DISCRETE EVENT SIMULATION OF PV13 ELEVATOR SYSTEM

by

Chai June Rong, Chew Hoo Wing, Chia Wee Hang

Table of Contents

1 Introduction

1.1 Introduction to the project

An elevator/lift is being defined as a vertical transportation tools that moves between a building's floors (*Elevator - Wikipedia*, 2017). The elevators system has been considered as an essential facility in most of the modern high-rise buildings. Each elevators system might have different configurations such as whether the functionality of "close door" button actually works or not (Feldman, 2013) and the decision making on which lift should be assigned duty in a service calling event.

The elevator system chosen for this project is the residential elevator system in Platinum Lake PV13. This project is about simulation study of elevator system in Block A of the Platinum Lake PV13 condominium. The focus of this project is about passengers' queue waiting for the lifts to reach the ground floor. Based on the data gathered during peak hours, passengers often need to wait a long queue before the lift reaches the ground floor. In addition, there is a high possibility that the passengers who arrive later in a lift trip might not be able to take the lift as the lift is fully filled.

There are several reasons observed that caused the current problems such as the lift that is currently moving downward will be assigned task to reach ground floor although there is another lift which is idle at the floor closer to the ground floor. We assume such decision-making mechanism of the lift system was made according to the PV13 management's priority in focusing the wear-and-tear on the elevator and energy efficiency rather than the passenger experience. Secondly, the capacity of one lift is not enough for one fetching round. There are often more than 13 persons (maximum capacity of current lift) waiting for the lift in one fetching round during the peak hours from 5pm to 9pm. Additionally, the speed of the moving lift is rather slow that makes the waiting queue for each fetching round becomes longer.

1.2 Objective

The primary objective of this project is to build a simulation model for solving the long passenger waiting time and fully loaded lift that delayed some passengers for the next round in Block A of the Platinum Lake PV13 Condominium during peak hours from 5pm to 9pm.

We have proposed several suggestion solutions to address the issues mentioned above for improving the current system. All these solutions are made based on the observed problems found in the current system. First, we suggest the PV13 management to change the elevator system's decision-making mechanism to focus on passenger experience by assigning task to move to ground floor to any other lift which is idle and nearer to the ground floor if there is any instead of the currently moving downward one. Next, we also suggest the PV13 management to procure new elevators which have capacity up to 20 persons compared to the existing capacity of 13 persons. Finally, the speed of moving elevator is suggested to be increased up to 1.4 times of the current speed and this might not necessarily involving replacing the current lifts on duty since the current speed is not yet reach the maximum limit stated in manufacturer's catalogue (Feldman, 2013).

1.3 Scope

The data collection will be carried at the ground floor of Block A of the Platinum Lake PV13 Condominium during peak hours which is 5pm to 8pm. The data collection will be carried out for two days for the same period. The samples to be investigated including the passengers arrived at ground floor lobby and all the four lifts during the data collection time.

Process involved will be the time between passengers that arrive at the ground floor lobby and the time he/she able to take the lift that reach the ground floor.

NetBeans IDE 8.2 will be used to develop the java simulation program for this project.

Assume every passenger from other floors will only choose their destination as ground floor.

All four lifts will be considered, and the lift might be coming from any of the 24 floors and the destination will be the ground floor. The lift might stop at any floor to fetch passengers from other floors going down before it reaches the ground floor.

The data collection in this project will considered the lift moving upward as the lift that is currently unavailable.

1.4 Problem statement

The prominent problem statement of this simulation project is how to build a suitable simulation model for the scenario of the elevator system in Block A of the Platinum Lake PV13 Condominium during peak hours. Furthermore, the constructed simulation will be used in solving two major problems which includes how to reduce waiting time of the passengers when waiting for the lift service at ground floor and how to reduce the occurrence of a fully loaded lift that caused some of passengers delayed for another round of fetching service.

2 Background of Study

2.1 Background of the project

Platinum Lake PV13 is 2 towering blocks of 24-storey condominium located in Danau Kota, Setapak, Malaysia. There are total of 4 elevators for each residential block which consists of 3 standard lifts and 1 bomba lift, each with the same capacity for maximum of 13 passengers. However, we will only consider three lifts in this simulation project since one of the lift is not available for fetching passengers during our data collection period.

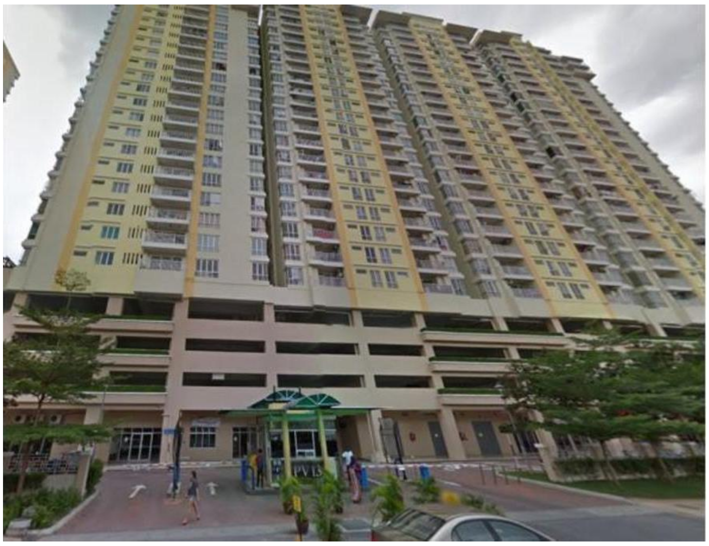


Figure 2.1.1 PV13 Condominium outside view

Figure 2.1.2 & 2.1.3 PV13 Block A Ground Floor Lobby with Four Elevators View

2.2 System Flow

Platinum Lake Condominium PV13 Block A Lift System

	Elevator			
23	Lift 1 (down)			
22				
21				
20 ... 7				
6				
5			Lift 3 (idle)	
4				
3				
2				
1				
G		Lift 2 (full)		Lift 4 (Unavailable)

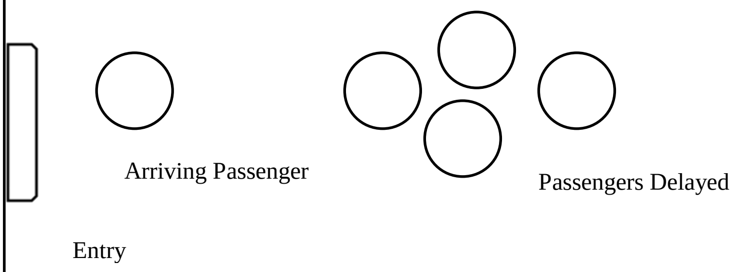


Figure 2.1: System flow for the elevator system in Block A of the Platinum Lake PV13 Condominium (top down view)

- **Explanation of the system flow process:**

1. First batch of passenger(s) arrived the ground floor lobby at time 0 seconds.

2. First batch of passenger(s) pressed the "UP" button to request for elevator service from ground floor to other floors. The difference in time between the first passenger arrival and "UP" button press time is omitted since it does not affect the system behavior. Thus, first passenger arrival time and button pressed time will always be the same for each lift trip/fetching round respectively.

