Traffic Analysis for a Multi Car Lift System Used as Local Group

Stefan Gerstenmeyer

thyssenkrupp Elevator Innovation GmbH, Bernhäuser Str. 45, 73765 Neuhausen, Germany
The University of Northampton, School of Science and Technology, The University of Northampton, UK

Keywords: multi car lift system, elevator, traffic analysis, handling capacity, quality of service, departure delay, Monte Carlo simulation

Abstract. In a circulating multi car lift system, multiple lift cars are sharing shafts. Shafts are used as one way tracks and cars are changing between shafts horizontally. Handling capacity depends on the time between two subsequent cars (multi car cycle time). If these transportation systems are used in buildings as local groups, people's individual destinations lead to different stops of cars. That affects the average multi car cycle time.

This paper explores the average multi car cycle time in a pure incoming traffic situation of a multi car lift systems used as local group considering quality of service constraints. The traffic analysis is established by applying Monte Carlo simulation that calculates an additional multi car cycle time avoiding "traffic jams". Based on a simplified calculation model handling capacity results are presented for different numbers of served floors and different numbers of passengers per car. Results are affected by floor to floor distances and required distances between cars.

1 INTRODUCTION

1.1 Circulating multi car lift system

In a circulating multi car lift system (MCLS) multiple lift cars are sharing the same shafts. This kind of lift system has been widely considered [1, 2, 3, 4]. Vertical shafts are used as one way tracks – one in the up direction, another in the down direction (see Figure 1). Cars do not have ropes and are propelled by linear motors. The lift cars can move vertically and horizontally. Exchanger units enable change in the orientation of car movement between vertical and horizontal [5]. A preferred case of application for a circulating MCLS is connecting entrance lobbies with sky/transfer lobbies as shuttle lifts [6]. But a circulating MCLS is not limited to shuttle applications. It can also be used for a local lift group to distribute passengers to their final destination floors [7]. Accepted rules of lift behaviour [8, 9, 10, 11] are applied also to MCLSs. Additional rules [7] need to be considered to reduce departure delays [12] caused by "traffic jams". Departure delays are caused by different number of stops and different stops for different cars.

Cycle time: The multi car cycle time (t_{cy}) is the time between two subsequent cars e.g. departing from the main entrance floor from the same shaft door [6]. There is a minimum possible cycle time depending on stopping and exchanger times of cars.

Delaying stops: Stops of a leading car can block the shaft and delay the processing of a following car stop sequence. Figure 2 shows a general example of a spatial plot of the positions of two subsequent cars. $D1(t)$ is the position of the leading car and $D2x(t)$ is the position of the following car. The leading car 1 ($D1(t)$) has one "delaying stop" that causes a safety distance violation (or a "traffic jam") if car 2 ($D2x(t)$) departs from the bottom landing after a minimum possible cycle time (t_{cy}). A longer cycle time between cars can avoid these "traffic jams" of lift cars. The following car arrives later at the main entrance floor. Therefore, an additional time needs to be added to the minimum possible cycle time. The additional time between two subsequent cars avoiding any "traffic jams" for the following car in an up direction shaft depends on the stop sequence of the leading car and the following car.

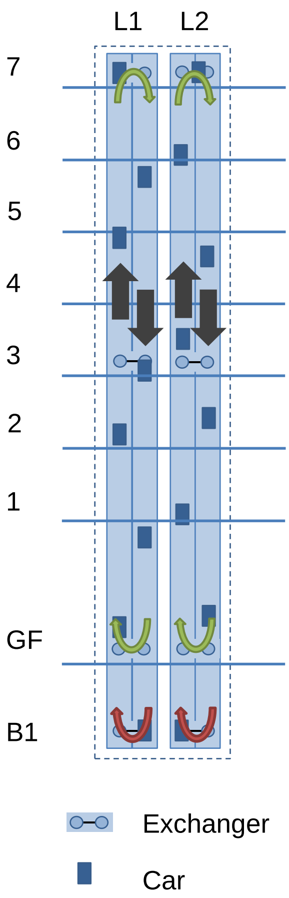

Figure 1 MCLS as local group

An additional cycle time delay (t_{CyD}) for the following car 2 ($D2(t)$) results in a longer cycle time at the main entrance floor and avoids the safety distance violation (see Figure 3). "Delaying stops" need to be calculated to derive the additional cycle time. Both stopping sequences (the leading car stopping sequence and the following stopping car sequence) need to be analysed and compared.

