Scheduling of Maglev Elevators

SIMULATING MULTIPLE ELEVATOR CARS IN A TWO SHAFT SYSTEM

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Simulating multiple elevator cars in a two shaft system

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Elevator systems have been quite similar for more than a hundred years and it has only quite recently become more feasible to have elevators being able to switch shafts allowing the construction of a system with more than two elevator cars in a single shaft. Such a system is to be constructed and tested during 2016 and functions using magnetic levitation technology. This new system calls for new algorithms to schedule the assignment of the passengers’ calls.

Different strategies based on the collective control algorithm were developed to schedule the maglev system. The strategies were tested in a simulation of a twenty-five floor building and compared to a traditional system of one elevator car per shaft using the collective control scheduling strategy. The results show that in two out of the three scenarios simulated the maglev system performs better than the traditional system when average waiting time and average traveling time are compared. The traditional system beats the maglev system by a lot under the interfloor traffic scenario and adding more elevator cars improved the maglev systems performance but not enough to be as good as the tradition system.

The conclusions drawn are that it is hard to schedule the maglev system to spread the cars out. It is also clear that the maglev system requires more elevator cars or improved scheduling to perform as well as the traditional system during the interfloor traffic scenario but is performing equally well or better during the up and down-peak scenarios. Further simulations are required to confirm these conclusions as the schedulers used are quite simple.
Sammanfattning

Hissystem har sett väldigt lika ut i över hundra år och det har först nyligen blivit mer rimligt att konstruera hissystem där hissvagnar kan byta schakt och tillåter att det finns flera hissvagnar i samma schakt. Ett sådant system kommer att testas under 2016 och fungerar genom användning av magnetiskt levitation. Detta nya system kräver att nya algoritmer utvecklas för att schemalägga vart hissvagnarna ska åka.

Olika strategier baserade på Collective control strategin utvecklades för att schemalägga maglev systemet. Strategierna testades i en simulering av en kontorsbyggnad med tjugofem våningar och jämfördes med ett traditionellt system med en hissvagn per schakt där schemaläggaren Collective control användes. Resultaten visar att i två av de tre scenarierna presterar maglev systemet bättre än det traditionella systemet när man jämför medelväntiden och medelresetiden. Det traditionella systemet är mycket bättre än maglev systemet i interfloor scenariot och att lägga till fler hissvagnar förbättrar maglev systemets prestation men inte tillräckligt för att vara lika bra som det traditionella systemet.

De slutsatser som kan dras är att det är svårt att schemalägga maglev systemet för att sprida ut hissvagnarna jämt i byggnaden. Det är också tydligt att maglev system behöver fler hissvagnar eller en förbättrad schemaläggare för att prestera lika bra som det traditionella systemet i interfloor scenariot, men där maglev presterar lika bra eller bättre i de två andra scenarierna. För att bekräfta dessa slutsatser krävs det fler simuleringar med mer avancerade schemaläggare då de som används är rätt simpla.
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1. Introduction

Elevators have been used in buildings to transport people and goods since the second half of the nineteenth century and are a common sight in multistory buildings today. The usage of elevators makes all floors of a building easily accessible which has allowed the construction of higher buildings. Technical improvements have further increased this effect, but with bigger buildings more space for elevators is required to serve the increased number of people needing go up and down the building.

To increase the capacity of groups of elevators different scheduling algorithms have been developed. These strategies aimed for increasing the elevator systems capacity while not increasing the need for space. Further development has focused on finding new systems that improve capacity while needing less space than a traditional one elevator car per shaft system with the same capacity.

In 2014 the elevator company Thyssenkrupp announced that they have developed a new type of elevator that is not rope dependent. This elevator system is supposed to be based on magnetic levitation technology and be able to not only move cars up and down in a shaft but also sideways between different shafts (Thyssenkrupp, 2014). This introduces a new factor to the scheduling of the elevator cars and requires new scheduling algorithms to be developed to control them.