3. The lift system will decide which lift to be assigned based on the following situations:

a. If there is only one lift is currently moving down, then it will be assigned the task to go down to serve the passengers at ground floor who requested for elevator service.

b. If there is more than one lift which is currently moving down, then the one which is at the lowest floor (closest to the ground floor) will be assigned the task to go down to serve the passengers at ground floor who requested for elevator service. (Do not consider the condition where the lift which is originally at the higher floor reached the ground floor faster due to reasons such as different stopping time at other floors etc.)

c. If there is no lift currently moving down, then the lift which is idle and at the lowest floor will be assigned the task to go down to serve the passengers at ground floor who requested for elevator service.

d. If all three lifts are currently going up, then the system will wait until any lift which change to idle or going down then assign that lift to go down to serve the passengers at ground floor who requested for elevator service. (involve an uncertain length of time from moment of "UP" button being pressed until the lift being assigned).

4. After the assigned lift started its departure way to the ground floor, there might be an uncertain amount of lift stopped event occurred because of passengers at other floors (between the departure floor and ground floor) who request for elevator service to go down to ground floor.

5. There might be second or more batches of passenger(s) arrived the ground floor lobby after the first batch of passenger(s) arrival/ "UP" button pressed. Thus, the total number of passengers in queue might keep increasing until the assigned reach the ground floor.

6. Once the assigned lift reached the ground floor, passengers will enter the lift after the original passenger in the lift getting out of the lift. Two situations might be happened here:

a. If the lift is not fully loaded, passenger take the lift arrived at ground floor and leave the ground floor.

b. If the lift is fully loaded, passenger must wait for the next fetching round from another lift.

One complete lift trip/fetching round is considered ended until here. The number of passengers who were delayed for this lift trip was not added into the next lift trip because there are too many probabilistic events might be occurred in between e.g. some of them might choose to leave the queue, another lift which is not originally assigned reached the ground floor before the next lift trip cycle begins etc. Since we want to focus on solving the passenger waiting time and number of passengers delayed for one lift trip cycle hence these uncontrollable and irrelevant details will be omitted.

3 Methodology

3.1 Type of Simulation used

This is a **Dynamic** simulation since it the system states such as the floor of each lift, status of each lift, length of passenger queue etc. change over time. On the other hand, this is a **Probabilistic** simulation since the passenger arrival time, number of passengers arrived, current floor and status of each elevator when the "UP" button is pressed, number of lift stopped occurrences in the trip, length of each stopped time, number of interval passenger arrival, and elevator reaching time etc. will be the random inputs to the system. Additionally, this is a **Discrete** simulation as well since all these system states involved change instantaneously at separate point of time.

3.2 Event routine description

- **Events involved in PV13 Elevator system**

  . First Passenger Arrival at Ground Floor event

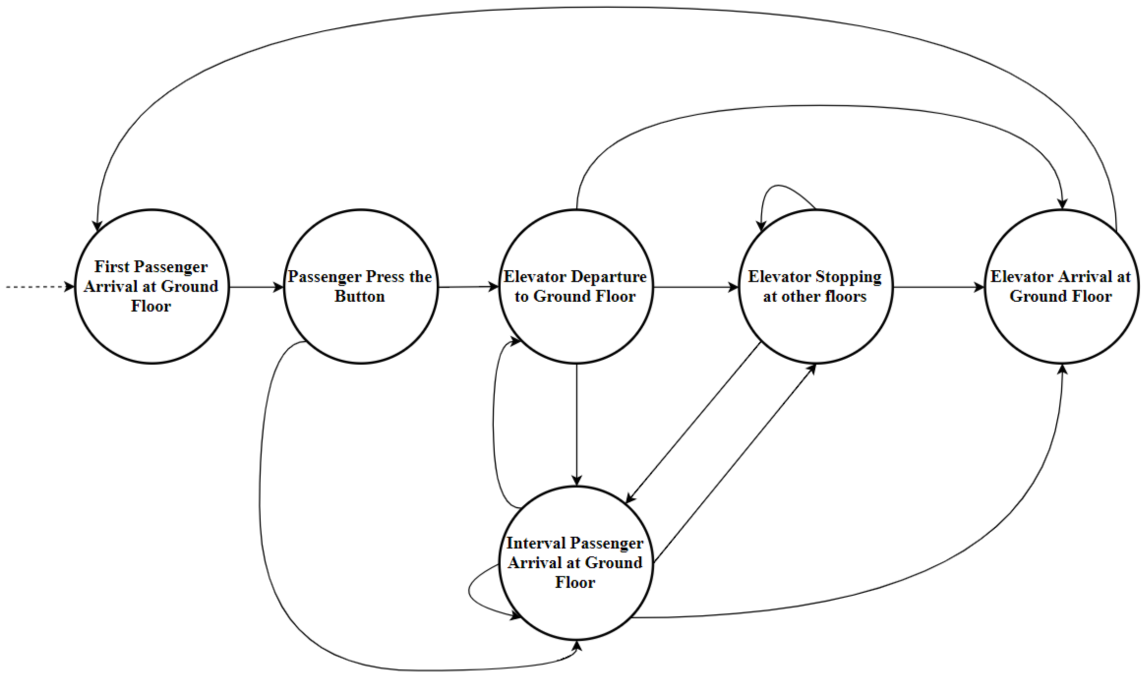
  . Passenger Press the Button event

  . Elevator Departure to Ground Floor event

  . Elevator Stopping at other floors event

  . Interval Passenger Arrival at Ground Floor event

  . Elevator arrival at ground floor/Passenger enter lift event.