The cycle time delay (delayed departure) can be determined if the following car has a later arrival at the bottom landing. Another option is that the following car has a delayed door opening for loading passengers. A later arrival or a delayed door opening at the bottom floor does not affect any passengers inside the cabin as the cabin always arrives empty. That increases the waiting time (WT) for passengers but reduces experienced departure delays inside the cabin. Waiting for a lift to arrive is an expected scenario for passengers in opposite to departure delays. The delayed door opening should only be applied if passengers are not aware of a car already waiting behind the shaft door. An additional cycle time can be reduced if flexible speed patterns are used (e.g. starting early with a reduced velocity). Adaption of the speed pattern is not considered in this paper's analysis.

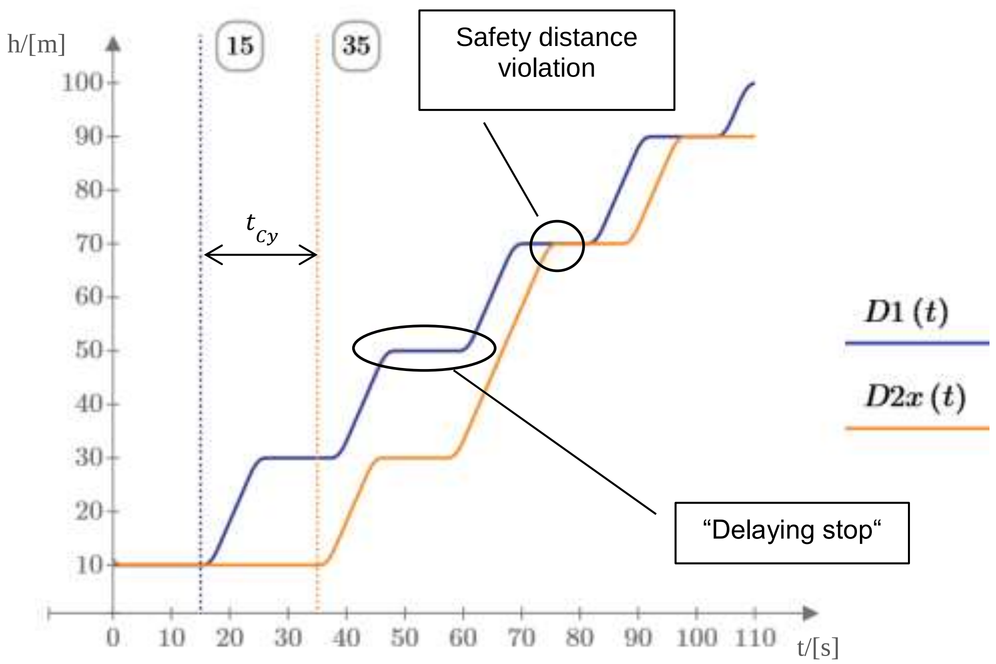

Figure 2 Spatial plot indicating a delaying stop

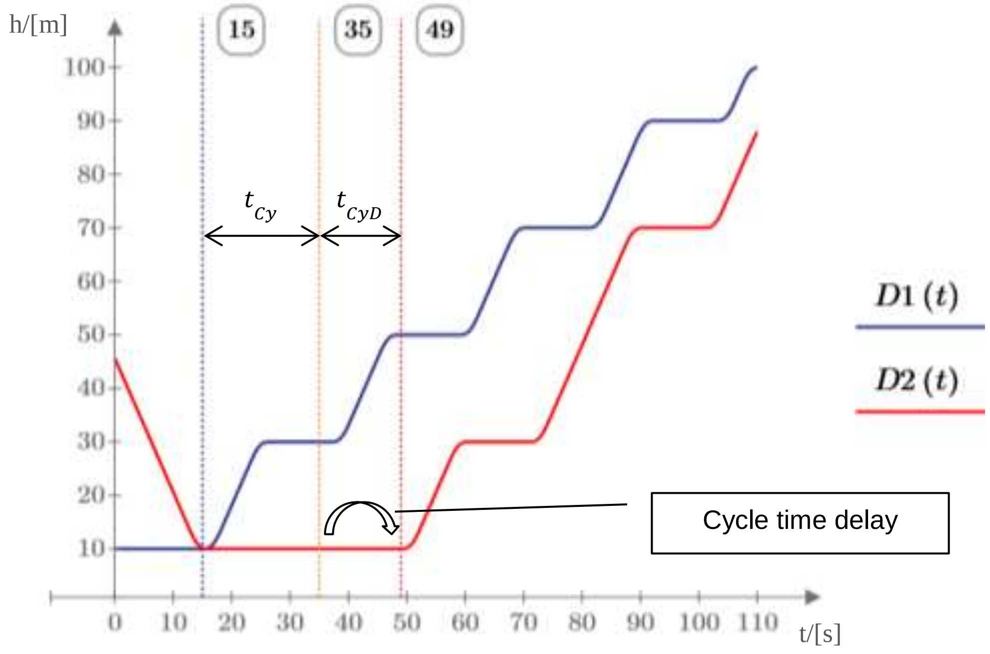

Figure 3 Spatial plot with an additional cycle time delay

1.2 Analysis methods

Lift traffic analysis is the "determination of statistical characteristics of passenger movements in an elevator […] system" [13]. In lift traffic design and analysis, different methods exist and are used. In general there are two categories: calculation and simulation [14].

1.2.1 Analytical method (calculation)

The classical method is an analytical, equation-based calculation – the round trip time (RTT) calculation [9, 13]. The RTT calculation is based on pure up peak traffic conditions. Based on several inputs (lift configuration and operation in a building) the average up peak interval of lifts departing from the main terminal floor is calculated. The RTT calculation has limitations as it is based on assumptions and simplifications. Modifications of the classical RTT calculation are necessary to address limitations analytically. These can be complex and especially combinations of addressed limitations become complicated [15]. Extensions to the classical RTT calculations overcome limitations [16]. The analytical method also does not consider individual dispatching and control algorithms of the lift system.

1.2.2 Simulation method (event based)

Lift traffic simulations are discrete event based or time-slice (timer-event-based) simulations. The whole process of passenger arrivals and transportation in lift cars is simulated including the lift functionality. As traffic simulation is closer to "real life" it has some advantages compared to RTT calculations [13]: it models the lift control system; it enables more realistic passenger arrivals rather than constant passenger arrival like assumed in the RTT calculation and it enables various types of results that can be analysed. The passenger waiting and transit time results are the main measure for quality of service, but other analysis is possible. Traffic simulation covers different kind of building configurations, traffic