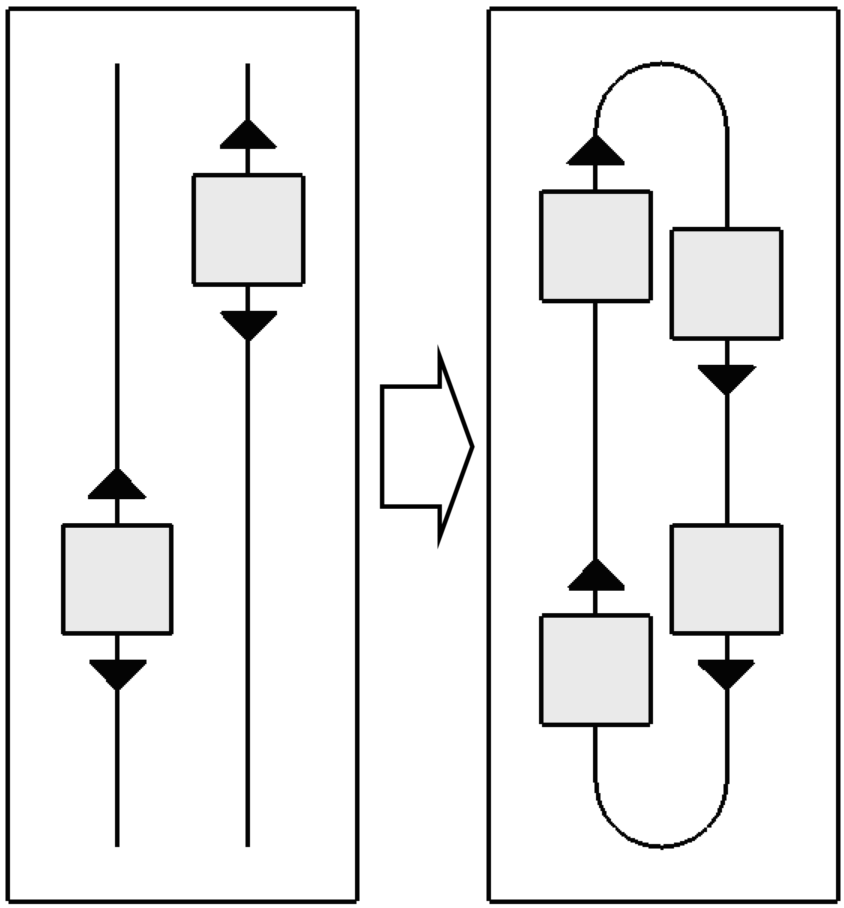
Master thesis
-Final report-

An optimised internal transport principle for a high-rise building



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ThyssenKrupp Elevator

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Preface

This report analyses different scenarios for an optimised internal transport principle for high-rise buildings. The research is a Master thesis project as part of the master Building Engineering at Delft University of Technology, faculty of Civil Engineering.

The idea for this subject first arose during a workshop "high-rise 2007" at Delft University of Technology. During this workshop, amongst other things, a lift system had to be designed for a fictitious building of 250 meters high. In my opinion, the total lift system, with conventional lifts, takes up a lot of valuable space. This made me wonder whether it would be possible to reduce the area taken up by this vertical transportation system.

Above all, I would like to thank the graduation committee, prof. dipl.-ing. J.N.J.A. Vamberský, prof. ir. C.H.C.F. Kaan, ir. J.W. Welleman, dr. ir. W. Daamen and J.C. Bakker for their input and trust from the very beginning of the research. The subject deals a lot with buildings but it is definitely not a standard building engineering subject.

During every meeting, I was given a lot of positive energy through their comments and feedback. This energy enabled me to continue my research with a strong focus and with a lot of confidence. My thanks also go out to those who took the time and effort to read the report and were so kind as to make remarks and give advice.

Finally, I would like to apologise to my friends and my family for all conversations about lifts, which you probably all found boring. However, these conversations lifted my research to a higher level.

Delft, October 2008

Joost Colsen

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Summary

Vertical transportation systems take up a lot of valuable floor space, especially in high-rise buildings. This master project analyses different scenarios for reducing the floor space used by the vertical transportation system, by introducing another principle of vertical transportation: the loop transport principle. Conventional lifts have been used for over 150 years and the main transportation principle has not changed since. Conventional lifts are optimised, due to technical progress and a smarter control of lift cabins, but cabins still move up and down in the same shaft. If it would be physically possible for cabins to move independently and behind each other, the number of cabins in two shafts could be more than two (figure 1).