x

Figure 3.2: Event Graph

3.3 Simulation steps

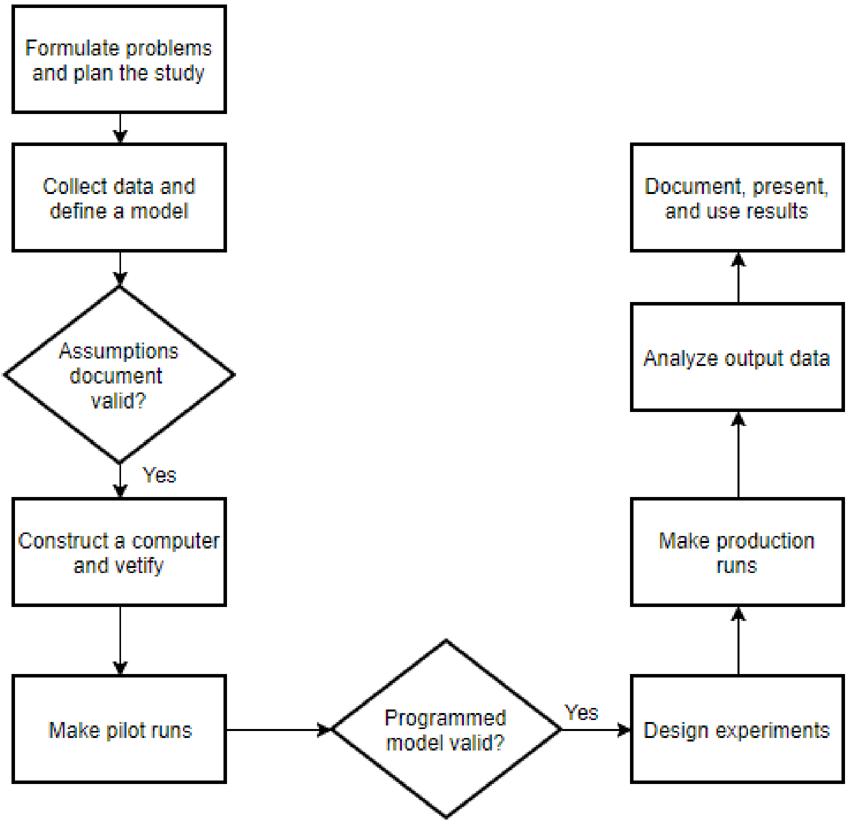


Figure 3.3: Simulation Steps illustration

Step 1: Formulate the problems and plan the study

The problem of long passenger waiting time and fully loaded lift that delayed some passengers for the next round in Block A of the Platinum Lake PV13 Condominium during peak hours from 5pm to 9pm was discovered and stated. Meetings for the study are conducted among the team members and together with the tutor to determine project issues such as the overall objective, scope of the model etc.

Step 2: Collect data and define a model

According to the tutor's requirement for this project, a six hours of data collection was conducted at Block A of the Platinum Lake PV13 Condominium on 7/12/2017 from 3pm to 9pm. Data was collected in csv format and focused on the lift trips/fetching round to ground floor only. Information such as clock time, event types and details such as number of passengers arrived/delayed, lift states etc. were collected.

Step 3: Assumption document valid?

Unfortunately, a proper structured walk-through was not conducted with the tutor in this project. There is only an informal inspection on the data conducted by the team members only to ensure the model's assumption are correct and complete. This was conducted before any code was done to prevent significant reprogramming later.

Step 4: Construct a computer program and verify

The lift system model was programmed in Java using NetBeans IDE 8.2 and it takes around 2 weeks' time. The general programming language was used to build this project because of its flexibility in adjusting the model to fit our needs besides adhering to the rules set by tutor that simulation package was not allowed to be used in this project.

Step 5: Make pilot run

Make pilot run for validation purpose.

Step 6: Programmed model valid?

The constructed lift system model was compared to the existing system (based on collected data) in terms of the performance measures such as average waiting time for a lift trip etc. Model factors/parameters especially the empirical distribution for each random variate were carefully adjusted to close the gap between the programmed model between the existing system as much as possible.

Step 7: Design experiments

System configurations such as length of each simulation run was fixed at 21600 seconds and total number of 10 independent runs was used to construct the confidence intervals.

Step 8: Make production runs - Make production run for next stage use

Step 9: Analyze output data

The absolute performance of the existing model was determined under the agreed configuration stated in Step 7 and then different proposed solutions such as changing lift system decision-making mechanism/search optimization, increase lift capacity up to 20 and increase lift speed were applied to the model, tested and compared with the original model in a relative sense.

4 Assumption Document

4.1 For First Passenger Arrival at Ground Floor event:

a. The first passenger arrival time occurred at clock time 0 second (The system only started once there is first passenger arrived at ground floor lobby).

b. The number of passenger for each arrival can be varied from 1 to 15 (based on collected data).

4.2 For Passenger Press the Button event:

a. The current state and floor of each three lifts at the moment of the “UP” button being pressed will be randomly generated since this simulation model do not track the continuous lift information after the passengers enter the assigned lift which arrived at the ground floor (end of one lift trip/fetching round cycle).

b. The difference in time between the first passenger arrival and “UP” button press time is omitted since it does not affect the system behavior. Thus, first passenger arrival time and button pressed time will always be the same for each lift trip/fetching round respectively. e.g. if first passenger arrival time is 1803 seconds then the button pressed time will also be 1803 seconds.

c. If all three lifts are currently going up when the first batch of passengers in a lift trip pressed the service “UP” button, then there will be an uncertain amount of delay from moment of “UP” button being pressed until the lift being assigned and which lift (1,2,3) being assigned after the departure delay will also be a randomly generated element. In this case, there might also be interval passenger arrival event(s) occurred before the lift departure event occurred.

4.3 For Elevator Departure to Ground Floor event:

a. If there is any lift that is currently going down or idle, then that particular lift will be assigned to the ground floor. In this case, the lift departure time will be same as the “UP” button press time which is same as the first passenger arrival time i.e. both first passenger arrival time, button pressed time and lift departure time will be the same for each lift trip/fetching round if not all three lifts are going up when the “UP” button being pressed.

b. After the lift departure event, a random number of interval passenger arrivals and lift stopped events will be generated and scheduled. This was done so to simulate real world scenario as realistic as possible as there would be stochastic occurrences of passenger arrivals and lift stopped events during the lift trip from original floor to the ground floor.

c. If the lift is originally at ground, it is being considered as departure from ground floor, 0.

