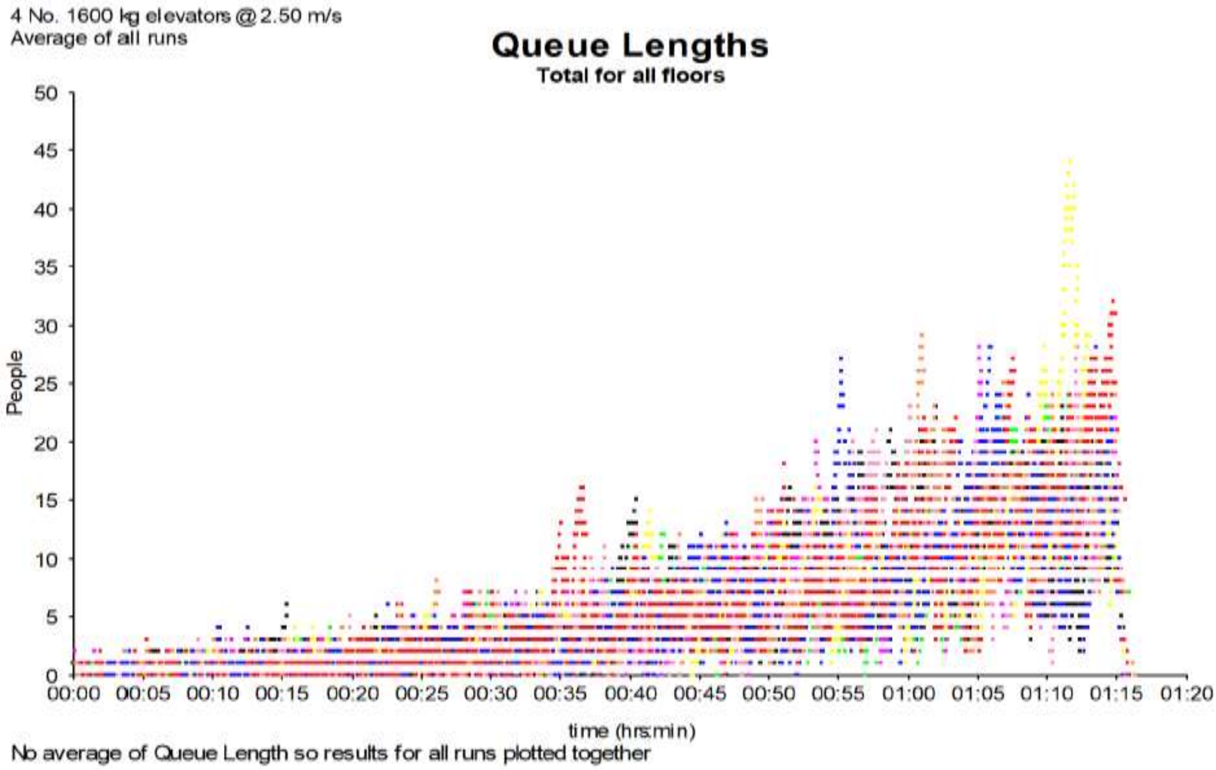
A Step Profile increments the number of arriving passengers, placing an increasing demand on the lift system. The number of persons is increased every 5 minutes until the system becomes saturated (overloaded). Although this simulation used the same lift and building data, it is not essential as this is comparing one dispatching system against another, however, each comparison must use the same data set.

Initially, Elevate was set to assess a Lunch Time mix of 45% Up , 45% Down & 10% Inter-floor , as described in the BCO [3] and then the 40 %, 40%, 20%, to accommodate the client's brief.

Whilst many outputs and results are available from Elevate, Time to Destination, Queue lengths and Waiting Times, were selected. Moreover, Waiting times is a specific parameter in the BCO [3] requirements and an integral component of the original appraisal. Many people would prefer to be travelling, even with more stops, than standing around waiting. This is a personal and psychological factor. It is another subject and worthy of a separate study.

