Enhancing the Inter-Linked Monte Carlo Simulation Method (iL-MCS) to Reflect Random Passenger Inter-Arrivals

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Abstract. The Monte Carlo Simulation method (MCS) has been successfully used to find the value of the lift round trip time under general traffic conditions, including cases such as multiple entrances, unequal floor heights, unequal floor populations, rated speed not attained in one floor journey, as well as the variation in group control algorithms (e.g., destination group control).

In conventional Monte Carlo Simulation, the various trials (or scenarios) are completely disconnected, where the end of one trial does not influence the following trial. Past research work presented the new extension of the Monte Carlo Simulation, by inter-linking each trial or scenario in the Monte Carlo Simulation with the next one, where it links the trials such that the end conditions of one trial become the initial conditions of the following trial. This "interlinking" allows the method to reflect the effect of the random passenger destinations on the value of the round-trip time.

The past research work examined in detail the effect of the first source of randomness in the lift system: the randomness of the origins and destination of passenger. It did not, however, examine the effect of the randomness caused by variable passenger inter-arrival time (following an exponential probability distribution).

This paper will also include the effect of bunching on the value of the round trip time as well as the queue length at the landing.

1. INTRODUCTION

The lift round trip time has for a long time formed the basis of sizing and selecting the number and speed of lifts in a building [1] following the assessment of demand [2]. Even with the advent of simulation, most designers still use the round-trip time as the basis for the initial phase of the design based on calculation and then follow it up with simulation runs to refine the final design.

The calculation of the value of the round-trip time has traditionally been based on using an equation that was developed and expanded in the 1980s [3] which relies on the lift kinematic equations ([4], [5]). The main drawback of this equation is that it is only applicable and correct in a special set of conditions such as incoming traffic, independent passenger decisions, rated speed attained in one floor jump, and a single entrance. Several researchers have attempted to extend the application of this equation to more general cases ([6], [7], [8]). An attempt was also made to extend the equation to accurately incorporate all these special conditions [9].

One of the most notable successes in this area was the application of the Monte Carlo simulation (MCS) method to find the value of the round-trip time under incoming traffic conditions [10] and then under general traffic conditions [11]. It was also used to find the value of the average travelling time [12]. In one of the latest papers, MCS was used to evaluate the round-trip time for destination group control [13].

In all these papers that used the Monte Carlo simulation to find the value of the round-trip time, the trials were completely independent. Each trial was kept separate from the preceding and the succeeding trials. An improvement was introduced by linking each of the trials to the following trial in [14]. It introduced the concept of interlinking the consecutive trials to better reflect the randomness in the lift traffic system. Specifically, it *interlinked* the trials to reflect the effect of the variability in the value of the round-trip time that is caused by the randomness of the passenger destination. It only considered one source of randomness: the randomness in the passenger destinations.

This paper extends this approach by taking into consideration the other source of randomness, which is the arrival times of the passengers (assumed to follow a Poisson distribution).

The conventional Monte Carlo simulation approach assumes that the number of passengers in each round trip is constant. By contrast, in the interlinked MCS approach, the number of passengers generated in each trial is not constant, but dependent on the previous value of the round-trip time.

The car capacity has been assumed to be limited, thus better reflecting the reality of the fluctuations in the value of the load in the lift car.

Another factor that has been taken into consideration is the phenomenon of bunching [15], [16]. The effect of bunching on the variability of the value of the round-trip time and the consequential variability of the number of passengers arriving has been taken into consideration.

The Monte Carlo Simulation method has also been successfully used in verifying the calculation of the round trip for more complex and larger buildings containing hypothetical two-dimensional buildings ([17] and [18]).

The next section identifies the two sources of randomness in the lift traffic system (from which all other manifestations of randomness arise). The third section identifies the two possible approaches that can be followed in generating random arrivals of passengers in time (based on either a Poisson probability distribution function for the number of passengers arriving in a period of time or based on an exponential distribution function for the inter-arrival time between consecutive passengers). Section four shows the results for the passenger queue length and the round-trip time. Section five shows the effect of "interlinking" on the handling capacity of the lift traffic system. Conclusions are drawn in the last section of the paper.