<u>4.4 For Elevator Stopping at other floors event:</u>

a. Lift stopped event can occur before or after another lift stopped event or interval passenger arrival event.

b. Each lift stopped event will takes a random stopping time.

<u>4.5 For Interval Passenger Arrival at Ground Floor event:</u>

a. Interval passenger arrival event can occur before or after another interval passenger arrival event or lift stopped event.

b. Each interval passenger arrival event will have a random number of arrived passengers.

<u>4.6 For Elevator arrival at ground floor/Passenger enter lift event:</u>

a. The time when the assigned lift reaches the ground floor will be calculated based on the sum of the time the assigned lift stayed at floor from its starting floor added up together with all the interval interarrival time and lift stopping time occurred in that particular lift trip.

b. The elevator arrival at ground floor event can be considered as the passenger enter lift event as well since the differences in time involved is meaningless to be considered in this simulation model.

c. The number of passengers who are unable to enter the lift because of its fully loaded situation will be considered as the number of passengers delayed.

d. The number of passengers who were delayed for this lift trip was not added into the next lift trip because there are too many probabilistic events might be occurred in between e.g. some of them might choose to leave the queue, another lift which is not originally assigned reached the ground floor before the next lift trip cycle begins etc. Since we want to focus on solving the passenger waiting time and number of passengers delayed for one lift trip cycle hence these uncontrollable and irrelevant details will be omitted.

5 System Modelling

5.1 Conceptual model

5.1.1 Entity

Three lifts and passengers. Lift will be expressed as a single explicit model called "LiftState" describing the respective lift no, current floors and status/direction of each lift.

5.1.2 System state

Q(t): number of passengers in waiting queue at ground floor lobby

LF(t): lift floor and status

5.1.3 Events

"Passenger Arrival" event, "Button Pressed" event, "Lift Departure" event, "Lift Stopped" event, "Enter Lift" event

5.1.4 Event notices:

- (t, Passenger Arrival, n), representing a passenger arrival event occurred at time t with n passengers.
- (t, Button Pressed, L1(f, s) L2(f, s) L3(f, s)), representing a button pressed event occurred at time t with lifts L1, L2 and L3's respective f floors and s states at that moment.
- (t, Lift Departure, Li, f), representing a lift departure event of lift Li occurred at time t from floor f.
- (t, Lift Stopped, Li), representing a lift stopped event of lift Li occurred at time t.
- (t, Enter Lift, Li, n), representing an enter lift event into lift Li arrived at ground floor occurred at time t with n passengers delayed.

5.1.5 Activities

Passenger Interarrival Time, Number of Passengers for each arrival, Number of Interval Passenger arrival, Lift Floors for each lift, Lift States for each lift, Delay Time for Departure (if all lift states are up during button pressed), Lift to be picked for next departure after delay, Number of Interval Passenger arrival in between the delay of departure, Number of Lift Stopped, Lift Stopping Time, Interval Time until Next Lift Trip occur after the "Enter Lift" event

5.1.6 Delay:

The time the first batch of passengers spent in waiting queue when the button is being pressed until the first batch of passengers enter the assigned lift which reached ground floor.

5.2 Data collection

A six hours of data collection was conducted at Block A of the Platinum Lake PV13 Condominium on 7/12/2017 from 3pm to 9pm. Data was recorded using an Android apps called "Event Logger" developed by ShaddowApps which allows the recorded data being output in csv format. Only the lift trips/fetching round to the ground floor are recorded and other unnecessary details are neglected. Information such as clock time, event types and details such as number of passengers arrived/delayed, lift states etc. were collected.

Table 1 Data Collected in Table Form (First 23 rows)

Clock Time	Event Types	Number of Passengers Arrived / Lift Floors and States	Lift Floors / Number of Passengers Delayed
0:00:00	Passenger Arrival	1	
0:00:00	Button Pressed	19U3U4U	
0:00:17	Lift Departure	L3	23
0:00:51	Passenger Arrival	2	
0:01:03	Lift Stopped	L3	19
0:01:43	Lift Stopped	L3	12
0:01:46	Passenger Arrival	1	
0:02:15	Passenger Arrival	1	
0:02:19	Lift Stopped	L3	11
0:02:35	Enter Lift	L3	0
0:11:37	Passenger Arrival	1	
0:11:37	Button Pressed	1D10I9I	
0:11:37	Lift Departure	L3	1
0:11:41	Enter Lift	L3	0
0:12:02	Passenger Arrival	2	
0:12:02	Button Pressed	17I22D16I	
0:12:02	Lift Departure	L2	22
0:12:51	Enter Lift	L2	0
0:13:01	Passenger Arrival	1	
0:13:01	Button Pressed	20I7I18D	
0:13:01	Lift Departure	L1	18
0:13:09	Lift Stopped	L1	15
0:13:36	Lift Stopped	L1	4

5.3 Input analysis and modelling

This is for us to generate the random variates that we need used in our simulation model based on the probability distribution of the collected data. These random variates will be serve as the input into our simulation system.

Types of Inputs for the simulated lift system:

- Passenger Interarrival Time
- Number of Passengers for each arrival
- Number of Interval Passenger arrival
- Lift Floors for each lift, Lift States for each lift
- Delay Time for Departure (if all lift states are up during button pressed)
- Lift to be picked for next departure after delay
- Number of Interval Passenger arrival in between the delay of departure
- Number of Lift Stopped
- Lift Stopping Time
- Interval Time until Next Lift Trip occur after the “Enter Lift” event

The input distributions for each input type:

Passenger Interarrival Time:

Interval	Frequency	Relative Frequency (PDF)	Cumulative Frequency (CDF)
1<=x<25	354	0.5380	0.5380
25<=x<50	173	0.2629	0.8009
50<=x<75	71	0.1079	0.9088
75<=x<100	33	0.0502	0.9590
100<=x<125	15	0.0228	0.9818
125<=x<150	5	0.0076	0.9894
150<=x<175	5	0.0076	0.9970
175<=x<=565	2	0.0030	1.0000

Number of Passengers for each arrival:

Interval	Frequency	Relative Frequency (PDF)	Cumulative Frequency (CDF)
1<=x<3	515	0.7827	0.7827
3<=x<6	117	0.1778	0.9605
6<=x<9	19	0.0289	0.9894
9<=x<=15	7	0.0106	1.0000

Number of Interval Passenger arrival:

Interval | Frequency | Relative Frequency (PDF) | Cumulative Frequency (CDF)

1<=x<2 | 1 | 83 | 0.4743 | 0.4743

2<=x<4 | 43 | 0.2457 | 0.7200

4<=x<6 | 18 | 0.1029 | 0.8229

6<=x<9 | 23 | 0.1314 | 0.9543

9<=x<=15 | 8 | 0.0457 | 1.0000

Lift Floors for each lift:

Interval | Frequency | Relative Frequency (PDF) | Cumulative Frequency (CDF)

1<=x<6 | 211 | 0.4019 | 0.4019

6<=x<12 | 104 | 0.1981 | 0.6000

12<=x<18 | 129 | 0.2457 | 0.8457

18<=x<=24 | 81 | 0.1543 | 1.0000

Lift States for each lift: (discrete)

x | Frequency | Relative Frequency (PDF) | Cumulative Frequency (CDF)

Up | 238 | 0.4533 | 0.4533

Down | 138 | 0.2629 | 0.7162

Idle | 124 | 0.2362 | 0.9524

Ground | 25 | 0.0476 | 1.0000

Delay Time for Departure (if all lift states are up during button pressed)

Interval | Frequency | Relative Frequency (PDF) | Cumulative Frequency (CDF)

1<=x<31 | 10 | 0.2381 | 0.2381

31<=x<62 | 11 | 0.2619 | 0.5000

62<=x<93 | 10 | 0.2381 | 0.7381

93<=x<124 | 3 | 0.0714 | 0.8095

124<=x<=155 | 8 | 0.1905 | 1.0000

Lift to be picked for next departure after delay

x | Frequency | Relative Frequency (PDF) | Cumulative Frequency (CDF)

L1 | 7 | 0.1667 | 0.1667

L2 | 14 | 0.3333 | 0.5000

L3	21	0.5000	1.0000

Number of Interval Passenger arrival in between the delay of departure

Interval	Frequency	Relative Frequency (PDF)	Cumulative Frequency (CDF)
0<=x<1	160	0.9143	0.9143
1<=x<2	7	0.0400	0.9543
2<=x<3	5	0.0286	0.9829
3<=x<12	3	0.0171	1.0000

Number of Lift Stopped

Interval	Frequency	Relative Frequency (PDF)	Cumulative Frequency (CDF)
1	29	0.3053	0.3053
2	20	0.2105	0.5158
3	19	0.2000	0.7158
4	12	0.1263	0.8421
5	6	0.0632	0.9053
6	3	0.0316	0.9368
7	4	0.0421	0.9789
8	2	0.0211	1.0000

Next Trip Interval Time

Interval	Frequency	Relative Frequency (PDF)	Cumulative Frequency (CDF)
1<=x<20	56	0.3200	0.3200
20<=x<40	59	0.3371	0.6571
40<=x<60	31	0.1771	0.8343
60<=x<80	14	0.0800	0.9143
80<=x<542	15	0.0857	1.0000

Choose the appropriate distribution for this simulation

Since there is only 6 hours of data being collected, it might be less representative of the actual system if we adopt the Maximum-Likelihood parameter estimation and then fit into the hypothesized distributions such as Exponential, Poisson etc. Hence, we decided to employ the empirical distributions

Uniformity and Independence Test

Kolmogorov-Smirnov Test and Chi-Square Test (600 random numbers with 10 intervals) were applied to ensure the uniformity of random numbers generated by the Linear Congruential Generator (LCG) used in this programmed model. The LCG applied in this programmed model was initialized with the following values (z0 = 7, a = 5, c = 3, m = 8192) to ensure full period and a large m is used to prevent repetitive pattern occurred before the simulation run is finished (m should be larger than the number of random numbers needed and a good choice m = 2^13 to ensure computational efficiency on binary-based computers). Test for Autocorrelation (i=3, l=5, N=30) was employed with significance level of 0.05 for the first 30 random numbers generated by LCG.

```
Is Full Period? true

Chi-Square Test
Interval|Oi|Ei|Oi-Ei|(Oi-Ei)^2|(Oi-Ei)^2/Ei

1|79|60|19.00|361.00|6.02
2|57|60|-3.00|9.00|0.15
3|65|60|5.00|25.00|0.42
4|55|60|-5.00|25.00|0.42
5|62|60|2.00|4.00|0.07
6|64|60|4.00|16.00|0.27
7|54|60|-6.00|36.00|0.60
8|48|60|-12.00|144.00|2.40
9|59|60|-1.00|1.00|0.02
10|57|60|-3.00|9.00|0.15
Sum|                               10.50

Is Uniform? true

Kolmogorov-Smirnov Test

D+ = 0.05
D- = 0.00

D  = 0.05

Critical Value  = 0.056

Since D<= crtical value, H0 accepted

Test for Autocorrelation

0.01025390625,0.0164794921875,0.02392578125,0.028564453125,0.0360107421875,0.0023
rho= -0.2495,sigma= 0.128,Z0= -1.9492
Since -1.96 <= Z0=-1.9492 <= 1.96, therefore the hypothesis of independence cannot be rejected.
```

Figure 5.3 The result of full period test, Chi-Square Test, Kolmogorov-Smirnov Test and Test for Autocorrelation

6 Computer simulation development

6.1 Usage of general purpose programming language

The programming language used to construct this simulation model is Java. The general programming language was used to build this project because of its flexibility in adjusting the model to fit our needs which is focused on the lift service to ground floor event only besides adhering to the rules set by tutor that simulation package was not allowed to be used in this project. In addition, since this is a non-profitable project which has not been sponsored by any party thus general programming language with no additional software cost is definitely more favorable compared to the simulation package software that incurred license fees. Moreover, since the team member of this project have the knowledge and experience in Java programming language development for around 2 years thus no additional training is required here while using simulation package will most probably impose a learning period.

6.2 Development Process

The development tool chosen for this simulation project is the NetBeans IDE 8.2. The whole development period takes around 2 weeks' time. First, the collected data recorded in modelling.csv file was first read into NetBeans java class by using opencsv library package and then several classes such as LiftState and Event were created based on the pattern of collected data. Then, a lift system simulation model was constructed first with java.util.Random class as input data. After ensuring the programmed model follows the behavior of the actual lift system, then 10 empirical distributions were drawn from the collected data and then a Linear Congruential Generator was used to input into these empirical distributions for getting the corresponding output random variates which are used to replace the java.util.Random as the random input into the simulation model.