1.1 Problem statement

The old scheduling algorithms cannot be used directly to control the maglev elevator system efficiently; therefore simple algorithms which control this type elevator system will be implemented. Comparisons between these algorithms and a traditional one elevator car per shaft system will be made using the criteria average waiting-time and total travel time to see how well they perform.
To limit the studies the scheduling algorithms will be used to schedule a simulated elevator system in an office building with twenty-five floors. Furthermore the elevator cars in the system will be limited to only have room for ten passengers.

### 1.2 Hypothesis

The expected result is that maglev elevator will have a similar average waiting and total traveling time as a traditional system with an equal number of elevator cars.

### 1.3 Terminology

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>Up-peak</td>
<td>Incoming rush of people, entering the lobby to go to upper floors.</td>
</tr>
<tr>
<td>Down-peak</td>
<td>Outgoing rush of people, leaving upper floors to go to the lobby.</td>
</tr>
<tr>
<td>Interfloor traffic</td>
<td>Traffic between different floors of a building.</td>
</tr>
<tr>
<td>Outgoing traffic</td>
<td>Traffic from the upper floors to the lobby.</td>
</tr>
<tr>
<td>Incoming traffic</td>
<td>Traffic from the lobby to the upper floors.</td>
</tr>
<tr>
<td>Elevator car</td>
<td>The cage that is moving up and down in the shafts.</td>
</tr>
<tr>
<td>Waiting time</td>
<td>The time before an elevator car that a passenger can enter arrives.</td>
</tr>
<tr>
<td>Travel time</td>
<td>The total time a passenger spends from arriving at the elevators and arriving at their destination floor.</td>
</tr>
<tr>
<td>Traditional system</td>
<td>An elevator system where there is only one car in each shaft and they cannot change shaft.</td>
</tr>
<tr>
<td>Maglev System</td>
<td>An elevator system where multiple elevator cars can be in a single shaft and they can change shaft.</td>
</tr>
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### 2. Background

The first section of the background introduces different types of elevator systems starting with the traditional one leading up to systems which uses more than one car per shaft. The following section will introduce some of the algorithms used for scheduling elevators and
group control. In the last section some of the important aspects of elevator traffic are introduced.

2.1 Elevator variants

Figure 2.1 shows two different elevator systems. A traditional system is illustrated on the left and one example of an multiple elevator cars per shaft system on the right. In the traditional system the elevator cars are always bound to the shaft they are in while this is not always true for the multiple elevator cars per shaft systems. The following sections introduce different elevator systems in more detail.

![Elevator systems](image)

*Figure 2.1 Elevator systems. The left system is a traditional system and the other is a multiple elevator cars per shaft system with shafts designated for up and down traffic.*
2.1.1 One per shaft

Electric elevator have existed since 1889 (Strakosch, G. and Caporale, R. 2010, p.4) where the common design found everywhere have been of the type of one elevator car per shaft. Systems that are commonly seen is the one button or an up and down button design. To increase capacity in systems where more than one elevator shaft is used, different group control algorithms are used to maximize efficiency (Strakosch, G. and Caporale, R. 2010, p.164).

2.1.2 Two per shaft

Bigger buildings requires several elevator shafts, the more stories the more elevator space is required, which makes building huge buildings unfeasible due to a disproportionate amount of elevator space requirement (Barker, 1997, p.61-63). Nowadays there are are variants where there are two elevator cars in the same elevator shaft. Two elevators in the same shaft introduce problems such as a single elevator not being able to reach every floor. To solve this elevator shafts with two elevators are used in groups together with the traditional system of one elevator car per shaft (Strakosch and Caporale, 2010, p.177). This design is used to increase capacity where there are existing shafts. One example where it is used is a hospital in South Korea where three normal elevators shafts were replaced by two of Thyssenkrupps Twin elevator and one normal elevator. This system uses a destination based system which altogether is used to increase the capacity of the system. (Thyssenkrupp, 2010).