2. THE TWO SOURCES OF RANDOMNESS IN LIFT TRAFFIC SYSTEMS

The two sources of randomness in lift traffic systems are identified below:

1. The first source of randomness is the arrival time of the individual passengers. It has been suggested that the arrival of passengers for service follows a Poisson distribution (more precisely, the number of passengers arriving in a specified period follows a Poisson distribution, and this random variable is a discrete random variable). It is more common to model this process by examining the inter-arrival time between consecutive passengers, which follows an exponential distribution, whereby the random variable is a continuous random variable.

2. The second source of randomness in lift traffic systems is the randomness of the passenger origin and destination floors. In the general case, it is assumed that the passenger origin and destination selections are independent. When the building under consideration has a single entrance and the type of traffic is incoming only, the origin floor is the same for all passengers and the source of randomness is the passenger destination floors. Each passenger is assumed to select a destination based on the probability density function for the floor destinations, which is based on the number of occupants on each floor.

The randomness of passenger origins and destinations is introduced into the system by using the so-called Origin-Destination matrix (OD matrix) and applying random sampling. Full details can be found in [11].

These two sources are the source of all randomness in the lift traffic system, and any other display of randomness in the lift has its roots in one or both of these two sources. For example, the variability of the round trip is caused by the random passenger destinations (2nd source above), and the variability of the number of passengers boarding the lift car is caused by both the first and second sources above. A third possible source of randomness is the arrival of passengers in batches of more than one passenger (e.g., two or three).

It is also worth remembering that the variability of the round-trip time for each lift will lead to the time between the successive arrivals of the lifts at the landings being variable, a phenomenon known as bunching ([15], [16]). It is widely accepted that bunching can lead to the loss of handling capacity and an increase in passenger waiting time. It is also very common that bunching can lead to the reversal of the sequence of lift movements around the building (i.e., with four lifts in the group, and assuming they start in the sequence of A, B, C, and D, this could later become A, C, B, D).

The second source of randomness has been modelled in [14] (and more specifically, the passenger destinations only, as the building under consideration has only one entrance and the type of traffic is incoming only). Its effects on the variability in the value of the round-trip time, the number of passengers boarding the lift car, and the passengers left queuing behind at the landing were all explored.

This paper adds the other source of randomness, which is the random arrival time of passengers.

3. MODELLING THE RANDOM ARRIVAL TIME OF PASSENGERS.

In order to model the random passenger arrivals, there are two options:

1. Evaluate the number of passengers arriving in a period of time assuming a Poisson arrival process for the number of passengers arriving.
2. Evaluate the inter-arrival time between consecutive passengers assuming an exponential probability density function (pdf) for the inter-arrival time.

The decision was taken to follow the second approach in this case. A function has been created in MATLAB that generates the inter-arrival time between successive passengers using the exponential probability density function. It then keeps on repeating this process until the whole period has elapsed. By summing up all the passengers that have arrived in that period, it arrives at the total passengers arriving.

The inputs to this function are the average passenger arriving (λ) in units of passenger per second, and it assumes a Poisson arrival process.

4. RESULTS FOR ROUND TRIP TIME (RTT) AND QUEUE LENGTH

The modelling of the inter-linked Monte Carlo simulation has been implemented in MATLAB. The random passenger arrival has been implemented based on the exponential pdf for the inter-arrival time.

The same hypothetical building was used as that in [14]. By definition, the very nature of the interlinked MCS requires that more than one round trip be run. In the results that will be shown later in this paper, the number of consecutive round trips has been set to 100 (i.e., 100 interlinked round trips).

The number of MCS trials was set to 1000 (i.e., 1000 trials). The average of all 1000 trials was taken when reporting the results.

The results for the queue length (in passengers) and the round-trip time (in seconds) are shown in Figure 1 below. The results shown are the average of all the 1000 MCS trials. The length of the interlinked simulation is 100 round trips (as can be seen from the length of the x-axis, which has units of "round trips").

As can be seen from the results, the following conclusions can be drawn:

1. The queue length continuously grows in length. The figure shows the two cases with random arrivals: Poisson and constant arrival, where both show a queue developing. Under the hypothetical case where the round-trip time is calculated using an equation, it assumes that all passengers are removed in each round trip (which is obviously not true in any of the two cases studied above).

