The Round Trip Time Simulation: Monte Carlo Implementation and Consistency with Other Techniques

Matthew Appleby, Richard Peters

Peters Research Ltd, Great Missenden, HP16 9AZ, UK

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Abstract. Currently, the two main paradigms of lift traffic analysis applied by the lift industry are Round Trip Time (RTT) calculations and dispatcher-based simulations. General Analysis (GA) RTT allows classical uppeak RTT to be extended to account for complex scenarios such as mixed traffic patterns.

Now, Monte Carlo Simulation (MCS) will allow GA RTT to be extended to account for even more complex scenarios such as destination control. MCS sits in between the calculation and simulation paradigms; individual round trips are simulated, and the process is repeated many times to determine standard parameters including average number of stops, capacity factors and round trip time. In this paper, the authors discuss the implementation of MCS within lift traffic analysis software and demonstrate its consistency with classical RTT, GA RTT and full dispatcher-based simulation. The implementation allows MCS to fit within current design methodologies used in lift traffic analysis.

1 INTRODUCTION

A Round Trip Time (RTT) calculation determines the average time taken for a lift to complete a full round trip of the building based on a set of equations and input parameters. A RTT calculation will always produce the same set of results if the same equations and input parameters are used.

The uppeak RTT models a building where passengers are travelling only from the ground floor to their destination floor. This is the simplest form of traffic analysis which continues to be applied widely [1] [2].

The General Analysis (GA) RTT calculation [2] [3] extends the uppeak RTT model to account for multiple entrance floors and mixed (incoming, outgoing and interfloor) traffic. The GA fits neatly into the standard lift traffic analysis methodology as it takes a similar, although extended, set of inputs and produces a similar set of outputs.

Dispatcher based simulation [2] extends traffic analysis further, accounting for more complex circumstances by modelling the whole process of each individual calling a lift and travelling to their destination. The simulation is assessing every passenger trip rather than extrapolating results from a single average round trip of the lift.

Simulation is a powerful tool and can be used to model complex systems not easily analysed by RTT calculations, e.g. destination control, cars sharing a shaft [4] [5] [6]. However, the complexity of simulation tools means that they are normally based on proprietary intellectual property, and are not transparent or verifiable [7]. Hence CIBSE Guide D's recommendation [1] that practitioners should begin their planning exercise with a RTT before moving to simulation, paying careful attention to any major differences in design outcomes.

Monte Carlo Simulation (MCS) sits in between the calculation and simulation paradigms; individual round trips are simulated, and the process is repeated many times to determine standard parameters. MCS has created a lot of research interest in recent years [8] [9] [10] as it allows the modelling of complex systems without the need to apply dispatcher based simulation.

This paper addresses the implementation of MCS within lift traffic analysis software with a view to widen its application beyond the research community. The implementation allows MCS to fit within current design methodologies used in lift traffic analysis. Consistency with RTT calculations and dispatcher-based simulation for uppeak traffic is demonstrated.

2 IMPLEMENTING MONTE CARLO SIMULATION

This chapter describes the process of simulating a round trip. For a full MCS, these steps must be repeated a significant number of times to find an average RTT.

2.1 Generating Passengers

The first step in a MCS is to create a set of passengers and decide their origins and destinations. The approach proposed by Al-Sharif for MCS applies an Origin Destination matrix [11] [10]. This starts with a table containing the probabilities of a passenger going from an origin (row) to a destination (column) which sums to 1, see the example in Figure 1.

Origin / Destination	G	1	2	3	4	5
G	0	0.07	0.07	0.07	0.07	0.07
1	0.05	0	0.02	0.02	0.02	0.02
2	0.05	0.02	0	0.02	0.02	0.02
3	0.05	0.02	0.02	0	0.02	0.02
4	0.05	0.02	0.02	0.02	0	0.02
5	0.05	0.02	0.02	0.02	0.02	0

Figure 1 Probability Density Function of the Origin Destination Matrix

This is translated into a cumulative distribution function of the origin destination matrix by adding each value to the value of the element in the next box as shown in Figure 2.