6.3 Screenshot (output)

```
---1--------------------------------------------------
 Clock 0
(0, Passenger Arrival, 1)

---2--------------------------------------------------
 Clock 0
(0, Button Pressed, L1(1,U)L2(1,U)L3(7,U))

---3--------------------------------------------------
 Clock 94
(94, Passenger Arrival, 1)

---4--------------------------------------------------
 Clock 114
(114, Passenger Arrival, 1)

---5--------------------------------------------------
 Clock 114
(114, Lift Departure, L3 , 7)

---6--------------------------------------------------
 Clock 134
(134, Passenger Arrival, 1)

---7--------------------------------------------------
 Clock 135
(135, Passenger Arrival, 1)

---8--------------------------------------------------
 Clock 136
(136, Passenger Arrival, 1)

---9--------------------------------------------------
 Clock 137
(137, Passenger Arrival, 1)

---10--------------------------------------------------
 Clock 171
(171, Lift Stopped, L3)
```

```
---1415--------------------------------------------------
 Clock 21519
(21519, Passenger Arrival, 1)

---1416--------------------------------------------------
 Clock 21520
(21520, Passenger Arrival, 1)

---1417--------------------------------------------------
 Clock 21540
(21540, Passenger Arrival, 1)

---1418--------------------------------------------------
 Clock 21541
(21541, Passenger Arrival, 1)

---1419--------------------------------------------------
 Clock 21558
(21558, Lift Stopped, L1)

---1420--------------------------------------------------
 Clock 21575
(21575, Lift Stopped, L1)

---1421--------------------------------------------------
 Clock 21592
(21592, Lift Stopped, L1)

---1422--------------------------------------------------
 Clock 21609
(21609, Lift Stopped, L1)

---1423--------------------------------------------------
 Clock 21665
(21665, Enter Lift, L1,0)
```

...... to be continued

Figure 6.3.1 The lift system event simulation flow illustration

Figure 6.3.1 demonstrate the flow of the lift system events in a next-event time-advance mechanism.

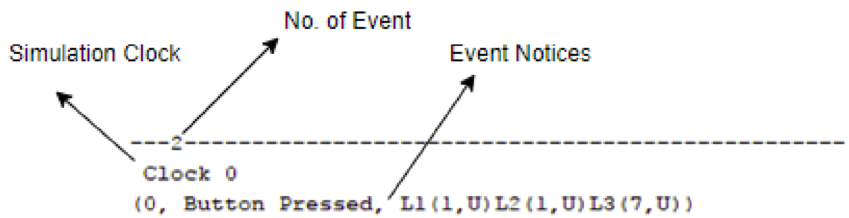


Figure 6.3.2 The lift system event simulation explanations

lift system event simulation explanations

Clock(seconds)	Number of Passengers Arrived	Button Pressed Time	Enter Lift Time	Waiting Time	Number of Passengrs Delayed
0	7	0	233	233	0
293	1	293	300	7	0
380	1	380	487	107	0
547	3	547	575	28	0
615	1	615	615	0	0
675	1	675	675	0	0
676	8	676	723	47	0
724	1	724	786	62	0
787	1	787	794	7	0
795	3	795	842	47	0
843	3	843	891	48	0
911	6	911	1001	90	0
1041	3	1041	1050	9	0
1070	3	1070	1079	9	0
1139	3	1139	1327	188	0
1367	14	1367	1674	307	1
1694	1	1694	1701	7	0
1702	11	1702	1819	117	0
1859	1	1859	1938	79	0
1939	1	1939	2086	147	0
2126	25	2126	2237	111	12
2257	5	2257	2345	88	0
2425	0	2425	2484	59	0
2504	1	2504	2549	45	0
2550	1	2550	2557	7	0
2597	1	2597	2604	7	0
2684	6	2684	2684	0	0
2685	1	2685	2685	0	0
2686	1	2686	2693	7	0
2686	0	2686	2834	148	0
2874	1	2874	2881	7	0
2941	1	2941	2941	0	0
2942	3	2942	2989	47	0
2990	1	2990	2997	7	0
3017	3	3017	3146	129	0
3147	1	3147	3271	124	0

…… to be continued

18166	8	18166	18254	88	0
18294	1	18294	18301	7	0
18302	1	18302	18361	59	0
18401	19	18401	18495	94	6
18515	1	18515	18515	0	0
18516	6	18516	18523	7	0
18516	0	18516	18530	14	0
18550	1	18550	18557	7	0
18577	5	18577	18664	87	0
18665	8	18665	18753	88	0
18793	1	18793	18800	7	0
18801	3	18801	18927	126	0
18947	7	18947	19037	90	0
19057	3	19057	19085	28	0
19145	1	19145	19252	107	0
19253	1	19253	19253	0	0
19293	8	19293	19302	9	0
19322	1	19322	19329	7	0
19330	21	19330	19546	216	8
19566	17	19566	19700	134	4
19720	3	19720	19788	68	0
19808	1	19808	19808	0	0
19809	1	19809	19855	46	0
19809	0	19809	19862	53	0
19863	1	19863	19942	79	0
19962	24	19962	20215	253	11
20235	3	20235	20365	130	0
20366	1	20366	20446	80	0
20466	1	20466	20590	124	0
20610	8	20610	20688	78	0
20728	4	20728	20904	176	0
20924	1	20924	20969	45	0
21009	1	21009	21016	7	0
21036	14	21036	21259	223	1
21299	8	21299	21449	150	0
21450	3	21450	21459	9	0
21479	5	21479	21665	186	0

Figure 6.3.3 The lift system event simulation table

6.4 Validation and Verification of simulation model

For this lift system simulation model, the techniques that can be adopted for increasing model validity includes collecting high-quality and useful information and data during the data collection stage based the specific area focused in this study ignoring irrelevant and uncontrollable details. Besides that, regular interaction with the tutor can also be conducted since tutor's knowledge of the system and modelling can greatly contributes the model validity. Furthermore, the sensitivity analysis can be applied in terms of choosing the suitable intervals of empirical distributions, the level of detail for a subsystem etc. Finally, the comparison in terms of performance measure will be made with the existing system based on the collected data and hence ensure the gap between the programmed model and existing system can be as close as possible.

```
Total Number of Lift Trips:           208
Total Number of Passengers:          3368
Total Waiting Time:                  17411 seconds
Total Numper of Passenger Delayed:   170
Total Interrarrival:                6424355 seconds
Total Number of Interrarrival:                   597


Average waiting time for a lift trip                    83.707 seconds

Probability that a round of passenger delayed   0.111

Probability that a passenger delayed for the next lift   0.050

Average time between arrival and expected time arrival  1907.469 seconds

Average waiting time for the passenger who waits          15.714 seconds
```