2.1.3 More than two per shaft

An early design of a system which allows for more than two elevator cars per shaft is the Odyssey system by Otis. This system would have worked by allowing the elevator car to move off the platform that is used to lift them. By allowing the car to move this way, the cars would be able to switch shafts and use dedicated loading stations. This result in there being at most one elevator in a shaft at a given time, but in total the system could have more than one elevator per shaft. (Barker, 1997, pp. 55-58).

The idea of being able to have more than two elevators per shaft is now becoming more feasible and the company Thyssenkrupp is developing a new elevator called Multi. Multi will use magnetic levitation to allow multiple elevators per shaft. Elevator movement between
different shafts and as well as sideways shafts will be possible and testing is set to begin during 2016 (Thyssenkrupp, 2014).

2.2. Elevator scheduling strategies

A number of strategies have been developed to come up with a good solution to the problem of which car should respond to which request. Some of these strategies are simple as the collective control while others are more complex and involve evolving algorithms or more detailed information such as knowing the destination of the passenger before entering the elevator. In the following sections a number of these strategies will be presented.

2.2.1. Collective control

Collective control is one of the simpler scheduling algorithms used and is applicable in elevator systems that have only one call button on each floor and in systems that have a designated button for each direction. In a one button system the first elevator to pass the floor will stop and answer the call, whereas in a two button system the closest car heading in the same direction as the passenger responds to the call. If a passenger wants to go down the closest car that is heading down and is currently above the floor of the passenger is picked to answer the call. As soon as a car has stopped on the floor to respond to the call the call signal is reset so no other car stops on the floor until it has passengers heading there or another call is made (Siikonen, 1993).

The strategy can be modified to make empty cars stop at designated floors when there are no passengers. Depending on what type of traffic is expected these floors could vary being the bottom floor when people are expected to enter the building and evenly spread across the upper floors when people are expected to leave the building. This will decrease the waiting time when traffic levels increase from lower to higher levels.

2.2.2. Destination based strategies

To schedule elevators there are more advanced algorithms, such as destination based systems. The system is based on the user selecting which floor he wants to go to before entering the elevator, instead of doing it after entering an elevator heading the right direction. This allows
scheduling the elevators in a way so they make fewer and closer stops, resulting in an increased capacity of the system. (Strakosch and Caporale, 2010, p.172-174). The use of a destination based system is also what allows systems that include the Twin elevator from Thyssenkrupp to work so that a user cannot mistakenly choose an elevator that is unable to reach his or her desired floor (Thyssenkrupp, 2010).

2.3 Five minute up-peak

In an office building the time where the elevator system is put under the most pressure is referred to as the five minute up-peak, this is when most people start working and all need to head from the lobby to their respective floor. During this time the amount of down traffic is around ten percent of the total traffic. The up-peak is bigger than the down-peak that happens in the afternoon due to quitting times usually being more spread out and elevator efficiency getting an increase due to people being more willing to squeeze together in an elevator wanting to get home as early as possible. Planning the capacity of the elevator system according to the five minute up-peak should result in sufficient capacity throughout the rest of the day (Strakosch and Caporale, 2010, p.31, 71, 265).

3. Method

In this project an elevator simulator has been implemented to gather data on the waiting and traveling time of passengers in a twenty-five story office building. The data has been collected from simulations of two different types of elevator systems, the traditional system and the maglev system. Each system has been simulated using its own scheduling algorithm to serve the passengers. To schedule the traditional system the collective control algorithm was chosen because it is easy to implement and is commonly used in smaller systems. It was also considered to be a good comparison algorithm due to it being a base for the scheduling algorithms developed.
3.1 Simulator

The simulator consists of a passengerspawner, a scheduler, an elevator controller, twenty-five floors and a number of shafts and elevator cars. The simulations were run with systems containing four, six and eight elevator cars. The traditional system was simulated with one shaft per elevator car and the maglev system with all of the elevators cars spread out in two shafts. The simulator was written in Java, because of it being a language known by both authors.