Origin / Destination	G	1	2	3	4	5
G	0	0.07	0.14	0.21	0.28	0.35
1	0.4	0.4	0.42	0.44	0.46	0.48
2	0.53	0.55	0.55	0.57	0.59	0.61
3	0.66	0.68	0.7	0.7	0.72	0.74
4	0.79	0.81	0.83	0.85	0.85	0.87
5	0.92	0.94	0.96	0.98	1	1

Figure 2 Cumulative Distribution Function of the Origin Destination Matrix

For each passenger to be served in the round trip, a random number between 0 and 1 is generated. In the cumulative distribution function of the origin destination matrix, the first number that is greater than or equal to the random number is used to determine the origin and the destination of passenger.

Figure 3 shows the random number generated, and the resulting passenger origin/destination for eight passengers.

Random:	0.41	0.57	0.05	0.88	0.94	0.30	0.82	0.18

Origin	1	2	G	5	5	G	4	G
Destination	2	3	1	G	1	5	2	3

Figure 3 List of passengers

2.2 Building Stop List

The next step is to sort the passenger into up traffic and down traffic and to add their stops to a set of lists, see Figure 4.

Up	1	2	2	3	0	1	0	5	0	3
Down	5	0	5	1	4	2				

Figure 4 Stops segmented into up and down

Next, each value in the up list is sorted into ascending order and each value in the down list is sorted into descending order, see Figure 5.

Up	0	0	0	1	1	2	2	3	3	5
Down	5	5	4	2	1	0				

Figure 5 Stops sorted ascending then descending

Repeating values in both lists can be removed as the lift does not need to know the number of passengers, all it needs is a list of floors to stop at. Finally, the two lists are concatenated together into one list of stops which if the lift travels around, every passenger will be delivered to their required floor, see Figure 6.

Stops	0	1	2	3	5	4	2	1	0

Figure 6 List of stops

2.3 Round Trip Time

The list of stops provides the basis for calculating the lift round trip accounting for travel time between the stops, doors times and passenger transfer times.

The process of generating passengers and calculating the round trip time is repeated multiple times yielding many round trip time values. The average of the individual round trip time values is reported as the MCS round trip time.

3 IMPLIMENTING THE RTT SIMULATION

3.1 The challenge with applying MCS

The MCS as described in the previous section follows the traditional RTT calculation by assuming the number of passengers loading the car at ground floor is a pre-determined number. Once the round trip time is determined, the handling capacity of the system can be calculated.

This is the only practical approach for manual uppeak RTT calculations. It has a number of limitations including:

- the handling capacity resulting from filling the car may be more than the anticipated passenger demand for this installation, yielding a pessimistic result for round trip time, interval, and car loading
- if the building has multiple entrance floors or interfloor traffic, a fully loaded car at the start of the RTT may prevent additional passengers loading at higher floors.

These issues are solved in traffic analysis software [2] by asking the user to enter the required passenger demand. The calculation then determines how full the car will be at every level to determine the maximum car loading. The inputs and outputs are effectively reversed, see Table 1. This reversal of inputs and output also aligns calculation with dispatcher based simulation.

Table 1 Reversal of inputs and outputs for advanced traffic analysis

Analysis type	Input	Output
uppeak RTT calculation and MCS	car loading *expressed in persons or as a capacity factor*	handling capacity *how many people can be transported per unit time*
enhanced uppeak, general analysis and dispatcher based simulation[1]	passenger demand *the rate at which people arrive persons per 5 minutes*	capacity factor *how full the car considered will be as a %.*

3.2 Generating passengers

An equivalent, but more widely used approach than the Origin Destination matrix applies the concept of arrival rates and destination probabilities [3] [2]. This combines passenger demand (how many people want to use the lift for a given unit of time) with a destination probability matrix which determines what proportion of the people arrive on the different floors and where they want to travel.

Consider a passenger demand of 13% with a traffic mix of 45% incoming, 45% outgoing and 10 % interfloor traffic. With ground and 5 upper floors populated by 80 people per floor, the arrival rate - destination probability table [12] is as presented in Table 2

[1] In simulation there is also a capacity factor input to limit car loading for a specific car size according to practical limitations. However, the analogous car loading in comparison to RTT calculations is reported as a simulation result.