8 STEP PROFILE SIMULATIONS – (MIXED TRAFFIC 40%, 40% & 20%) –

8.1 Next Car Available



Graph 1 Elevate step profile for Next Car Available control algorithm

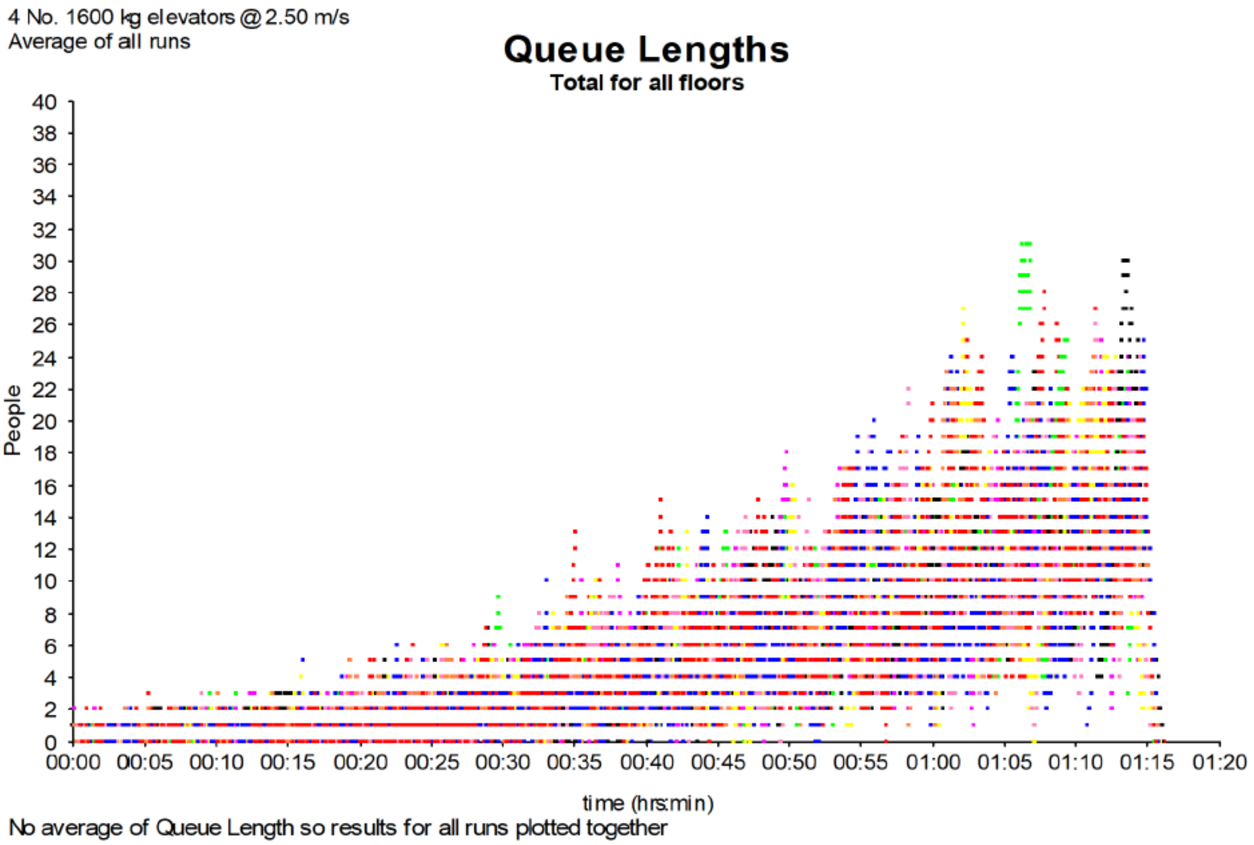
Queue lengths become intolerable at 52 minutes, leaving passengers waiting at the lift lobbies for the next car. 83 persons / 5 Minutes.

Queue Lengths of up to 16 persons.

Average Waiting Time - 23.5 s.

Time to Destination - 65.4 s.