types, lift configurations and types of lifts systems. But lift traffic simulations are more complex and time consuming compared to analytical calculations [17, 18]. If a traffic simulation is configured according to the assumptions of a RTT calculation it can be shown that results are consistent [17]. ELEVATE is a lift traffic simulation software [19] that is widely used in the lift industry for traffic design and analysis. It enables the connection of proprietary dispatchers for known roped lift systems [20]. It was shown that simulation results are consistent with real world results [21].

1.2.3 "Mixed" method (Monte Carlo simulation)

A kind of a "mixed" traffic design method uses the Monte Carlo simulation method to evaluate the RTT of a lift in up peak traffic condition [15]. If the building configuration becomes complicated it helps to overcome combinations of the mentioned limitations of the RTT calculation method. A random passenger generator generates the passenger's destinations for each round trip. The probability of the destination floors is based on the building population for each floor. To cover multiple entrance floors the arrival floor of the passengers is also generated based on the arrival probability for each entrance floor. A round trip calculator calculates each RTT. It uses a kinematic calculator to consider unequal floor heights and trips where the rated velocity is not reached. If the number of samples is 1000 it was shown that the accuracy of the results is <+/- 0.3% [22]. This is a good method if equations for the analytical calculation become complex.

2 MCLS AS LOCAL GROUP

2.1 Cycle time in local MCLS groups

To calculate the incoming handling capacity (HC) the average cycle time of a local circulating MCLS needs to be determined considering existing constraints like safety distance and avoiding departure delays/"traffic jams". The stop sequence in an up direction shaft of a leading car can be compared with the stop sequence of a following car. The number of delaying stops indicates an additional cycle time delay. Each following car is the leading car for the next following car. With the use of a Monte Carlo simulation multiple samples of leading and following car stop sequence comparisons can be made.

2.1.1 Additional cycle time delay

There is a necessary cycle time delay for each delaying stop. This additional delay depends on "time consumed when making a stop" [23] for intermediate stops. This includes the time for standing at the floor itself but also includes the longer time for acceleration and deceleration compared to the time passing the same distance with rated velocity. The standing time includes passenger transfer times and door times. For simplicity in this analysis the time consumed for each intermediate stop is calculated with the same duration of time although the number of transferring passengers may be different for each stop. For each delaying stop the cycle time needs to be delayed by the time consumed for a stop.