Table 2 Arrival rate – destination probability table example

Origin	Arrival Rate (persons per 5 minutes)	Destination Probabilities (%)					
		Ground	Level 1	Level 2	Level 3	Level 4	Level 5
Ground	27.0	0.00	20.00	20.00	20.00	20.00	20.00
Level 1	6.6	81.82	0.00	4.55	4.55	4.55	4.55
Level 2	6.6	81.82	4.55	0.00	4.55	4.55	4.55
Level 3	6.6	81.82	4.55	4.55	0.00	4.55	4.55
Level 4	6.6	81.82	4.55	4.55	4.55	0.00	4.55
Level 5	6.6	81.82	4.55	4.55	4.55	4.55	0.00

A first estimate of round trip time RTT_1 is required before a list of passengers can be generated for the MCS. This estimate will be revised the MCS repeated until the estimate is the same or very close to the round trip time calculated by MCS.

$$Number\ of\ pasengers\ transported\ _i = \sum[Arrival\ Rate] \cdot \frac{RTT_i}{Number\ of\ lifts}$$

If the first estimate of $RTT_1$is 120 seconds, and the software is considering a three lift group, then the number of passengers used in the first MCS simulation based on Table 2 will be:

$$Number\ of\ pasengers\ transported\ _1 = \frac{(27.0 +\ (6.6 \cdot 5))}{300} \cdot \frac{120}{3}\ = 8.0$$

The origin and destination of passengers can be generated as described in section 2.1 or as they would be for simulation [13] to create a table equivalent to Figure 3. The approach needs to allow for fractions of passengers. For example, if the number of passengers to be transported was 7.5, in half of the MCS calculations the number of passengers generated would be 7, and in the other half 8.

The software runs the MCS for many trials, each with a different passenger list, and assuming RTT_1. This yields an improved RTT estimate, RTT_2. The process is repeated until $RTT_{i+1} \approx RTT_i$. Interval is calculated by dividing the RTT by the number of lifts. Capacity Factor is determined by calculating the peak car loading in a round trip as a percentage of the available capacity. The Capacity Factor reported is the mean value of all the trials.

To convey the underlying approach of the application of MCS within the software [2], the authors have chosen to label this analysis type as RTT Simulation (RTTS).

4 COMPARISON OF RESULTS

To compare results, consider Example 4.1 from CIBSE Guide D [1] which is modelling the uppeak in an office building with 14 floors above ground. For a full set of parameters, refer to the Guide. The solution under consideration is a six 1600 kg car group with a rated speed of 2.5 m/s. The passenger demand is 12% uppeak (100% incoming).

Applying the computer program [2] the results for the four different analysis techniques are given in Table 3.

For the RTT Simulation, each MCS was based on 1000 trials. For the dispatcher simulation a group control dispatcher was selected with an uppeak mode which returned all empty cars to the ground floor and cycled their doors. Ten two hour simulations with the first 15 minutes and last 5 minutes disregarded to remove start and end effects.

Table 3 Comparison of results for CIBSE Guide D Example 4.1

	Uppeak	General Analysis	RTT Simulation	Dispatcher Simulation
Interval (s)	27.1	26.4	27.2	25.3
Capacity Factor by area (%)	71.6	69.6	71.1	66.8
Number of Stops (including ground)	9.3	9	9.5	Not available
Highest Reversal Floor (1 is ground floor)	14.4	14.2	13.4	Not available

The results demonstrate consistency between the different analysis techniques for the uppeak traffic condition.

5 DESTINATION CONTROL

5.1 Types of control

All the analysis methods in the previous sections assume conventional control. In conventional control, the passenger presses either an up or a down button when they arrive at their origin floor. Once they get in the lift, they select their destination floor and the lift then takes them to that floor. This means that the dispatcher has to make the assignment decision based on the origin and direction of travel alone as it does not yet know the destination. In all RTT calculations, the lifts are assumed to have the same round trip time.

In destination control, improved uppeak handling capacity is achieved through dispatching algorithms that divide the traffic so that passengers travelling to the same destination ride the lifts together. This reduced the average number of stops, and thus the RTT.

