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# Analysis of Lift Control System Strategies under Uneven Flow of Passengers

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**Abstract.** Modern embedded microcontrollers used in lift automation can provide the system operation under both static and dynamic strategies. The control system operating under dynamic strategy can change the lift system controls under different passenger behaviours, varying to improve the efficiency of service. However, it is extremely challenging to determine the system conditions leading to the decision to switch the control strategies. The present paper investigates the influence of the passengers' flow parameters on lift control systems strategies using a hybrid mathematical model combining agent-based and discrete event methods. It has been shown that the operation of the lift control systems, in the context of decision leading conditions, can be effectively assessed through a model analysis. The proposed model has been simulated using AnyLogic systems to estimate the impact of uneven flow of passengers on performance of a ten floor lift system. The results of simulations have been used to determine the optimum intervals between the calls and lift arrival time which lead to strategies that minimise passenger's waiting time.

**Keywords:** Lift control, dynamic control, AnyLogic, lift modelling.

## 1 Introduction

Due to rapid development of microelectronics, modern engineering control systems including lift control utilise specialised microcontrollers [1], [2] or universal microprocessors [3] replacing analogue or relay control circuits dominated in the past few decades. Implementation of digitally based controllers significantly expanded computational recourse of control systems and range of their control algorithms while reducing cost of system design.

Reengineering of lift control systems is often based on a simple reproduction of old control circuit algorithm using a digital control. This approach does not use advanced features and functions available in the digital platform. Alternatively, intensive employment of computational power of modern microcontrollers can make control more complex and "intelligent". However, the intelligent control requires more information about the controlled object in order to bring new features into control

system. Therefore, the systems should be modernised by installation of additional sensors [4].

## 2 Lift as Cyber-Physical System

Kim and Kumar [5] defined cyber-physical system (CPS) as an "engineered system in which computing, communication, and control technologies are tightly integrated." This definition covers a wide range of engineering systems including lifts.

In lift systems, electro-mechanical elements represent the physical component of CPS definition whereas lift control is related to the cyber aspect of CPS. Modern lift control comprises a variety of computational technologies providing effective and efficient operation of electro-mechanical elements. Passengers are able to interact to a lift control system using simple communication (buttons) and sensors. The service provided by a lift is actually physical vertical motion of passengers in up and down directions. Therefore the research in the area of lift systems including analysis, modelling and optimisation of lift control algorithms is directly linked to CPS [6].

## 3 Lift System

A conventional lift control provided operation of the system under static algorithm. It means that the control strategy is stable or unchanged during the system operation. However, modern digital controllers used to automate lift system can provide the operation under both static and dynamic control strategies. The lift control system operating under dynamic strategy can change the system behaviour if the passengers flow rate is vary [7]. In order to provide a dynamic strategy it is extremely challenging to determine the system condition leading to the decision to switch the control algorithm.

If lift is considered as a queuing system, the time of passenger service  $T_{serv}$  can be represented as:

$$T_{serv} = T_{dis} + T_{wait} + T_{mov} \quad (1)$$

where  $T_{dis}$  is the time of passenger dislocation from flat to lift's hall,  $T_{wait}$  is the passenger waiting time of lift arrival, and  $T_{mov}$  is the time of passenger carrying to a destination floor. Therefore, in terms of lift service efficiency, the primary task of lift system is to minimise  $T_{serv}$ .

Architectural design of lift systems also aims to reduce  $T_{serv}$ . It has been observed that the optimal lift allocation in a building affects on the service time reduction. Goetschalckx and Irohara [8] present an algorithm to choose the optimal floor topology based on minimising the vertical and horizontal motions ( $T_{dis}$ ) of passengers. Matsuzaki et al. [9] suggest the genetic algorithm for optimisation of the quantity and capacity of lifts using the same approach. Markos and Dentsoras [10] discuss an approach to determine the location of passenger lifts in a commercial building.