2.1.2 Stopping sequences and safe floors

Depending on passengers' destinations and assigned calls every lift car in a MCLS has an ordered sequence of stops at landings in the up direction shaft. For all cars the first stop needs to be the bottom landing. This stop at bottom landing is for passenger loading at the main entrance floor. The last stop must be the top landing of the up direction shaft. This top landing stop is necessary for the horizontal shaft changing of a car using the exchanger unit. It is expected and likely that there is no additional delay for the horizontal movement at the top floor. It can also be used for passenger unloading. There may be additional stops/floors between the bottom and the top floor.

It is also important to know the floors the following car is able to stop at depending on the leading car stops and required distance constraints. Depending on required distances and distances between floors a following car can stop directly below the leading car stop floor at the same time or, more likely, one floor needs to be in between the leading and following car stops. From the leading car stops sequence a safe floor sequence for the following car can be derived.

2.1.3 Comparison of stop sequences

There is at least the minimum possible cycle time between the first stop of the leading car and the first stop of the following car (the first stop is the bottom floor). To calculate the delaying stops a stop of the following car needs to be compared with the safe floor for the following car belonging to/derived from the leading car's stop ahead. The movement and all stops in the whole up direction shaft needs to be analysed and delaying stops can be counted and calculated.

2.1.4 Simulation/Calculation

The average cycle time for a local MCLS is expected to be higher than the minimum possible cycle time if "traffic jams" shall be avoided. To calculate an average cycle time in a pure incoming traffic the stopping sequences of multiple subsequent cars need to be compared. The stopping sequences of the cars are depending on the passengers destinations. To calculate the average cycle time of multiple subsequent cars the method of Monte Carlo simulation is used. This method was introduced to evaluate the round trip time (RTT) of conventional single car lift systems in pure incoming situations (see section 1.2.3). To evaluate the average cycle time in local circulating MCLSs the general structure is shown in Figure 4.