Figure 6.4.1 The lift system simulation model performance measures

```
Total Number of Lift Trips:           174
Total Number of Passengers:          4677
Total Waiting Time:                  14374 seconds
Total Numper of Passenger Delayed:   194
Total Interrarrival:                7703163 seconds
Total Number of Interrarrival:                   658


Average waiting time for a lift trip                    82.609 seconds

Probability that a round of passenger delayed   0.218

Probability that a passenger delayed for the next lift trip   0.041

Average time between arrival  1647.031 seconds

Average waiting time for the passenger who waits          11.601 seconds
```

Figure 6.4.2 The existing lift system model (collected data) performance measures

7 Output analysis and Proposed solution

The estimates and output results in a simulation model are generated from the input of random variables which may result in a large variance since these random variables are samples drawn from the probability distributions. Erroneous inferences about the system under study might occurred if the output results of the simulation model differ greatly for different replications. In most of the cases, one run clearly does not produce the desired estimates thus the model need to be put into production runs for multiple times and then perform proper output data analysis.

7.1 System performance measure

The performance of this lift simulation model was measures in terms of the average waiting time for a lift trip, probability that a lift trip/fetching round has passengers delayed, and average waiting time for the passenger who waits (if the lift is not initially at G floor).

7.2 Type of Simulation based on output analysis

This is a terminating simulation since the system starts at clock time 0 seconds and end at clock time 21600 seconds. The stopping condition is when the system clock time exceeds or equal to 21600 seconds.

7.3 Statistical analysis and outputs

Point estimates for number of lift trips, number of passengers, total waiting time, number of passengers delayed and passenger interarrival time was calculated based on confidence level of 0.95 and 10 simulation runs. The calculation results are as the following Figure 7.3.

This result indicates that at the confidence level of 0.95, the point estimate for average waiting time for a lift trips is 86.895 seconds with an error range of ±2.591, the point estimate for probability that a round of passengers delayed is 0.106 with an error range of ±0.008, the point estimate for the probability that a passenger is delayed for the next lift trip is 0.047 with an error range of ±0.002, the point estimate for average time between passenger arrival is 18 64.639 seconds with an error range of ±53.072, the point estimate for average waiting time for the passenger who waits is 16.930 seconds with an error range of ±0.725.

```
****1
Confidence Level: 0.95 Number of Runs: 10

Average Waiting Time for a lift trip
85.009,81.577,94.173,88.319,84.288,92.338,88.893,80.995,89.65,83.707,
Mean: 86.895, Variance: 19.979250111111114
Point Estimate: 86.895+-2.591

Probability that a round of passenger delayed
0.084,0.096,0.136,0.097,0.102,0.116,0.112,0.095,0.108,0.111,
Mean: 0.106, Variance: 2.0744444444444448E-4
Point Estimate: 0.106+-0.008

Probability that a passenger delayed for the next lift trip
0.042,0.048,0.048,0.045,0.053,0.044,0.052,0.045,0.046,0.05,
Mean: 0.047, Variance: 1.2777777777777774E-5
Point Estimate: 0.047+-0.002

Average time between arrival
1926.386,2031.409,1692.717,1807.007,1804.905,1906.52,1818.119,1849.78,1902.081,1907.469,
Mean: 1864.639, Variance: 8382.991986555555
Point Estimate: 1864.639+-53.072

Average waiting time for the passenger who waits
18.911,15.903,16.146,18.191,15.896,17.82,16.037,16.245,18.439,15.714,
Mean: 16.93, Variance: 1.5630593333333331
Point Estimate: 16.93+-0.725
```

Figure 7.3 Results of point estimates with confidence intervals

7.4 Proposed solution

The first proposed solution would be changing the elevator system's decision-making mechanism to focus on passenger experience by assigning task to move to ground floor to any other lift which is idle and nearer to the ground floor if there is any instead of the currently moving downward one.

The second proposed solution is increase the lift capacity up to 20 persons compared to the existing capacity of 13 persons.

The third proposed solution is to increase the speed of moving elevator up to 1.4 times of current speed.

Comparison between the proposed solution and current system in terms output.

First solution's output (Changing the lift system decision-making mechanism):

```
****1
Confidence Level: 0.95 Number of Runs: 10

Average Waiting Time for a lift trip
87.106,78.944,73.756,84.084,68.547,84.461,78.414,70.819,84.476,75.036,
Mean: 78.564, Variance: 41.02426433333332
Point Estimate: 78.564+-3.713

Probability that a round of passenger delayed
0.121,0.155,0.093,0.143,0.119,0.123,0.13,0.115,0.131,0.132,
Mean: 0.126, Variance: 2.7777777777777767E-4
Point Estimate: 0.126+-0.01

Probability that a passenger delayed for the next lift trip
0.036,0.048,0.037,0.04,0.044,0.039,0.039,0.046,0.038,0.045,
Mean: 0.041, Variance: 1.7555555555555556E-5
Point Estimate: 0.041+-0.002

Average time between arrival
1670.558,1743.043,1910.572,1752.293,1865.604,1649.528,1873.863,1824.805,1666.105,1860.976,
Mean: 1781.735, Variance: 9536.43626677778
Point Estimate: 1781.735+-56.605

Average waiting time for the passenger who waits
15.116,12.846,13.692,13.945,12.482,14.443,14.073,12.125,14.453,13.52,
Mean: 13.67, Variance: 0.8933218888888889
Point Estimate: 13.67+-0.548
```

Figure 7.4.1 Output Result of First Proposed Solution

Based on the output analysis result, the point estimate of average waiting time for a lift trip has been reduced from 86.895±2.591 to 78.564±3.713 and the point estimate of average waiting for the passengers who waits has also been reduced from 16.930±0.725 to 13.670±0.548. Both indicate that assigning task to move to ground floor to any other lift which is idle and nearer to the ground floor if there is any instead of the currently moving downward one did helped to reduce the passenger waiting time either in terms of one complete lift trip cycle or individual passenger. On the other hand, we did notice the increase in point estimate of the probability that a round of passenger delayed from 0.106±0.008 to 0.126±0.01 based on the output results but the reason behind is still not yet been identified.