3.1.1 Simulating a tick

In the simulation time is represented as ticks. A tick is a discrete unit of time and corresponds to approximately three seconds. During each tick three events occur. The first event is the chance of a new passenger appearing on a floor. If a new passenger appears he or she makes the desired up or down call by pushing one of the two buttons on the floor.

The second event is when a scheduler handles all the calls for elevators from the different floors and assigns them to the elevator cars in the system. The assignment of the calls are reevaluated each tick and each call is assigned to the elevator car that the scheduler see as the best option according to its strategy.

In the final event all elevator cars execute their current action. If the action is completed during the tick a new one is assigned to be executed in the next tick.

3.1.2 The elevator car

The actions an elevator car can perform are moving to a different floor or shaft, opening or closing its doors, dropping off or picking up passengers and idling. As mentioned in the last section every elevator car performs an action during each tick and if it is completed a new one is assigned for the next tick. The elevator cars next action depends on the previously completed action and the state of the elevator car. This makes it impossible to for example drop off any passengers before opening the doors.
Each elevator car has two queues for calls. The first queue contains the calls of the passengers inside the elevator car and is updated when they enter the elevator car. The second queue contains all calls assigned to the elevator car by the scheduler. When the elevator car answers a call it finds the closest call in the same direction in either queue and moves one floor towards it. The elevator car proceeds to do this until it has reached the target floor or until there is no destination in the current direction. If there is no destination in the current direction and there are in the other the elevator car switches direction, otherwise it idles until it is given a call to handle.

When an elevator car arrives at its current destination floor it opens its doors to allow passengers to move on and off. Passengers inside the elevator car are allowed to exit before any new passengers are allowed to enter, limiting the movement to a single direction and a maximum of three passengers during each tick. The elevator car remains stationary as long as passengers move or until it is full. It then closes its doors and tries to answer the closest call as described above.

### 3.2 Scenarios

Three different scenarios were simulated. These are the up-peak, the down-peak and the interfloor scenarios. The difference between the three scenarios is the passenger flow. In the up-peak the passengers have a 90 percent chance of spawning at the ground floor and going to any other floor. The opposite scenario of the up-peak is the down-peak where there is a 90 percent chance for their destination to be the ground floor. For both of these the other 10 percent are interfloor traffic, which is traffic that can start and end on any floor. The interfloor scenario consists of only this type of traffic.

### 3.3 Control strategies

Different control strategies are used to assign the floor calls to the elevator cars. The traditional system simulation was run with one strategy while the simulation with the maglev system was run with four different strategies. The following sections cover each of the strategies used in the simulations.
3.3.1 Scheduling of the traditional system

In the traditional system simulation a modified version of the collective control strategy was used. The strategy searches for two elevator cars. The first one is the closest elevator car which is going in the same direction as the passenger wishes to travel. The elevator car has to be on a floor below the passenger if the up-button is pressed or on a floor above the passenger if the down-button is pressed for it to be a valid option. The second elevator car is the idle elevator car closest to the floor of the call. The scheduler then chooses the elevator car that is the closer of the two if both are found. In the case that only one of the two is found it is selected and if none is found the scheduler will wait for the next tick to retry the assignment of the call.