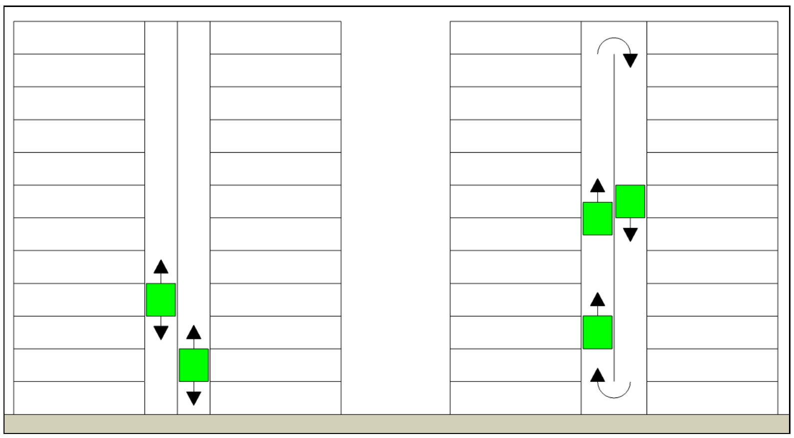

figure 1. Conventional lift (left). Loop transport principle (right)

Objectives
The aim of this master project is to get better insight in the functioning of the loop transport principle. The main research question is: What are the advantages and disadvantages of the loop transport principle compared to a conventional lift system and is it possible to reduce the space taken up by the vertical transport system by introducing the loop transport principle?

The loop transport principle
Every vertical transportation system consists of two elements namely the moving cabins and the control of the cabins. These two aspects are interdependent. The control determines when, and in which order, cabins serve requests from passengers.
At this moment, there is no technique that allows cabins to travel according to the loop transport principle. A patent research shows that several patents were already requested and ascribed that describe techniques for independent self-propelled cabins. These techniques can be used as a starting point for the development of the loop transport principle.

The model
A simulation model has been developed in a numerical computer environment using the programming language Matlab®. This model allows simulations to run lift systems with different parameter values in buildings with different characteristics to get more insight into the functioning of the loop transport principle compared to a conventional lift.
In order to achieve the model of the loop transport principle, the model of conventional lifts has been used as a basis. This model has been compared to an existing lift simulation program called Elevate®. The result of this comparison, for different simulations based on average waiting time, has the same order of magnitude. The used control algorithm for the loop transport principle is:

The first lift cabin that comes along the hall call location, in same direction as the travelling direction of the passenger, will stop to pick up this waiting passenger. When the first arriving cabin is full the next cabin will serve the hall call. When this cabin is also full, the next cabin will serve the hall call and

so on. The cabin will stop when passengers either want to leave the cabin or to enter a cabin with transport capacity; passengers with the longest waiting time at the stop place get the highest priority.

Within the model, a cabin is called via direction selection. When a passenger has given a hall call, the passenger will be assigned to a cabin that will serve him. When the cabin is full, the passenger will be assigned to another cabin. This is a static allocation. In case of a dynamic allocation at a certain moment, a re-calculation is made for all the waiting passengers to check whether the assigned cabin is still the best one, based on predetermined optimisation aspects.

Comparison of loop transport principle to a conventional lift
The model of the loop transport principle has been compared to the model of the conventional lift, by means of 5 minute simulations. For every parameter series, ten runs have been done to determine three factors; the average waiting time, the average travel time and the average journey time (journey time is waiting time plus travel time). An analysis of a fictitious office building during the morning up peak with 50 individuals per floor and two lift shafts is performed. The rest of the parameters values of the system are default parameters values. The capacity of the lift cabins and the number of floors varies and the maximum number of floors for the fictitious office building with a satisfactory lift system is determined, see table 1. A satisfactory lift system has a maximum average waiting time of 30 seconds and a maximum average travel time of 60 seconds.

table 1. Max. number of floors for a satisfactory vertical transportation system with two shafts.