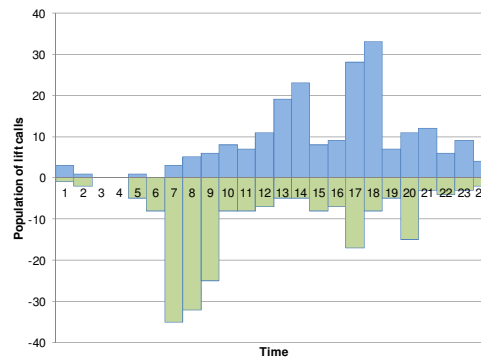
Many lift manufactories offer various effective solutions aimed to decrease the time  $T_{mov}$ . Company Otis [11], one of the world leaders in the lift industry, proposes models that can operate at a speed faster than 2.54 m/s. However, even so high speed will not significantly decrease the time  $T_{serv}$  without effective management strategies ensuring the reaction of control system on the passengers' queries flow rate [12].

#### 4 Lift Control Strategies

To reduce the number of parameters affecting the efficiency of control the system analysis employed single strategies. The list of available single lift control strategies is given below:

- Simple management (SM);
- Unilateral collective control with one button (up) (U1U);
- Unilateral collective control with one button (down) (U1D);
- Unilateral collective control with two buttons (up) (U2U);
- Unilateral collective control with two buttons (down) (U2D);
- Bilateral collective control with one button (B1);
- Bilateral collective control with two buttons (B2).

The analysis is focused on lift control strategies operating under uneven flow of passengers. Most of people are often following a scheduled behaviour which generates variable passenger flow rate in a residential building. If the daylight distribution of passengers flow is known or determined using various sensors then that can be used to change the control strategies in order to increase the efficiency of lift control system.



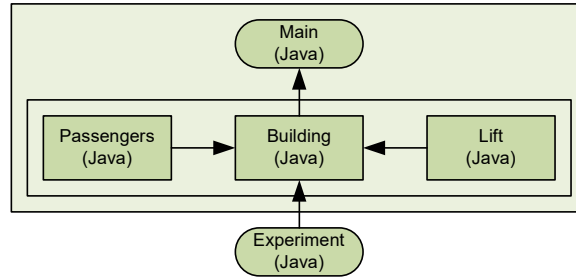
**Fig. 1.** Population of lift calls versus time in a residential building for a day (24 hours). Blue chart is the calls to move the lift cabin up; green chart is the calls to move the lift cabin down.

Fig. 1 shows a typical example of number of calls versus time in a residential building. The positive values are corresponding to "up" calls while the negative values are corresponding to "down" calls. It can be seen that during the morning peak

time the majority of calls are "down" calls whereas the majority of "up" calls belong to evening time [13].

#### 4 Lift Modelling

AnyLogic system [14] was used for modelling and simulation of the lift system. The suggested model combines agent-based and discrete event methods and has been created using an object-oriented programming technology. The model contains five classes: *Building*, *Passengers*, *Lift*, *Experiment* and *Main* as shown in Fig. 2. Agent-based behavior of the model is simulated using state diagrams (statecharts). Statecharts of the classes describe performance of agents in accordance of the control algorithms [15].



**Fig. 2.** Structure of the lift system model in AnyLogic having five classes: Passengers, Building, Lift, Experiment and Main.

#### 5 Model Simulation

The model implements a lift system in a ten-floor building ( $n_{floor} = 10$ ). The flow rate of passengers corresponds to a residential building – passengers appear on the floors at equal probability.

Time parameters in simulation are measured in sec. Variable parameters in the experiment are: the time interval between the arrivals of passengers *IBP* (Interval Between Passengers), lift capacity *EC* (Elevator Capacity) and lift efficiency *EE* (Elevator Efficiency). The lift efficiency is defined as an average value of occupancy rate of the lift cabin during moving time.

The following expression is used to find the average waiting time during the simulations:

$$T_{wait} + T_{mov} = \frac{1}{N} \sum_{i=1}^N (t_{out}^i - t_{inp}^i) \quad (2)$$

where  $t_{imp}$  is arrival time of the passenger in the call floor;  $t_{out}$  is the time when the passenger leaves the lift on the destination floor, and  $N$  is a quantity of passengers.