Example on how the strategy works:

1. A passenger presses the up-button on the 10th floor.
2. The scheduler searches for a matching elevator car to add the call for the 10th floor. It finds an elevator car at the 8th floor going up and assigns the call to it.
3. The elevator car moves up two floors, this takes a total of two ticks.
4. The elevator car opens the door, this takes one tick.
5. The elevator car checks if someone wants to leave it, waiting one tick for something to happen.
6. The elevator car then checks if someone wants to enter and our waiting passenger is picked up. The passenger presses the button for the 15th floor inside the elevator, and the call is added to the list of internal destinations. This takes one tick.
7. Since there are no more passengers on the floor heading up the elevator cars doors closes and the up-button on the floor is reset. This takes one tick.
8. The elevator car moves up five floors to the closest floor in the call queues, taking a total of five ticks.
9. The elevator cars doors open. This takes one tick.
10. The passenger leaves the elevator car and the passenger’s statistics are added to the log.
3.3.2 Scheduling the maglev system

For the maglev system simulation several control strategies were tested. All the strategies tested had two things in common. The first is that one shaft was designated for elevator cars moving upwards and the other for elevator cars moving downwards. Secondly all the strategies had the limitation that the elevator cars could only switch shafts at the top and bottom floor of the building.

The first strategy was an adaption of the collective control strategy to the new elevator system. The difference compared to the normal collective control strategy in the traditional system simulation was the added call for the top or bottom floor depending on if the elevator car was in the down or up shaft. This was added to keep the elevator cars moving as they cannot pass each other and would block each other if they started idling.

The second strategy expanded on the first and tries to spread out the calls evenly among the elevator cars. The strategy will first try to assign a call to an elevator car already having a call to that floor that is closer than seven floors from it. If no elevator car has a call to the floor the car with the fewest calls and closer than seven floors is assigned to it and lastly the elevator car closest to the floor will be assigned.

The third iteration of the strategy goes one step further and checks if there is an uneven spread of elevator cars in the two shafts. When an uneven spread is detected the first elevator car in the shaft with the most elevator cars does not get assigned any external calls until it has switched shaft. Further a fourth iteration of the strategy added the condition that more external calls could only be added to the elevator car if it was less than half-full.

4. Results

In this section results are displayed as a comparison between the average waiting and traveling time. The times are displayed in the discrete time unit used for the simulation where one tick is three seconds. Each simulation of a scenario was run with the same randomly generated passengers placements and destinations for each of the scheduling algorithms. The
The simulation was repeated 100 times with new randomly generated passenger placements and destinations for each scenario. The raw data from the simulations are included in the appendix.

In the graphs in the following sections the number corresponds as following. Number one is the scheduler of the traditional system. Two to five are the different schedulers used for the maglev system, where number two is the adapted collective control strategy, three is the evenly distributed calls strategy, four is the evenly spread out cars between the shafts strategy and five is the no external calls if half full strategy.

4.1. Waiting time

The average waiting time for each scheduling algorithm in the different scenarios is shown in figure 4.1 and figure 4.2. As it can be seen in the figures the collective control strategy (1) results in very long waiting times during the up-peak both when run with six and eight elevator cars while the maglev strategies manages the load equally well with low waiting times in both cases. Adding more elevator cars lowers the waiting time in the up-peak for all strategies and for the maglev strategies the improvement is 33-50%.

![Average wait time 6 elevators](image)

*Figure 4.1. Shows average wait time for a system with six elevator cars and the five different scheduling algorithms.*
Figure 4.2 Shows average wait time for a system with eight elevator cars and the five different scheduling algorithms.

During the down-peak the waiting time is the lowest for the passengers in the simulations where strategy four and five are used. These two are the strategies where elevator cars are evenly distributed between the shafts. The best maglev strategy has a waiting time that is half the one of the traditional systems in the six elevator car simulation and a bit better when two more cars are added.

Looking to the interfloor scenario the traditional system outperforms the maglev system considerably. In the six elevator car simulation the average waiting time for the traditional system is less than a quarter of the best maglev scheduling strategy and in the eight elevator car simulation the average waiting time for the traditional system is only a fifth of the best maglev scheduling strategy.

4.2. Total travel time

The average traveling time for each scheduling algorithm in the different scenarios is shown in figure 4.3 and figure 4.4. In the results the traditional system, with collective control performs the worst during the up-peak, but the best during interfloor and in the middle when dealing with the down-peak.
Figure 4.3. Shows the average total time for a system with six elevator cars and the five different scheduling algorithms.