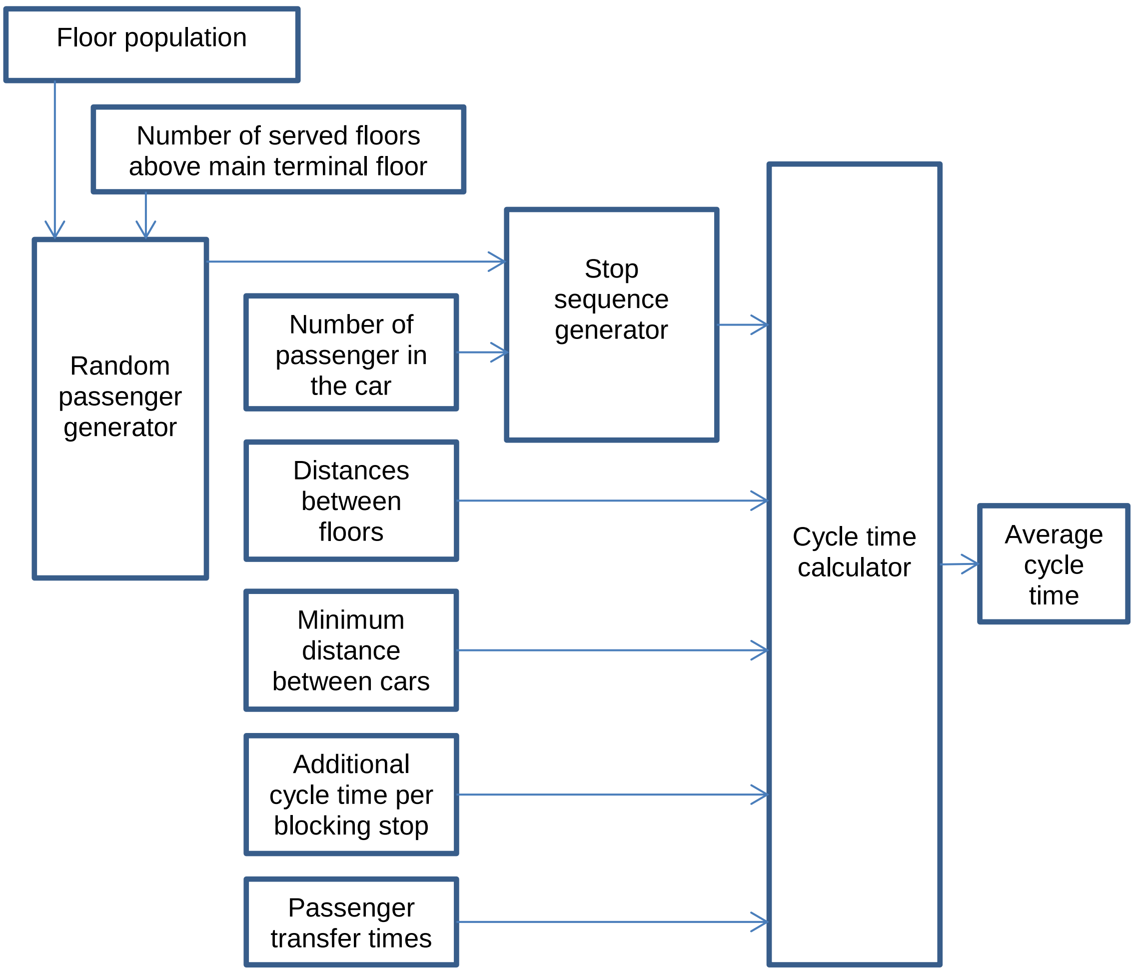

Figure 4 Structure of the Monte Carlo simulation to calculate the average cycle time

Random passenger generator: The file output of the passenger generator from the lift traffic simulation software ELEVATE [19] is used to generate an ordered passenger list with an arrival floor and a destination floor for each passenger. As input the number of floors and the floor population is necessary. The same population on each floor and a traffic mix of 100/0/0 for "in/out/interfloor" is used.

Stop sequence generator: The stop sequence generator assigns passengers from the ordered list to the next arriving lift car. Every car is filled up to the number of passengers fitting into the car. Depending on the destinations of the passengers in the car a stop sequence of the car is generated. A stop at the top floor is mandatory as it is used to move the lift car horizontally to the down direction shaft.

Cycle time calculator: The cycle time calculator comparing the stop sequences of a leading and a following car. Two subsequent cars are analysed and delaying stops are calculated avoiding departure delays and "traffic jams". A cycle time for the following car is calculated (minimum possible cycle time + additional cycle time delay). Input parameters for the cycle time calculator are distances between floors, minimum distances between cars, additional cycle time per blocking stop and passenger transfer times. The cycle times of multiple subsequent result in an average cycle time. An average pure incoming HC can be calculated.

2.2 Results

2.2.1 $d_{min} < d_{f2f}$

The average incoming HC derived from the average cycle time depends on the number of passengers per car and the number of served floors above the main entrance level. In case the minimum distance between cars is shorter than the floor to floor distances ($d_{min} < d_{f2f}$) the results depend on the number of passengers per car is shown in Figure 5. The diagram shows the results of one MCLS loop serving all calls in a 100% incoming traffic situation. If the number of served floors increases the probability of different stop sequences increases and therefore the probability of delaying stops increases. But there is a minimum HC. If number of served floors is high, the impact of additional served floors is less.