8.2 Estimated Time of Arrival



Graph 2 Elevate step profile for Estimated Time of Arrival control algorithm

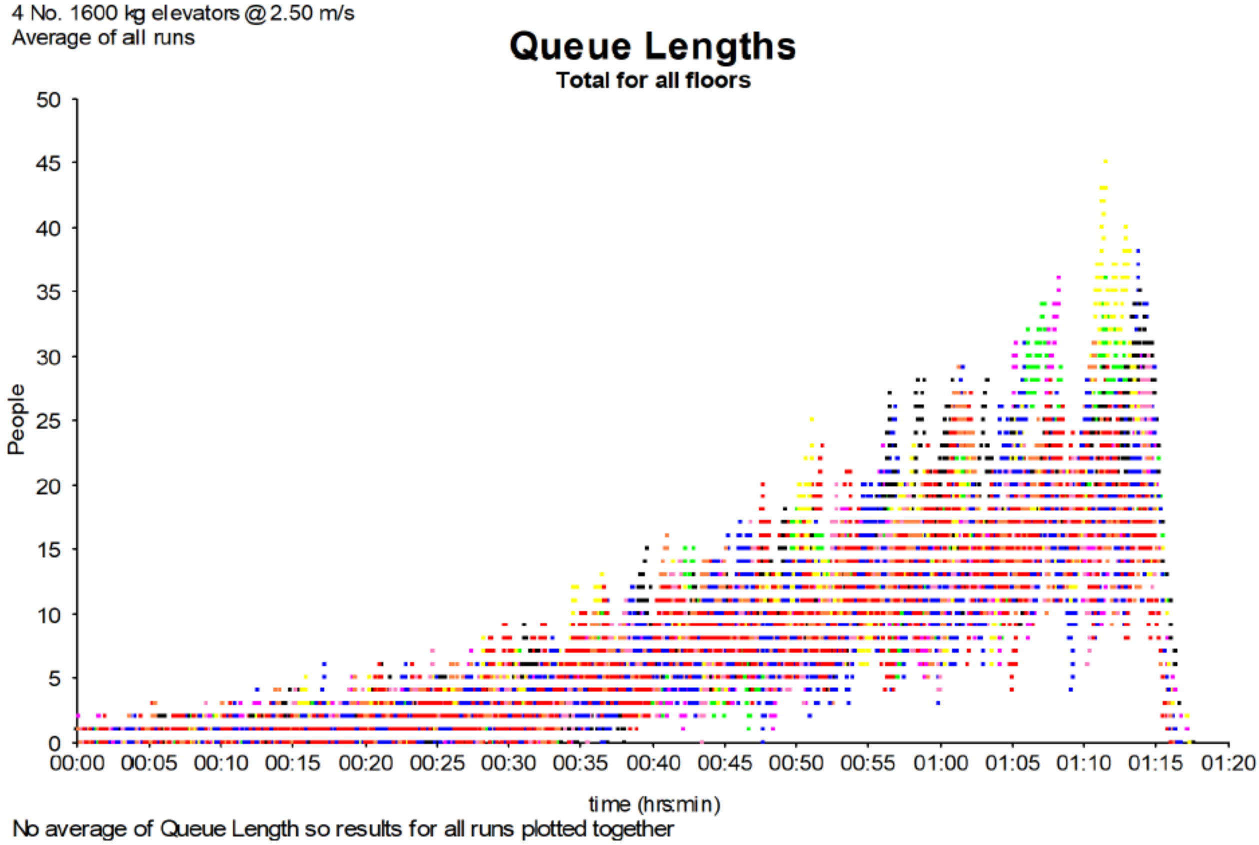
Queues rise and not being cleared at around 55 minutes. 91 person / 5 Minutes.

Queue Lengths of up to 18 persons.

Average Waiting Time - 22.7 s.

Time to Destination - 62.4 s.

8.3 Hall Call Allocation



Graph 3 Elevate step profile for Hall Call Allocation control algorithm

Queues rise and not being cleared at around 38 minutes - 68 person / 5 Minutes.

Queue Lengths of up to 17 persons.

Average Waiting Time - 33.2 s.

Time to Destination - 66.4 s.

Page:	1 of 5
Job:	Unity Square
Job No:	541002
Calculation Title:	Block C - Simulation - Step Profile
Made By:	BKV
Check By:	
File/Date:	Unity Sq-Block C-Peters Lunch (4x1600x2.5)-NCA (404020).elvx 12 Nov 2017 18:55:01

ELEVATE

Elevate Version 8.19 (Build 2206)
Abbacas Consulting Ltd

ANALYSIS DATA

Analysis Type	Simulation
Measurement system	Metric
Dispatcher Algorithm	Group Collective Traffic mode: Normal
Time slice between simulation calculations (s)	0.10
No of time slices between screen updates	10
No of simulations to run for each configuration	10
Random number seed for passenger generator	1
Energy Model	On
Currency	£
Price per kWh	0.12

BUILDING DATA

Floor Name	Floor Height (m)	No of people	Area (m²)	Area/person	Entrance Floor
Basement	3.00	0	-	-	Yes
Lower Ground	3.00	0	-	-	Yes
Podiom - Ground	3.50	107	1280.0	12.0	Yes
1	5.50	149	1787.0	12.0	No
2	4.00	160	1921.0	12.0	No
3	4.00	160	1921.0	12.0	No
4	4.00	160	1921.0	12.0	No
5	4.00	90	1083.0	12.0	No
6	4.00	90	1083.0	12.0	No
7		90	1083.0	12.0	No

Absenteeism (%)	10.00

ELEVATOR DATA

No of Elevators	4
Type	Single Deck
Capacity (kg)	1600
Car area (m²)	3.56
Door Pre-opening Time (s)	0.00
Door Open Time (s)	1.50
Door Close Time (s)	2.50
Door Dwell 1 (s)	3.00
Door Dwell 2 (s)	2.00
Speed (m/s)	2.50
Acceleration (m/s²)	1.20
Jerk (m/s³)	1.00
Start Delay (s)	0.50
Levelling Delay (s)	0.00
Home Floor	Podiom - Ground