2. The queue length is larger in the case of the Poisson arrival of passengers as opposed to the constant passenger arrival. This is expected, as the randomness of passenger arrivals makes it more difficult to clear the queue at the landing upon the arrival of the lift cars.

3. The value of the round-trip time for constant arrival seems to settle at a specific value and does not change any further. This shows that the system arrives at steady state conditions.

4. The steady state value of the round-trip time under Poisson passenger arrival conditions is slightly smaller than the value of the round-trip time under constant passenger arrival conditions. This is explained by the fact that the average passenger load inside the lift car is smaller under Poisson arrival conditions due to the random nature of the arrivals.

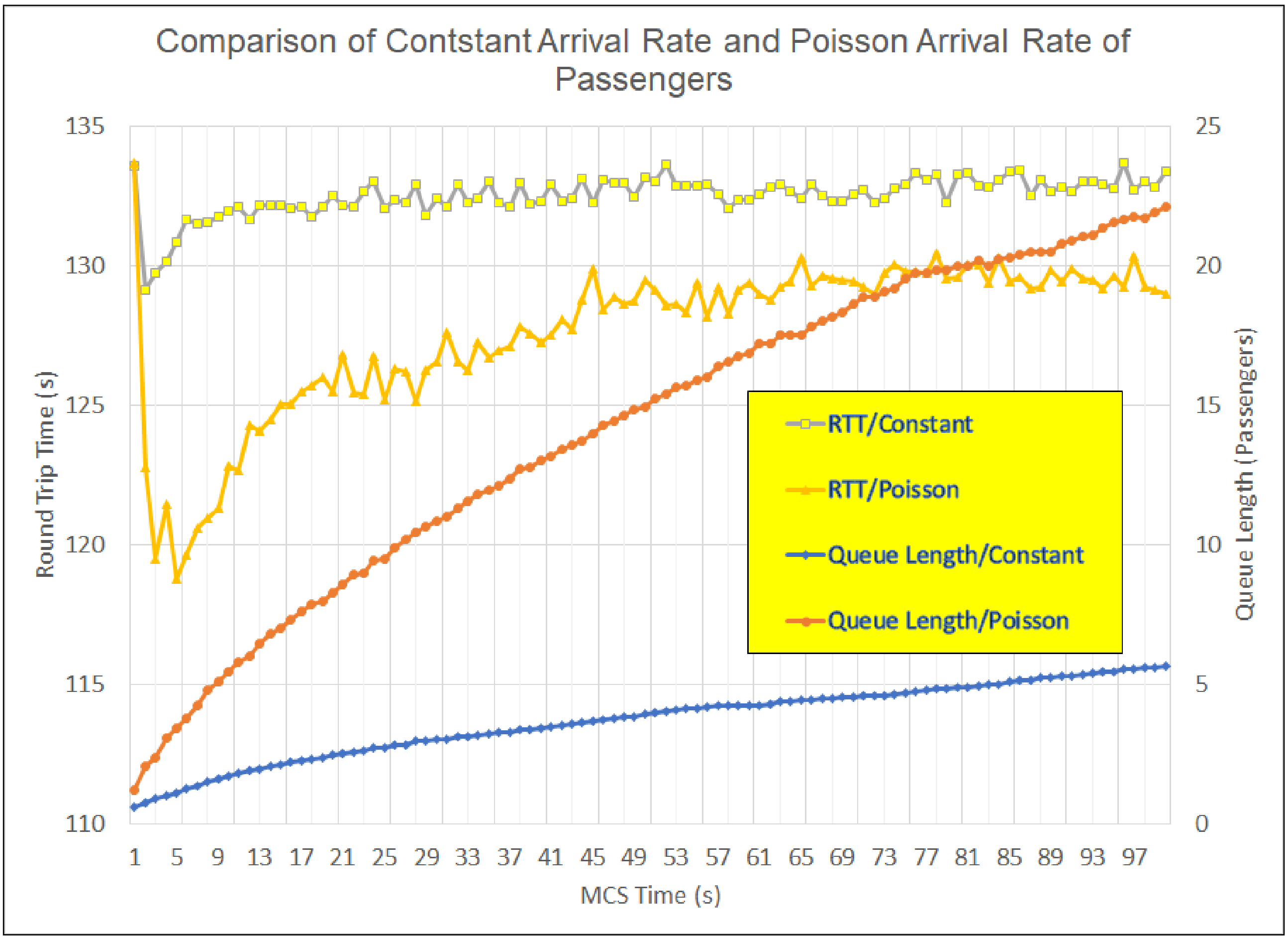

Figure 1 Comparison between the value of the Round-Trip Time (RTT) and the landing queue length under constant passenger arrivals and random passenger arrivals.

5. RESULTS FOR HANDLING CAPACITY

Following on from the results in the previous section, the question that would need to be answered is:

What is the overall effect on the handling capacity (HC%) of a smaller value of round-trip time and a smaller value of the number of passengers served in the lift car under random passenger arrivals?

In order to answer this question, the handling capacity of the lift system under random passenger arrivals in each round trip was calculated and compared to the calculated value of the handling capacity under constant passenger arrivals. The results are shown in Figure 2 below.

It is worth noting that the ideal handling capacity under the full absence of any random behaviour in the lift system is 12.5% (hypothetically 12.477%), based on the following parameters (assuming five lift cars in the group):

1. The number of passengers in the lift car in each round trip is 10 passengers.
2. The design value of the round-trip time under ideal conditions is 133.578 seconds.