Second solution's output (Increase the lift capacity up to 20):

```
Confidence Level: 0.95 Number of Runs: 10

Average Waiting Time for a lift trip
85.009,81.577,94.173,88.319,84.288,92.338,88.893,80.995,89.65,83.707,
Mean: 86.895, Variance: 19.979250111111114
Point Estimate: 86.895+-2.591

Probability that a round of passenger delayed
0.028,0.048,0.052,0.039,0.054,0.04,0.056,0.043,0.039,0.053,
Mean: 0.045, Variance: 7.933333333333333E-5
Point Estimate: 0.045+-0.005

Probability that a passenger delayed for the next lift trip
0.011,0.016,0.015,0.012,0.02,0.013,0.018,0.014,0.014,0.016,
Mean: 0.015, Variance: 7.444444444444445E-6
Point Estimate: 0.015+-0.002

Average time between arrival
1926.386,2031.409,1692.717,1807.007,1804.905,1906.52,1818.119,1849.78,1902.081,1907.469,
Mean: 1864.639, Variance: 8382.991986555555
Point Estimate: 1864.639+-53.072

Average waiting time for the passenger who waits
18.911,15.903,16.146,18.191,15.896,17.82,16.037,16.245,18.439,15.714,
Mean: 16.93, Variance: 1.5630593333333331
Point Estimate: 16.93+-0.725
```

Figure 7.4.2 Output Result of Second Proposed Solution

Based on the output analysis result, the point estimate of probability that a round of passenger delayed has been reduced from 0.106±0.008 to 0.045±0.005 and the point estimate of the probability that a passenger delayed for the next lift trip has also been reduced from 0.047±0.002 to 0.015±0.002. Both indicate that increasing the lift capacity up to 20 persons from originally 13 persons did helped to reduce the occurrence of a fully loaded lift that caused some of passengers delayed and the probability that an individual passenger will be delayed. On the other hand, average waiting time either for a lift trip or for individual passenger were not affected by this solution.

Third solution's output (Increase the speed of lift up to 1.4 times):

```
Average Waiting Time for a lift trip
82.912,79.161,79.656,81.188,78.042,87.883,81.452,79.567,81.137,79.579,
Mean: 81.058, Variance: 7.696367666666662
Point Estimate: 81.058+-1.608

Probability that a round of passenger delayed
0.12,0.106,0.118,0.092,0.106,0.138,0.09,0.106,0.11,0.106,
Mean: 0.109, Variance: 1.9222222222222232E-4
Point Estimate: 0.109+-0.008

Probability that a passenger delayed for the next lift trip
0.045,0.049,0.051,0.04,0.049,0.049,0.043,0.053,0.047,0.049,
Mean: 0.047, Variance: 1.5222222222222224E-5
Point Estimate: 0.047+-0.002

Average time between arrival
1916.288,1885.984,1642.322,1905.988,1929.141,1635.453,1882.842,1781.051,1912.831,1923.843,
Mean: 1841.574, Variance: 13196.73652100001
Point Estimate: 1841.574+-66.588

Average waiting time for the passenger who waits
16.238,14.707,14.684,17.611,15.118,14.487,17.209,14.57,16.669,15.065,
Mean: 15.636, Variance: 1.402746
Point Estimate: 15.636+-0.687
```

Figure 7.4.3 Output Result of Third Proposed Solution

Based on the output analysis result, the point estimate of average waiting time for a lift trip has been reduced from 86.895±2.591 to 81.058±1.608 and the point estimate of average waiting for the passengers who waits has also been slightly reduced from 16.930±0.725 to 15.636±0.687. Both indicate that to increase the speed of moving elevator up to 1.4 times of the current speed did helped to reduce the passenger waiting time either in terms of one complete lift trip cycle or individual passenger, but it is not as effective as the first solution. On the other hand, we did again notice the increase in point estimate of the probability that a round of passenger delayed from 0.106±0.008 to 0.109±0.008 but it not as significant as the first solution. Thus, we made a hypothesis that there exists a relationship such that the decrease in waiting time will cause the increase in the occurrence of passenger delayed but not vice versa since solution 2 does not affect the resulting waiting time. The existence of such relationship might largely because of the nature of the data that we have collected but further studies is definitely needed here.

8 Conclusion and Future Work

8.1 Conclusion

In this PV13 lift system simulation project, we have proposed three different solutions for solving two current problems that we have found with the existing system which are the long waiting time of the passengers when waiting for the lift service at ground floor and the frequent occurrence of a fully loaded lift that caused some of passengers delayed for another round of fetching service. The three solutions being proposed include changing the elevator system's decision-making mechanism, increase the lift capacity up to 20 persons and increase the speed of moving elevator up to 1.4 times of current speed. In order to measure the effectiveness of these solutions, relevant data was collected at Block A of the Platinum Lake PV13 Condominium on 7/12/2017 from 3pm to 9pm and then a lift system simulation model specifically focused on the lift trip to ground floor service was constructed. Then a series of steps such as constructing a linear congruential random number generator, generating input distributions from collected data, and output analysis of 10 runs of the simulation model with confidence level of 0.95 were done. Finally, the statistical output result was analysed using point estimators. From the results, we have found out that both changing the elevator system's decision-making mechanism and increase the speed of moving elevator can reduce the passenger waiting time and the former is a more effective approach. However, it is being discovered that both solutions will cause an increase in the occurrence of passenger delayed and it is assumed that the nature of the collected data is the suspected culprit. Nonetheless, the second solution which is increase the lift capacity up to 20 persons from 13 persons did effectively reduce the occurrence of a fully loaded lift that caused some of passengers delayed without affecting other aspect of the system such as waiting time.

8.2 Future work

Approaching the end of this project, there are several limitations have been found out in the current study. First, we are able to find out how effective is the proposed solution in solving the identified problem but other aspects of the solution such as its negative effects on other system states, cost of implementing such solution etc, has not yet been determined in this project. Second, only 6 hours of data collection within one day is insufficient for this lift system model as there are at least 10 input distributions needed to be fed into this simulation model. Additionally, due to the lack of more effective and advance data collection methods, the lift states of all the current lifts cannot be tracked continuously throughout the data collection period thus causing the loss of information (lack of continuity) between the end and start of each lift trip cycles. All these limitations are expected to be addressed in the future work.

References

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