5.2 The allocator

For MCS, this division of traffic can be modelled by introducing an allocator and having multiple epochs [10]. Instead of modeling a single round trip, or with MCS a single round trip multiple times, the traffic for *e* round trips is considered where *e* is the number of epochs. Passengers for *e* round trips is generated. Then traffic is separated into *e* groups according to the allocator logic.

An allocator uses transparent, straight forward rules to approximate the dispatcher logic. For destination control, Al-Sharif et al [10] considered two forms of allocator. The origin allocator sorts incoming traffic into ascending order of origin and outgoing traffic into descending order of origin. This allocator works well for incoming traffic. The destination allocator sorts incoming traffic into ascending order of destination and outgoing traffic into descending order of destination. This works well for outgoing traffic. Once sorted, the traffic is divided as equally as possible between the *e* epochs.

In the author's implementation, these two allocators have been combined: incoming traffic is sorted by destination and outgoing traffic is sorted by origin. Although achieved through detailed internal modelling in a dispatcher, this allocator reflects the outcome of a typical destination control algorithm.

In Al-Sharif et al [10] the number of epochs was assumed to be the number of lifts. However, they can be different, particularly in large groups. If the number of lifts is six and the number of epochs was six, then the allocator is assuming that only one in six lifts will be available to the passenger travelling up from the ground floor. This yields a lower interval and larger handling capacity, but longer waiting times.

5.3 Results

Table 4 shows the results for Example 4.1 for one to six epochs and a Dispatcher simulation applying the Destination Control (ACA) [2] algorithm configured for ‘time to destination optimisation’.

Table 4 Comparison of results for RTTS and Dispatch simulation applying Destination Control

	RTT Simulation						Dispatcher Simulation
	e=1	*e*=2	*e*=3	*e*=4	*e*=5	*e*=6	
Interval (s)	27.2	19.1	16.3	14.6	13.4	12.9	15.9
Capacity Factor by area (%)	71.1	50.4	43.5	38.5	35.6	33.6	41.9
Number of Stops (including ground)	9.5	6.3	5.1	4.4	4.0	3.7	Not available
Highest Reversal Floor (1 is ground floor)	13.4	10.6	9.7	9.3	8.6	8.8	Not available

The greater the number of epochs, the more opportunity there is for grouping passengers travelling to common destinations. Hence with increasing numbers of epochs, all RTTS results trend down (get better) as a reduced number of stops and highest reversal floor yields a lower round trip time, interval, and loading.

However, Table 4 results hide that with increased epochs passenger waiting times will increase as the passenger has to wait for their allocated lift instead of the next lift to depart. A real destination control dispatcher is making a tradeoff which account for waiting time, transit time times, and in some instances, required handling capacity to satisfy passenger demand.

In this example, the closest comparison between the RTT simulation and the Destination Control (ACA) algorithm is when there are three epochs. This is analogous to a look ahead factor [14] of three, i.e. the dispatcher will consider the next three lifts in its allocation of a new passenger. This would be a reasonable assumption to balance the competing factors being considered in many destination control algorithms.

Different destination control dispatcher options could be modeled by changing the number of epochs, e.g. *e*=1 would reasonably correspond waiting time optimisation. In the example above, increasing the number of epochs to *e*=3 brings the results closer to ‘time to destination optimisation’. For maximum theoretical handling capacity, and some level of ‘anti-saturation control’, *e=number of lifts* would be a reasonable representation.

6 CONCLUSION

Monte Carlo Simulation (MCS) is a technique used to tackle problems in many fields spanning finance, engineering, physical sciences and even gaming. It can be used when estimating the value of a variable that is dependent on a set of random input variables.

The application of MCS to lift traffic analysis is relatively new. However, the need to provide analysis of increasing complex systems without developing increasing complex formulae make it an attractive approach to benchmark dispatcher based simulation results.

To work within an existing lift traffic software design paradigm, MCS needed to be applied in a way where the user inputs the required passenger demand and tests a pre-determined lift configuration. This adds complexity to software code but simplifies its application for the user.

Consistency of results for uppeak traffic has been demonstrated between established traffic analysis techniques and MCS. If assumptions are consistent, the results should be similar.