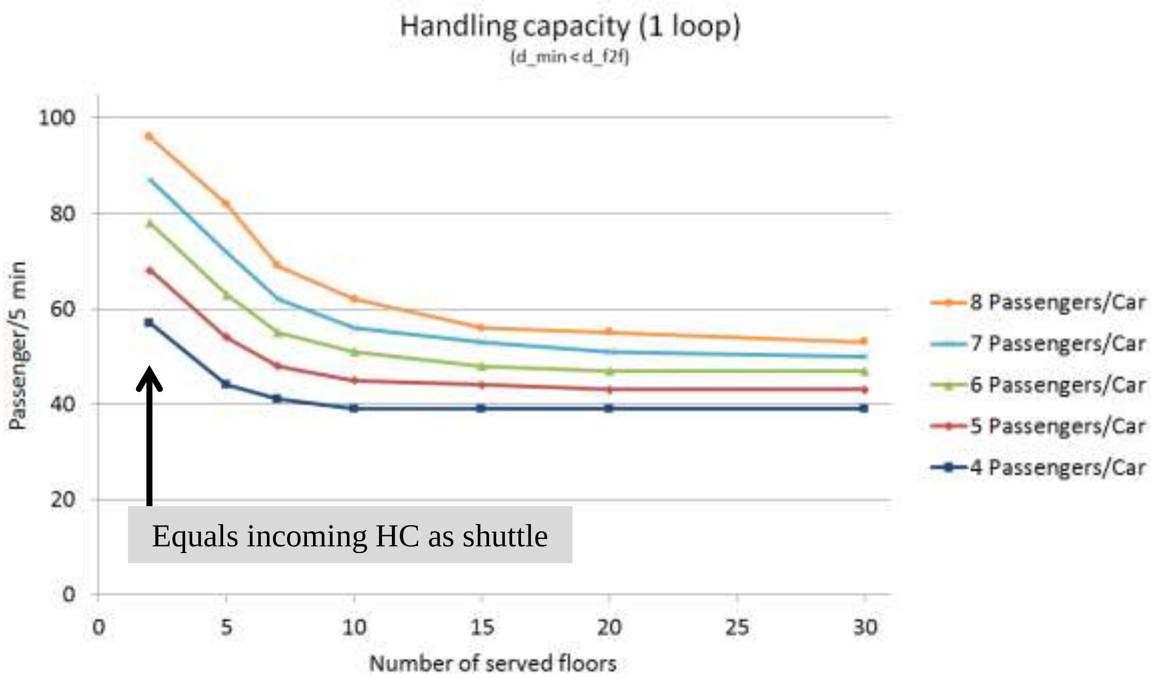

Figure 5 Average incoming HC5 for one local circulating MCLS loop

2.2.2 $d_{f2f} < d_{min} < 2\ d_{f2f}$

It is very likely that the minimum distance between cars is longer than the floor to floor distances ($d_{min} > d_{f2f}$). HC will be affected if a following car has to stand at least two floors below a stopped leading car ($d_{f2f} < d_{min} < 2\ d_{f2f}$). Figure 6 compares the results with 8 passengers per car with two cars able to stand next to each other ($d_{min} < d_{f2f}$) and an additional floor required between two stopped cars ($d_{f2f} < d_{min} < 2\ d_{f2f}$). It is assumed that the distance from the main entrance floor to the floor above is longer than the minimum distance. This is a reasonable assumption because main entrance floors are often high.

The additional safety distance constraints reduce the HC. If a leading car is standing at a floor it also blocks the landing below. If the lift system serves a low number of floors the negative effect is higher than serving more floors.

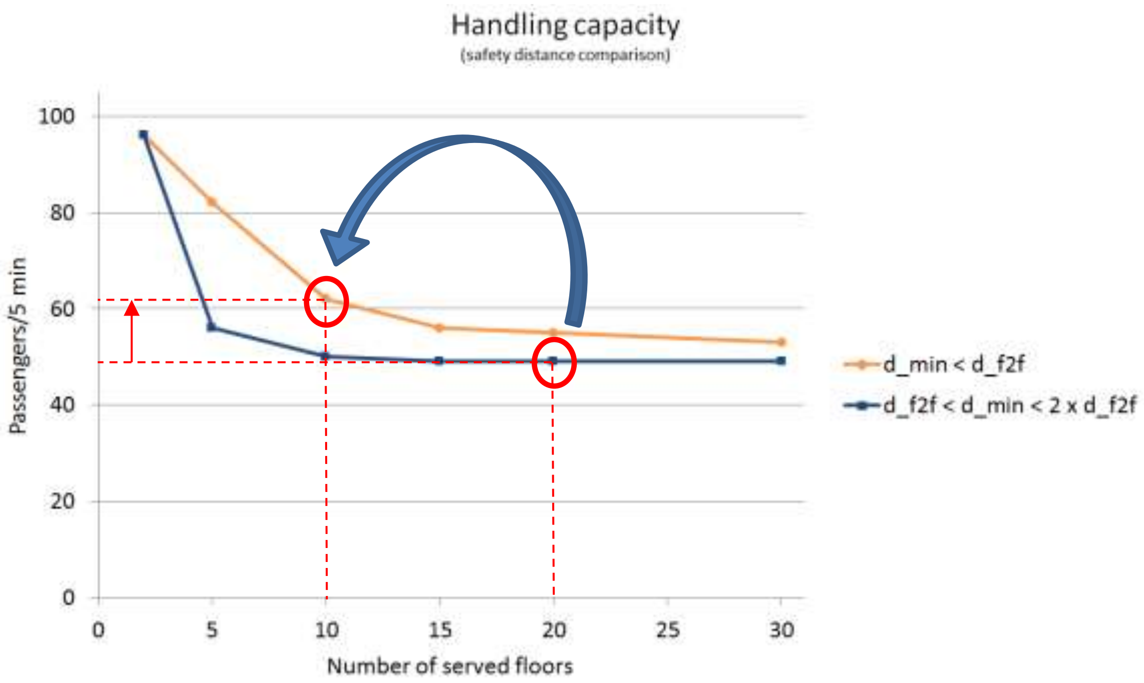

Figure 6 HC depending on the safety distance constraints

"Served floor assignment": In a group of two circulating MCLS the served floors from the main entrance lobby can be split between loops in an alternating manner similar to interleaved zones [9] (see Figure 7). This reduces served floors per MCLS loop and increases the distance between served floors. Therefore, the HC5 can be increased (see Figure 6).