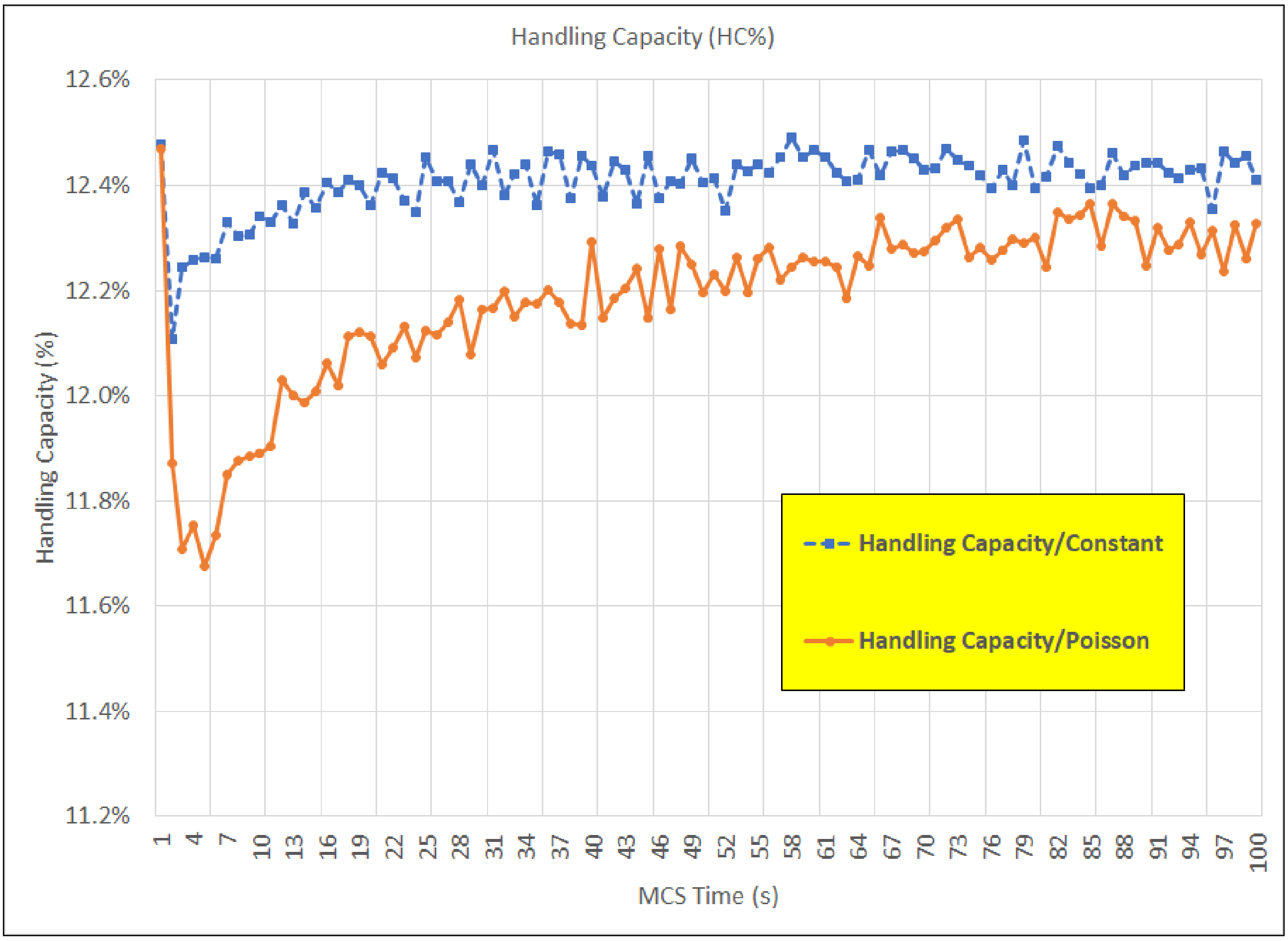

Figure 2 Comparison between the handling capacity (%) under constant passenger arrivals and random passenger arrivals.

Based on Figure 2 above, it can be seen that the handling capacity reaches a steady state value in both cases of constant passenger arrivals and random passenger arrivals. The following conclusions can be drawn:

1. The handling capacity in both cases is slightly smaller than the design handling capacity of 12.5% (hypothetical 12.477%).
2. There exists a slight loss in handling capacity when the randomness of passenger destinations under constant arrival conditions is introduced.
3. There is a further loss in handling capacity when random passenger arrivals are also taken into consideration.

6. CONCLUSIONS

The Monte Carlo simulation has been successfully used to find the value of the lift round trip time under general conditions, such as the multiple entrances, general traffic conditions, and rated speed not attained in one floor jump. It has also been used to find the value of the passenger transit time as well as the round-trip time under destination group control.

A previous paper has extended the use of the Monte Carlo simulation method to allow it to reflect the random nature of the passenger boarding the lift in each round trip and the random variations in the value of the round trip. This has been done by interlinking the consecutive trials by using the final value from one trial as the starting value for the next trial.

This paper has extended the case to include all the types of random variations expected in the lift system (namely: the variability in passenger destinations and the random passenger inter-arrival time).

The results show that the round-trip time is smaller when random passenger arrivals are assumed compared to constant passenger arrivals, and that the handling capacity is also smaller.