PASSENGER DATA

Arrangement	Conventional for Single Deck elevators
Template	Step profile
Minimum (% pop per 5 mins)	1.00
Maximum (% pop per 5 mins)	15.00
Step duration (mins)	5.00
Step height (%)	1.00
Incoming (%)	40.00
Outgoing (%)	40.00
Interfloor (%)	20.00
Passenger Mass (kg)	75
Passenger Area (m²)	0.21
Loading Time (s)	1.20
Unloading Time (s)	1.20
Stair Factor (%)	5.00
Capacity Factor by Mass (%)	80.00
Capacity Factor by Area (%)	100.00

Floor Name	Entrance Bias
Basement	8.00
Lower Ground	8.50
Podiom - Ground	83.50

Figure 4 Example of the Elevate data for the simulations

Except for the Despatcher Algorithm the detail was the same for each Step Profile simulation

9 OBSERVATIONS

The HCA performance saturates quicker than the NCA and ETA.

The ETA performs for a little longer than the NCA.

To check the trend, two further Step Profiles were run:

A larger peak - 70 % up traffic, 20% down traffic and 10% inter-floor.

A more closely balanced traffic mix - 35%, 35%, 30%.

The results of all the Step Profiles clearly indicate all three control systems saturating sooner as the inter-floor mix rises. However, in each case the ETA held out a little longer. Not by a large margin, once again the difference is small and subtle.

Like the original investigation, these results felt counter intuitive, especially considering the claims made by some of the more vocal advocates of Hall Call Allocation.

10 CONCLUSIONS

From these results and observations, it was clear that each control system reacts and responds differently. This is further supported by other academic studies.

Unless enhanced with sectoring or zones. the Next Car Available system can only react to the calls placed on the system; it follows a very simple algorithm.

The ETA has a little more "intelligence"; it responds to differing lobby conditions as it monitors how long a Hall Call has been placed. A Hall Call's priority increases with time and is answered sooner.

The HCA responds to the initial information (i.e. numbers of passengers and which floors they want to travel to). It will consider all permutations before allocating a lift car to a passenger.

On face value, the HCA appears to have most of the advantages. It reduces journey times and makes better use of the cars by grouping people together. It reduces the possibility of duplicate journeys and cars following each other. Waiting Times may be a little longer, but the overall journey time can be reduced as the lift cars make fewer stops. The Round Trip Time (RTT) consumes less time [6].

The HCA control system out performs the traditional NCA and ETA systems in peak conditions. However, it struggles with increased two-way inter-floor traffic found during a lunch peak as there are fewer opportunities to group passengers as effectively as there are in peak conditions [7].

A well-designed HCA will provide improvements over an NCA. However, when the demand changes, a good ETA system will provide a small advantage, due to its ability to constantly re-evaluate the calls as new people arrive and place Hall Calls. The HCA is unable to re-evaluate; its decision is based on the information provided by the passengers as they arrive. Its intention has been announced, the lift car is committed; it is final and irreversible.

So, the answer to the investigation. Simply put, it is all due to the ETA's ability to adapt to change!

As revealed by this enquiry, the results of the calculations and simulations can be subtle and need to be carefully examined and interpreted. Each system considered need be vigorously tested under various traffic profiles to reveal the performance, the benefits and the disadvantages.

Some eager sales personnel are offering Hall Call Allocation as a panacea to all lift problems. In some instances, it works well but as this investigation has revealed there are limitations. It may therefore be appropriate to conclude with an axiom, "Designer be aware"! That is; be aware of all the benefits and the limitations of each system considered.

Whilst being attentive to the latest technologies, designers will serve their clients and the users of the system better when exercising even more care; reviewing all the foreseeable traffic probabilities, and control combinations, before making recommendations or offering solutions.

11 EPILOGUE - HALL CALL ALLOCATION - THE FUTURE?

The quest for a more responsive Group Control System – two possibilities:

Hybrid systems: - As described by Len Halsey [10] where the control system consists of two parts, with the HCA system on the main floor(s) to cope with the uppeaks and a standard two button system on the upper levels to improve the inter-floor traffic performance. From this investigation it appears that the upper floors will be better managed by a well-designed ETA based algorithm.

An internet of things: – Maybe Apple, Google or Microsoft will develop applications that interface with the HCA controller. Then re-evaluation and car changes could be instantly brought to the attention of the passengers via a smart phone, watch, ear buds, necklace, etc.

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BIOGRAPHICAL DETAILS

Barry Vanderhoven started in the industry as a lift and escalator apprentice in the early 70s with Marryat & Scott and has worked in many departments and disciplines within the VT world. Barry has been a Director and joint owner of Abbacas Consulting Ltd since 1995.