Figure 4.4. Shows the average total time for a system with eight elevator cars and the five different scheduling algorithms.

All the maglev strategies have similar average traveling times during the up-peak with both six and eight elevator cars. The traveling time is considerably better than the traditional system. The average total time is about one quarter of the traditional systems in both cases.
Out of the four maglev scheduling strategies the fourth and fifth performs the best in the down-peak. Both strategies have better average total time than the traditional system. The fourth strategy was the best when six elevator cars were simulated and the fifth when the number of elevator cars was eight.

In the interfloor simulation the best performing maglev strategy was the fifth. Despite being the best it has more than double the average total time compared to the traditional system using six elevator cars. When two more elevator cars are added it performs better but it is still not as good as the traditional system.

5. Discussion

We expected that the maglev system would be as effective as the traditional system when they had an equal amount of cars. The results we got when simulating the different control strategies do not agree with this. The simulations show that the fourth and fifth strategy are performing better than the traditional one during the up and down peak simulations but worse during the interfloor simulation.

The traditional system has problems dealing with the up-peak scenario. This can be observed by the bad results it got compared to the schedulers of the maglev system. Upon further inspection on where each elevator car moved during the simulation of the up-peak it could be observed that a lot of the elevator cars would eventually end up being idle on the top floor of the building with only two to four elevator cars being kept in motion to serve all of the calls. This resulted in a lot of passengers being left unserved at the end of the up-peak simulation and high waiting time for those who actually got served. The result of the up-peak simulations for the traditional system is therefore more likely to be similar to the results of a simulation where fewer elevator cars were used. Essentially this makes it a simulation of two to four traditional elevators instead of the intended six or eight.

In the maglev system the schedulers that spread the elevator cars out in the two shafts are the ones that perform the best. Comparing them to the traditional system one can see that they
outperform it in all but the interfloor traffic where the traditional system clearly beats them by a lot. One of the reasons is that elevator cars has a tendency to bunch up, in the way that they end up close behind each other, especially for the first scheduler where one could see in the end that they were all just one floor behind each other. This is a serious issue since if several elevator cars are lined up after each other and the first elevator car stops to pick up or drop of passengers all the trailing elevator cars has to wait for the first one to start moving again.

Adding more cars improved the results for the maglev system during the simulation. This can clearly be seen when comparing the results from the six and eight elevator car simulations. Taking this a step further and adding even more elevator cars might improve the results even more. There is probably a number of elevator cars in the system when this effect disappears due to the increased blocking that would occur from having more elevator cars. What the optimal number of elevator cars would be depends on the building’s size and how well the scheduler performs. Since we have not performed simulations with more elevator cars than eight we cannot clearly tell if adding even more elevator cars would improve the performance of the maglev systems to the traditional systems level and if it would affect the results of the other scenarios in either direction.

In general the spreading out of the elevators was the main problem for the scheduling strategy to solve and is quite hard when not being able to determine where a passenger wants to go before entering the elevator. This means a destination based call system might help as it can schedule the elevator cars to pick up people already heading to a floor where the elevator car is going to stop resulting in fewer stops. It might also help the elevator cars to not get in the way of each other, avoiding cases where an elevator car gets stuck with stops higher up than the other one ahead of it.

5.1 Method discussion

One problem with the current simulator is that it performs the elevator cars actions in sequence. This causes problems with blocking when the elevator cars move around in the multiple elevator cars per shaft systems. The way this presents itself is that if two elevator
cars in the same shaft are on the floors next to each other the elevator car that is behind will be stopped from moving if it tries to move before the car ahead of it does. This increases the travel times of the passengers riding the elevator car and the waiting time for the passengers waiting for the elevator car to answer their call. This affects the simulation results making the performance of the maglev strategies a little worse than they should be.