The practical significance of using the concept of "interlinking" is that it can provide the designer with more insights into the efficiency of the selected design. For example, the designer can observe how fast and how long queues will develop, and the consequential effect this would have on lobby sizes. This is particularly relevant when comparing destination control systems with conventional control systems. In addition, the result might help to better estimate waiting passenger times and transit passenger times.

Further work will be carried out in the future to identify the effects of enlarging the car capacity and how it impacts the queue length at the landing. It is expected that enlarging the car capacity sufficiently can be successfully employed to overcome both random effects of passenger destinations and the random passenger arrivals. This will be confirmed in future research to stipulate the exact increase in the rated car capacity required in order to fully restore the handling capacity of the lift traffic system and to reduce or eliminate the queue length at the landing.

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BIOGRAPHICAL DETAILS

Lutfi Al-Sharif received his Ph.D. in elevator traffic analysis in 1992 from the University of Manchester. He worked for 9 years for London Underground, London, United Kingdom in the area of lifts and escalators. In 2002, he formed Al-Sharif VTC Ltd, a vertical transportation consultancy based in London, United Kingdom. In 2006, he co-founded the Mechatronics Engineering Department at the University of Jordan, Amman Jordan, and progressed to full professor at the University of Jordan, where he spent 13 years as a faculty member, Mechatronics Engineering Department Head for six years and Vice Dean for Academic Affairs. Professor Al-Sharif is currently Vice President of Al Hussein Technical University in Amman, Jordan, and a part-time consultant for Peters Research Ltd. He is also a member of the management committee of the lift and escalator symposium.