In the analysed examples the lift stop time ( $T_{stop}$ ) was equal to 5 sec and the time of moving between floors ( $T_{floor}$ ) equals 3 sec.

Let's estimate average value of  $T_{wait}$  for a low rate down stream of passengers under UID control strategy. We consider that after service of current passenger, lift will stay on the first floor.

$$T_{wait}^{down} = \frac{T_{floor}(n_{floor} - 1)}{2} + T_{stop} = \frac{3(10-1)}{2} + 5 = 18.5s \quad (3)$$

The waiting time  $T_{wait}$  can be adjusted using knowledge of passengers flow peaks where control algorithm has to be changed according a new behaviour of lift system.

In the case of downstream scenario having morning peak the waiting time  $T_{wait}$  can be decreased due to the following control strategy: after servicing of a querying passenger, lift does not stay on the first floor; it will move in a position in the middle of building – new park zone. For ten floors building it corresponds to sixth floor ( $n_{floor} = 5$  for the equation below). In this case the waiting time equals:

$$T_{wait}^{down} = \frac{T_{floor}(n_{floor} - 1)}{2} + T_{stop} = \frac{3(5-1)}{2} + 5 = 11s \quad (4)$$

This control strategy brings the benefits of 7.5 sec comparing to (3). Let's call such control strategy as “down modification”.

Similar estimation of  $T_{wait}$  can be used for a low rate upstream of passengers and UID control strategy. After service of a passenger, lift will stay on the destination floor:

$$T_{wait}^{up} = \frac{T_{floor}(n_{floor} - 1)}{2} + T_{stop} = \frac{3(10-1)}{2} + 5 = 18.5s \quad (5)$$

In the case of upstream scenario having evening peak of passenger flow the waiting time  $T_{wait}$  can be decreased using the following control strategy: after the servicing of a querying passenger, lift does not stay at the destination floor; it returns to the first (ground) floor. In this case the waiting time equals:

$$T_{wait}^{up} = 0 \quad (6)$$

It brings the benefits of 18.5 sec comparing to (5). This control strategy is called “up modification”.

Let's estimate  $T_{wait}$  for low rate mixed stream of passengers with equal probability of up and down directions queries.

$$T_{wait} = (T_{wait}^{up} + T_{wait}^{down}) / 2 \quad (7)$$

For “down modification”:

$$T_{wait} = (18.5 + 11) / 2 = 14.75s \quad (8)$$

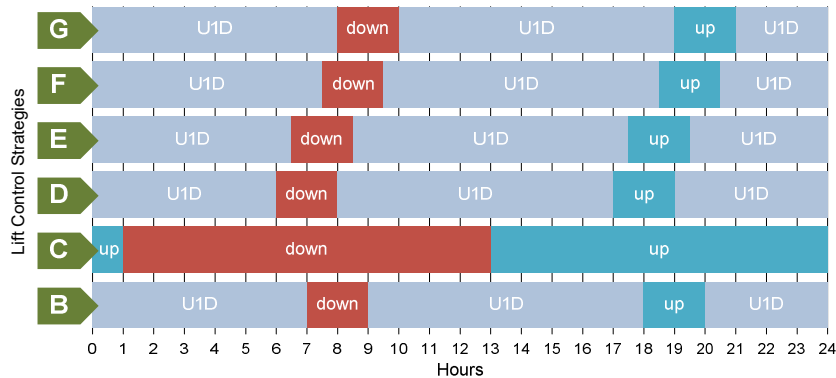
For “up modification”:

$$T_{wait} = (0+18.5) / 2 = 9.25s \tag{9}$$

The value of  $T_{wait}$  for not modified UID strategy under up and down streams of passengers is exactly the same:

$$T_{wait}^{down} = T_{wait}^{up} = 18.5s \tag{10}$$

In previous work [16] authors compared the efficiency of various strategies while this work aims to assess the impact of accuracy in determination of the peak of passenger flow. Fig. 3 presents six versions of UID lift control strategy (B–G) widely used in civil buildings. Each version includes up and down modifications acting in accordance to the shown schedule. The version C provides operation of up and down modifications within proposed upper and down peaks of passengers flow. It means that the lift control system has determined the peaks of uneven flow of passengers correctly. The version B simply switches the strategies every 12 hours according to the passenger’s stream, while the versions D–G provide the same operation as the version C with 30 mins time shift. The versions D–G simulate low accuracy determination of the flow peaks switching the modified control strategies earlier or later.