For the analysis destination control, dispatching decisions need to be made which consider more than one average round trip. These decisions have been simplified and included in an ‘allocator’. How this traffic is divided, reflects different modes of operation in destination control systems. Consistency of results for uppeak traffic has been demonstrated between a dispatcher simulation with a destination control algorithm and a MCS using three epochs.

Consistency between MCS and dispatcher based simulation for mixed traffic will depend on how well the allocator reflects the underlying principles of the dispatcher. Further work is required to understand the correlation of results for mixed traffic, and to understand the relationship between interval and waiting time in the context of MCS.

MCS sits in between the RTT calculation and dispatcher based simulation paradigms. To convey the underlying approach of the application of MCS to lifts, the term RTT Simulation (RTTS) has been chosen to label the implementation described in this paper.

The application of MCS and RTTS is likely to become more prevalent as engineers seek new ways to analyse more complex lift systems. It also provides insights into the limits of an idealised dispatcher which informs dispatcher design.

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REFERENCES

[1] CIBSE, “CIBSE Guide D: 2015, Chapter 3 and 4,” London, Chartered Institution of Building Service Engineers, 2015.

[2] Peters Research Ltd, “Elevate Traffic Analysis and Simulation Software,” [Online]. Available: www.peters-research.com.

[3] P. R. D, “Lift Traffic Analysis: Formulae for the General Case,” *Building Services Engineering Research and Technology,* vol. 11, no. 2, 1990.

[4] R. Smith and R. Peters, “Analysis of Elevator Performance and Passenger Demand with Destination Control,” in *Elevator Technology 17, Proceedings of ELEVCON,* Thessaloniki, 2008.

[5] R. Smith and R. D. Peters, “Enhancements to the ETD Dispatcher Algorithm,” in *Elevator Technology 14*, 2004.

[6] S. Gerstenmeyer and R. D. Peters, “Multicar Dispatching,” in *6th Symposium of Lift and Escalator Technologies,* Northampton, 2016.

[7] B. GC, “Can lift traffic simulators be verifiable, transparent, repeatable & reproducible,” in *10th Symposium on Lift and Escalator Technologies,* Nothampton, 2019.

[8] L. Al-Sharif, O. F. Abdel Aal and A. M. Abu Alqumsan, “The Use Of Monte Carlo Simulation To Evaluate The Passenger Average Travelling Time Under Up-Peak Traffic Conditions”.

[9] S. Gerstenmeyer, “Traffic Analysis for a Multi Car Lift System Used as Local Group,” in *9th Symposium on Lift and Escalator Technologies*, Northampton, 2018.

[10] L. Al-Sharif and R. D. Peters, “Using the Monte Carlo Simulation to Evaluate the Round-Trip Time Under Destination Group Control,” in *9th Symposium of Lift and Escalator Technologies*, Northampton, 2018.

[11] L. Al-Sharif and A. M. Abu Alqumsan, “An integrated framework for elevator traffic design under general traffic conditions using origin destination matrices, virtual interval, and the Monte Carlo simulation method,” *Building Services Engineering Research and Technology 36.*

[12] Peters Research Ltd, “Elevate Advanced Training Course Example,” Peters Research Ltd, Great Missenden, 2020.

[13] R. D. Peters, L. Al-Sharif, A. Hammoudeh, E. Alniemi and A. Salman, “A Systematic Methodology for the Generation of Lift Passengers under a Poisson Batch Arrival Process,” in *5th Symposium on Lift and Escalator Technologies*, Northampton, 2015.

[14] G. C. Barney and S. M. dos Santos, in *Elevator Traffic Analysis Design and Control*, London, Peter Peregrinus, 1985.

BIOGRAPHICAL DETAILS

Matthew Appleby is a Software Engineer with Peters Research Ltd. He is part of the team working on enhancements to Elevate and related software projects. He joined Peters Research in 2019 and is studying part time for a Digital Degree Apprenticeship.

Richard Peters has a degree in Electrical Engineering and a Doctorate for research in Vertical Transportation. He is a director of Peters Research Ltd and a Visiting Professor at the University of Northampton. He has been awarded Fellowship of the Institution of Engineering and Technology, and of the Chartered Institution of Building Services Engineers. Dr Peters is the principal author of Elevate, elevator traffic analysis and simulation software.