Cabin capacity (passengers)	Maximum number of floors for conventional lift	Maximum number of floors for loop transport principle
6	8	19
8	9	17
10	9	17
12	9	17

Normative for the conventional system is the waiting time which exceeds the maximum of 30 seconds when the number of floors increases. For the loop transport principle it is possible to keep the average waiting time, for a relatively large number of floors, below the 30 seconds limit. Leading for the loop transport principle is that the travel time exceeds the maximum of 60 seconds. The model shows that larger cabins result in shorter average waiting times, but longer average travel times; this is the case for both systems. A well functioning loop transport principle results in a system which acts more as a taxi whereas a conventional lift acts as a bus. Conventional lifts fill up and after that they will stop several times to deliver passengers. The loop transport principle has a more individual functioning, so smaller cabins can be used to achieve the same or better transport capacity

Optimisation points for a better system
The model describes the basic loop transport principle; the functioning of basic loop transport principle can therefore be quantified. The loop transport principle can function better in a particular building, depending on the function of the building or the wishes of the owner. Opportunities to improve the loop transport principle are based on two aspects; the control of the lift cabins and the way cabins move through the building. It is important to know that these two aspects are interdependent.
A dynamic allocation, instead of static allocation, can be used to do a recalculation after every time step and determine the best movements and actions for a cabin. Another aspect in the control of the lift is the way in which passengers call a lift. The model uses a direction selection, which means that when a destination selection is used; the system knows more about the passengers and can anticipate on this information. The way cabins move through the building can differ from the basic loop transport principle. Within the basic loop transport principle, cabins move entirely to the top or to the bottom to change their vertical direction. There are other variants of the loop transport principle where this is not necessary. Variants for the basic loop transport principle are; loop in loop (figure 2), 3-1 loop transport principle (figure 3) and the cabin out loop (figure 4).

Loop in loop

Within the loop in loop principle it is not necessary for cabins to move entirely to the top or to the bottom of the building to change vertical direction. This is positive when one part of the building requires more traffic compared to other parts (see figure 2).

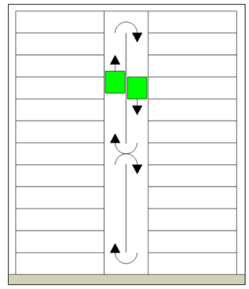

figure 2. Loop in loop transport principle

3-1 loop transport principle

The system can be adapted on a particular traffic pattern. During the morning up peak, relatively more passengers want to travel upwards and relatively fewer passengers want to travel downwards. During this period, more shafts can be used for up peak traffic to increase capacity. At the end of the working day, the system can be used the other way around. During daytime, when both traffic directions are comparable, the system can use two basic loop transport principles (figure 3).

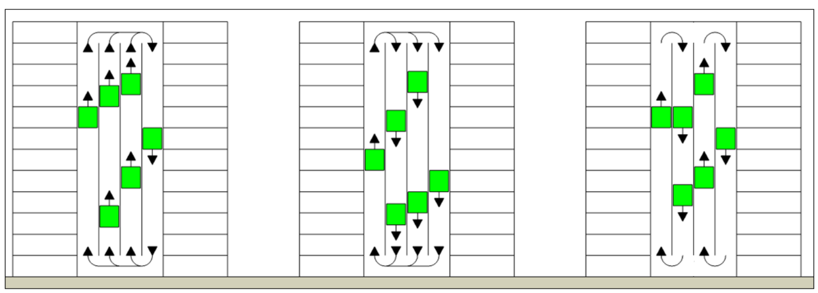

figure 3. 3-1 loop principle. Configuration for up-peak traffic (left). Configuration for down-peak traffic (middle). Configuration for two-way- or midday traffic (right)

Cabin out loop

Stops take up time, during which the cabin blocks the shaft. Within the cabin out loop transport principle, cabins can pass cabins which stop to load and unload. The principle where the cabins move inside the loop for stops is an interesting variation because it may result in a loop in loop principle as well (figure 4).

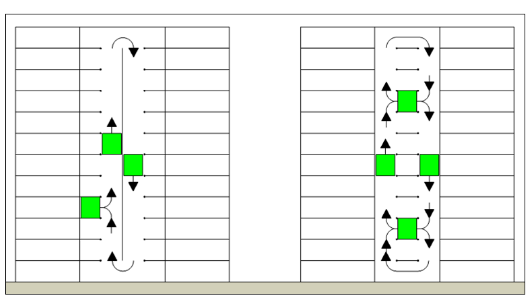

figure 4. Cabin out loop principle “outside” (left). Cabin out loop principle “inside” (right)

Case study

A case study is done for a fictitious office building of 60 floors which accommodates 5,000 individuals. A conventional lift would result in a vertical transport system of 17 shafts where the loop transport principle results in a vertical transport system with 8 shafts. The space taken up by the vertical transport system would be about twice as much in case of conventional lift compared to the loop transport principle for this particular case.