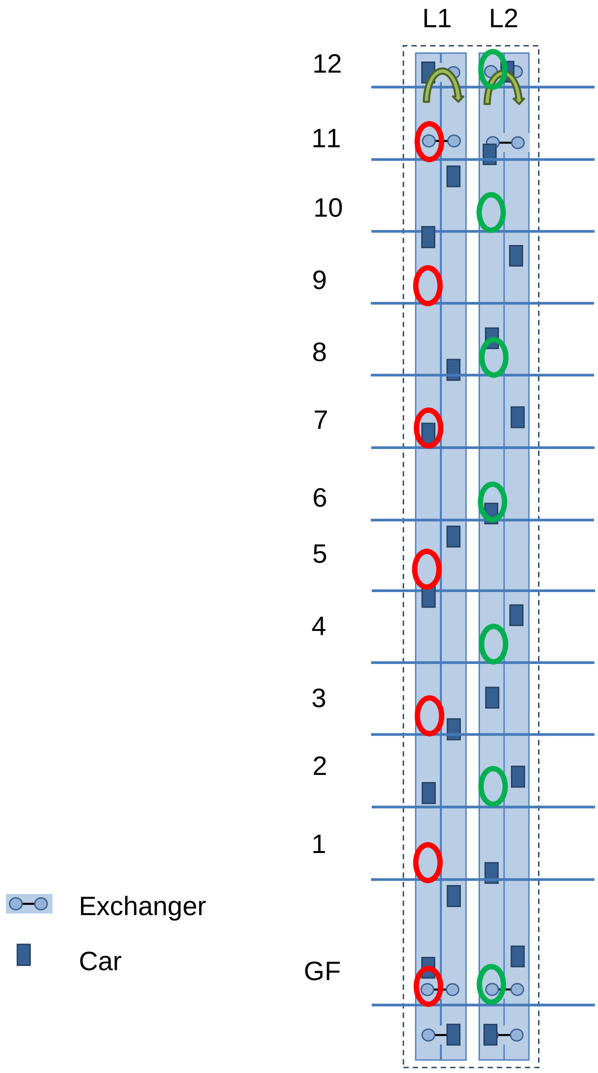

Figure 7 Alternating floor assignment of multiple MCLS loops

3 CONCLUSION

This paper introduces traffic analysis for a circulating MCLS used as local group. Based on a simplified additional cycle time calculation the HC for a 100% incoming traffic is calculated avoiding "traffic jams". The Monte Carlo Simulation method is used. The result for different numbers of served floors and different numbers of passengers per car were calculated. In case of a higher number of served floors the probability of a different number of stops increases and the cycle time needs to be increased to avoid "traffic jams". If more than about 15 floors are served, it is not needed to increase the cycle time further. An increased cycle time reduces HC compared to a shuttle application. Furthermore, safety distance and distance between served floors affects results. If cars cannot stand next to each other at two adjacent floors the HC is further reduced.

If multiple MCLS loops are operated as a common lift group, the performance of each loop can be improved with destination control or "served floor assignment" (compare with sub zoning for conventional lifts) because the operation of each MCLS loop can be optimised.

Full traffic simulation including control algorithms are needed to prove the results. Control algorithms need to provide expected system behaviour. Interfloor traffic may affect the minimum possible cycle time if "traffic jams" shall be avoided. Interfloor traffic may cause additional stops. Additional stops can have a negative effect on calculated delaying stops but also can have a positive effect on calculated delaying stops.

REFERENCES

[1] Elevator World, (1996) An elevator go round. *Elevator World*, **44**(1), pp. 42

[2] Jappsen, H. (2002) High Rise Elevators For The 21st Century. In: *Elevator Technology 12, Proceedings of Elevcon 2002.* The International Association of Elevator Engineers.

[3] Godwin, A. (2010) Circular transportation in the 21st century (without the 'beautiful' counterweight!). In: *Elevator Technology 18, Proceedings of Elevcon 2010.* The International Association of Elevator Engineers.