Another problem that might affect the results is the way we simulate passengers arriving at the elevator. In each simulation the chance that a passenger appears in each tick is fifty percent. This results in an average of five hundred people entering the system every simulation run. The passengers are introduced independently of each other but the time between their introductions is not, since only a single passenger can be introduced in any given tick. This can make our simulation a bit unrealistic since the passenger introduction might be to spread out during the simulation compared to how passengers would turn up at work in a real up-peak situation.

Similar to the problem with the passenger flow during up peak is the number of passengers during interfloor traffic. The up and down peaks are when the most passengers use the system. Since we have simulated the same number of passengers for each scenario this means that the interfloor simulation probably handles more traffic than it actually should. This does not affect the traditional system as much as the maglev system since the traditional systems scheduler’s bottleneck is during the up-peak.

5.2 Future opportunities
There are a number of things that could result in an interesting project of the future. One of these is adding the destination based system for making calls for an elevator. This will make the result in the scheduler having more information about the passengers in the system when making its decision about which elevator car to send to each request. Also allowing the elevator cars to switch shafts at multiple or any floor will allow the creation of more advanced schedulers.
6. Conclusions

One of the conclusions that we can draw is that it is hard to make a scheduler that spreads the maglev elevator cars evenly in the building. This is essential for making the system run smoothly and not having the elevator cars be in the way of each other.

From the results we can draw the conclusions that the maglev system would require improvements or a lot of more cars to perform at the same level as the traditional system during interfloor traffic, but during the other scenarios the maglev can perform better or similar with the same system in terms of average waiting and total travel times.

Further studies are required to confirm these conclusions with better schedulers as the schedulers used in this report have some issues and are quite simple.
7. Bibliography


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## 8. Appendix

### 8.1. Output from 6 elevator cars simulations

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<tbody>
<tr>
<td></td>
<td>Up peak</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---Scheduler---</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Average wait:</td>
<td>181,846</td>
<td>20,729</td>
<td>15,714</td>
<td>17,409</td>
<td>16,477</td>
</tr>
<tr>
<td>Worst wait:</td>
<td>488,39</td>
<td>87,76</td>
<td>80,33</td>
<td>78,65</td>
<td>88,99</td>
</tr>
<tr>
<td>Average travel:</td>
<td>207,872</td>
<td>54,607</td>
<td>48,481</td>
<td>50,422</td>
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<tr>
<td>Worst travel:</td>
<td>521,12</td>
<td>130,45</td>
<td>114,47</td>
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<tr>
<td>Total served:</td>
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<td>471,51</td>
<td>473,76</td>
<td>473,86</td>
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<td>Interfloor</td>
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<tr>
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<td>1</td>
<td>2</td>
<td>3</td>
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<td>5</td>
</tr>
<tr>
<td>Average wait:</td>
<td>14,932</td>
<td>84,191</td>
<td>56,780</td>
<td>60,421</td>
<td>54,265</td>
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<tr>
<td>Worst wait:</td>
<td>88,14</td>
<td>260,61</td>
<td>309,28</td>
<td>329,56</td>
<td>303,26</td>
</tr>
<tr>
<td>Average travel:</td>
<td>33,827</td>
<td>123,294</td>
<td>85,785</td>
<td>88,449</td>
<td>79,784</td>
</tr>
<tr>
<td>Worst travel:</td>
<td>122,93</td>
<td>329,96</td>
<td>335,97</td>
<td>358,37</td>
<td>332,33</td>
</tr>
<tr>
<td>Total spawned:</td>
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<td>500,52</td>
<td>500,52</td>
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</tr>
<tr>
<td>Total served:</td>
<td>483,39</td>
<td>426,23</td>
<td>445,64</td>
<td>451,71</td>
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<tbody>
<tr>
<td></td>
<td>Downpeak</td>
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<tr>
<td>---Scheduler---</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Average wait:</td>
<td>48,990</td>
<td>78,460</td>
<td>63,381</td>
<td>60,547</td>
<td>55,834</td>
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<tr>
<td>Worst wait:</td>
<td>421,16</td>
<td>675,6</td>
<td>691,63</td>
<td>185,48</td>
<td>411,6</td>
</tr>
<tr>
<td>Average travel:</td>
<td>77,866</td>
<td>153,832</td>
<td>102,854</td>
<td>56,276</td>
<td>59,573</td>
</tr>
<tr>
<td>Worst travel:</td>
<td>477,48</td>
<td>707,73</td>
<td>710,44</td>
<td>200,62</td>
<td>421,95</td>
</tr>
<tr>
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<td>501,78</td>
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</tr>
<tr>
<td>Total served:</td>
<td>415,74</td>
<td>251,49</td>
<td>374,37</td>
<td>472,51</td>
<td>466,14</td>
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### 8.2. Output from 8 elevator cars simulations