**Fig. 3.** The schedule of modified lift control strategies. U1D is the unilateral collective control with one button (down) lift control strategy, up is "up modification" of U1D control strategy, down is "down modification" of U1D control strategy.

In order to conduct the simulation IBP was varying to change the passenger flow rate. The parameters chosen for simulation are: IBP<sub>peak</sub> = 30 sec, IBP<sub>normal</sub> = 210 sec; down peak has been predicted from 7 to 9 hours, upper peak – from 18 to 20 hours.

Table 1 presents results of simulation of control strategies UID (not modified) and versions B and C in terms of lift cabin capacity (column EC). It can be seen that for all experiments versions B and C show better waiting time  $T_{wait}$  comparing to UID, while version B has better lift efficiency (EE) compared to C.

Table 2 shows the results of simulation of all analysed strategies. Since the strategies C-D simulate accuracy of peak flow determination the results demonstrate the influence of accuracy of peak detection on the lift efficiency and the waiting time.

It can be seen that the mistakes in peak time determination bring stronger influence on the time waiting but not on the elevator efficiency.

**Table 1.** Results of simulation of control strategies UID and versions B and C.

EC	UID		B		C	
	$T_{wait}$	EE	$T_{wait}$	EE	$T_{wait}$	EE
$IBP_{peak} = 30s, IBP_{normal} = 210s$						
2	13.4s	0.30	11.4s	0.28	10.3s	0.24
3	13.1s	0.20	11.2s	0.18	10.3s	0.16
4	12.9s	0.15	11.4s	0.14	10.7s	0.12
$IBP_{peak} = 30s, IBP_{normal} = 150s$						
2	12.9s	0.3	10.9s	0.28	10.1s	0.24
3	13s	0.20	11.7s	0.19	10.7s	0.16
4	12.7s	0.15	11.8s	0.14	10.7s	0.12
$IBP_{peak} = 30s, IBP_{normal} = 90s$						
2	11.8s	0.30	10.5s	0.28	9.8s	0.24
3	12.1s	0.20	11s	0.19	9.3s	0.16
4	12.1s	0.15	11.5s	0.14	9.2s	0.12
$IBP_{peak} = 40s, IBP_{normal} = 160s$						
2	12.2s	0.28	8.1s	0.27	7.7s	0.22
3	11.7s	0.19	9s	0.18	7.9s	0.15
4	12.1s	0.14	8.9s	0.13	7.9s	0.11
$IBP_{peak} = 50s, IBP_{normal} = 150s$						
2	10.8s	0.28	7.9s	0.26	7.7	0.22
3	11.1s	0.19	7.7s	0.17	7.7	0.15
4	11.1s	0.14	7.8s	0.13	7.3	0.11

**Table 2.** Results of simulation of control strategies B - G. ( $IBP_{pick} = 30$  sec,  $IBP_{normal} = 210$  sec)

EC	B		D		E		F		G	
	$T_{wait}$	EE	$T_{wait}$	EE	$T_{wait}$	EE	$T_{wait}$	EE	$T_{wait}$	EE
2	11.6s	0.28	12.5s	0.29	12.5s	0.29	12.4s	0.28	13.2s	0.29
3	11.3s	0.18	12.8s	0.19	12.1s	0.19	12.3s	0.19	12.7s	0.19
4	11.3s	0.14	12.4s	0.14	11.8s	0.14	12.7s	0.14	13.3s	0.15

### 3 Conclusion

It has been shown that the agent-based modelling in AnyLogic system can be effectively used for assessment of the impact of changes in control strategies on the lift operation. The modelling and simulation can provide the solution of the time interval between the calls led to switching of the control strategies in order to



minimise passenger's waiting time. The variable passenger flow rate obtained from the simulation can be used as an input parameter for analysis of various lift control strategies.

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