[4] ThyssenKrupp Elevator AG (2014) *New era of elevators to revolutionize high-rise and mid-rise construction* [online]. Available from: http://www.urban-hub.com/ideas/new-era-of-elevators-to-revolutionize-high-rise-and-mid-rise-construction/ [Accessed 04/20, 2015].

[5] Jetter, M. and Gerstenmeyer, S. (2015) A Next Generation Vertical Transportation System. In: *Wood, A. & Gabel, J. (eds.), The Future of Tall: A Selection of Written Works on Current Skyscraper Innovations. Addendum to the Proceedings of the CTBUH 2015 International Conference, New York, 26–30 October 2015.* Chicago: Council on Tall Buildings and Urban Habitat.

[6] Gerstenmeyer, S. and Peters, R. (2017) Circulating multi car lift system – traffic concept and analysis. *Transportation Systems in Buildings - Special Issue 2016* [online], Available from: http://journals.northampton.ac.uk/index.php/tsib/article/download/107/88 [Accessed 03/03, 2017].

[7] Gerstenmeyer, S. and Peters, R. (2016) Multicar dispatching. In: *Symposium on Lift and Escalator Technologies.* Northampton: The Lift and Escalator Symposium Educational Trust.

[8] Closs, G. D. (1970) *The computer control of passenger traffic in large lift systems.* PhD Thesis, The University of Manchester Institute of Science and Technology.

[9] Barney, G. (2003) *Elevator Traffic Handbook.* London: Spoon Press.

[10] Levy, D., Yadin, M. and Alexandrovitz, A. (1977) Optimal control of elevators. *International Journal of Systems Science.* 8 (3), 301-320.

[11] Siikonen, M. (1997) *Planning and Control Models for Elevators in High-Rise Buildings.* Research Reports A68. Helsinki University of Technology, Systems Analysis Laboratory.

[12] Gerstenmeyer, S., Peters, R. and Smith, R. (2017) Departure delays in lift systems. In: *Symposium on Lift and Escalator Technologies.* Northampton: The Lift and Escalator Symposium Educational Trust.

[13] CIBSE (2015) *CIBSE Guide D: 2015 Transportation systems in buildings.* London: The Chartered Institution of Building Services Engineers.

[14] Al-Sharif, L. and Al-Adem, M. (2014) The current practice of lift traffic design using calculation and simulation. *Building Services Engineering Research.* 35 (4), 438-445.

[15] Al-Sharif, L., Aldahiyat, H. M. and Alkurdi, L. M. (2012) The use of Monte Carlo simulation in evaluating the elevator round trip time under up-peak traffic conditions and conventional group control. *Building Services Engineering Research.* 33 (3), 319-338.

[16] Al-Sharif, L. and Abu Alqumsan, A. M. (2015) Stepwise derivation and verification of a universal elevator round trip time formula for general traffic conditions. *Building Services Engineering Research and Technology.* 36 (3), 311-330.

[17] Peters, R. (2013) The Application of Simulation to Traffic Design and Dispatcher Testing. In: *Symposium on Lift and Escalator Technologies.* Northampton: The Lift and Escalator Symposium Educational Trust.

[18] Al-Sharif, L., Abu Alqumsan, A. M. and Khaleel, R. (2014) Derivation of a universal elevator round trip time formula under incoming traffic. *Building Services Engineering Research.* 35 (2), 198-213.

[20] Peters, R. (2002) Current technology and Future Developments in Elevator Simulation. *International Journal of Elevator Engineers.* 4 (2)

[21] Smith, R. (2011) *Determination of Lift Traffic Design Requirements based on New Technologies and Modern Traffic Patterns.* PhD Thesis, The University of Northampton, unpublished.

[22] Al-Sharif, L., Abdel Aal, O. F. and Abu Alqumsan, A. M. (2011) The use of Monte Carlo simulation to evaluate the passenger average travelling time under up-peak traffic conditions. In: *Symposium on Lift and Escalator Technologies.* Northampton: The Lift and Escalator Symposium Educational Trust.

[23] Peters, R. (1998) *Vertical transporation planning in buildings.* Doctor of Engineering Thesis, Brunel University, Department of Electrical Engineering and Electronics.

BIOGRAPHICAL DETAILS

Stefan Gerstenmeyer has many years of experience in R&D for lift controls, group and dispatcher functions/algorithms, including traffic analysis and multi car lift systems. He is working as Chief Engineer/Head of Traffic and Group Control at thyssenkrupp Elevator. He is a post graduate research student at the University of Northampton.