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<tbody>
<tr>
<td></td>
<td>Uppeak</td>
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<td></td>
</tr>
<tr>
<td>---Scheduler---</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Average wait:</td>
<td>170,362</td>
<td>10,265</td>
<td>9,116</td>
<td>9,889</td>
<td>9,306</td>
</tr>
<tr>
<td>Worst wait:</td>
<td>474,62</td>
<td>63,33</td>
<td>66,8</td>
<td>64,1</td>
<td>68,44</td>
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<tr>
<td>Average travel:</td>
<td>196,097</td>
<td>40,818</td>
<td>39,049</td>
<td>40,193</td>
<td>38,945</td>
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<td>Worst travel:</td>
<td>508,83</td>
<td>104,83</td>
<td>101,17</td>
<td>103,61</td>
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<td>Total served:</td>
<td>271,92</td>
<td>477,19</td>
<td>479,25</td>
<td>478,65</td>
<td>478,85</td>
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### Interfloor

<table>
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<tr>
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<th>2</th>
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<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average wait:</td>
<td>8,824373</td>
<td>65,02422</td>
<td>52,35481</td>
<td>52,1776</td>
<td>44,81063</td>
</tr>
<tr>
<td>Worst wait:</td>
<td>60,8</td>
<td>210,31</td>
<td>303,93</td>
<td>309,94</td>
<td>269,63</td>
</tr>
<tr>
<td>Average travel:</td>
<td>24,77303</td>
<td>101,9224</td>
<td>81,72953</td>
<td>80,34057</td>
<td>69,88995</td>
</tr>
<tr>
<td>Worst travel:</td>
<td>87,04</td>
<td>279,35</td>
<td>332,7</td>
<td>337,9</td>
<td>294,46</td>
</tr>
<tr>
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<tr>
<td>Total served:</td>
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<td>437,36</td>
<td>447,65</td>
<td>447,54</td>
<td>457,15</td>
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</table>

### Downpeak

<table>
<thead>
<tr>
<th>---Scheduler---</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average wait:</td>
<td>46,36705</td>
<td>65,68184</td>
<td>50,01146</td>
<td>19,60722</td>
<td>18,67101</td>
</tr>
<tr>
<td>Worst wait:</td>
<td>408,03</td>
<td>626,52</td>
<td>586,69</td>
<td>108,37</td>
<td>123,88</td>
</tr>
<tr>
<td>Average travel:</td>
<td>74,77718</td>
<td>136,906</td>
<td>89,2945</td>
<td>49,28498</td>
<td>43,47025</td>
</tr>
<tr>
<td>Worst travel:</td>
<td>465,6</td>
<td>654,44</td>
<td>603,75</td>
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<td>136,96</td>
</tr>
<tr>
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<td>501,06</td>
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<tr>
<td>Total served:</td>
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<td>318,73</td>
<td>413,35</td>
<td>474,51</td>
<td>478,93</td>
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