Concluding remarks

The model of the basic loop transport principle, developed in this master project, illustrates that a building using the loop transport principle can satisfactory serve significantly more floors compared to a building using a conventional lift. Starting point for this comparison is that both buildings use the same floor space per floor used for vertical transportation (two shafts) and the vertical transportation system provides satisfactory travel and waiting times. The loop transport principle can be further improved on the control aspect and the way in which cabins move through the building. Systems for the loop transport system are, as far as could be found, not directly available. Techniques which can be used for the physical movement of cabins for the loop transport principle are described in patents.

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1 Introduction

Buildings are getting taller and taller due to the increasing scarcity of land. High-rise buildings are also seen as status symbols. Due to that, the race for the highest building has not ended yet. Lifts are a problem in higher buildings, especially at the bottom of a building where relatively more people are transported. In higher buildings comparatively more space is consumed by the vertical transportation systems. Therefore vertical transportation in high-rise buildings needs to take a development step in order to require less space within a building. The vertical transportation principle and thus the vertical transport system needs to be optimised and is investigated in this project. A vertical transportation system requiring less space will influence the economic feasibility of higher buildings in a positive way.

The basic principle for lifts has not changed since the first lifts appeared. A lift cabin is transported upwards by a cable through a lift shaft and the cabin is going down through the same lift shaft. From an infrastructural point of view this is not logical, so inefficient and not common. When looking at a road or a railway, but also at the electrical transportation in an electrical cable or the heat flow through a radiator, the main transportation principles are one-way principles. So, if the basic transportation principle of a one-way track in a (high-rise) building is introduced, there could be a lot of benefits in the ratio between used space in a building for vertical transport and the transportation comfort for passengers. The capacity per shaft becomes bigger, therefore less shafts are needed for the same transport capacity. This principle will be called the loop transport principle.

Chapter 2 describes the problem formulation and the research objectives for this master project. Chapter 3 describes capacity aspects of vertical transportation by a lift and the assessment criteria. In chapter 4 a SWOT-analysis is given if space reducing transportation systems are on the market and to analyse effects of space reduction in transportation systems. Chapter 5 deals with space reducing methods which are used nowadays, were in the past or could be used in future. Chapter 6 expresses the loop transport principle and variations on the loop transport principle; attention will be paid to technical requirements and safety. Chapter 7 explains how to investigate how much space could be gained with a loop transport principle for vertical transportation. Chapter 8 describes a case study for a fictitious office building of 60 stories and shows the difference between a conventional lift and the loop transport principle expressed in used space for vertical transportation that performs satisfactory. Chapter 9 describes the concluding remarks and the recommendations for this master project.

2 Problem definition and objectives

This chapter will describe the problem and the associated objectives for this master project.

2.1 Problem description

The taller a building, the more complex the vertical transportation. In high-rise buildings there are mostly sky lobbies where you can change lifts to continue your trip to your final destination. However, the same principle is used: the lift cabin is going up and down through the same shaft. This principle has shortcomings. If you look hypothetically to an infinitely high building and imagine the lift cabin as a point and the lift shaft as an infinitely long line, the point can move up and down over the infinitely line. This is actually the conventional transport principle. If the point is moving infinitely high at the long line it will never reach infinitely low. Although this is a mathematical approach, it shows that the higher a building becomes the less efficient current lift systems are.
An infinitely high tower will never be built, but buildings become taller and taller. When looking at a very high building and the lift cabin is at the top, all the floors below the top can not be served by this lift through this shaft at that moment. If a one-way track is introduced in a high-rise building (the loop transport principle) this is, however, possible. More benefits can be gained by adding more than two lift cabins in two lift shafts. The exact number of lift shafts and cabins depends on the height of the building. This way it would be possible to obtain acceptable waiting times for a high-rise building which is also economically feasible. The economic feasibility of a building becomes mainly stipulated by the let-able floor space of a building. Floor space used for vertical transport can not be let, so therefore it is important to minimize this space. In figure 5, the loop transport principle is shown.

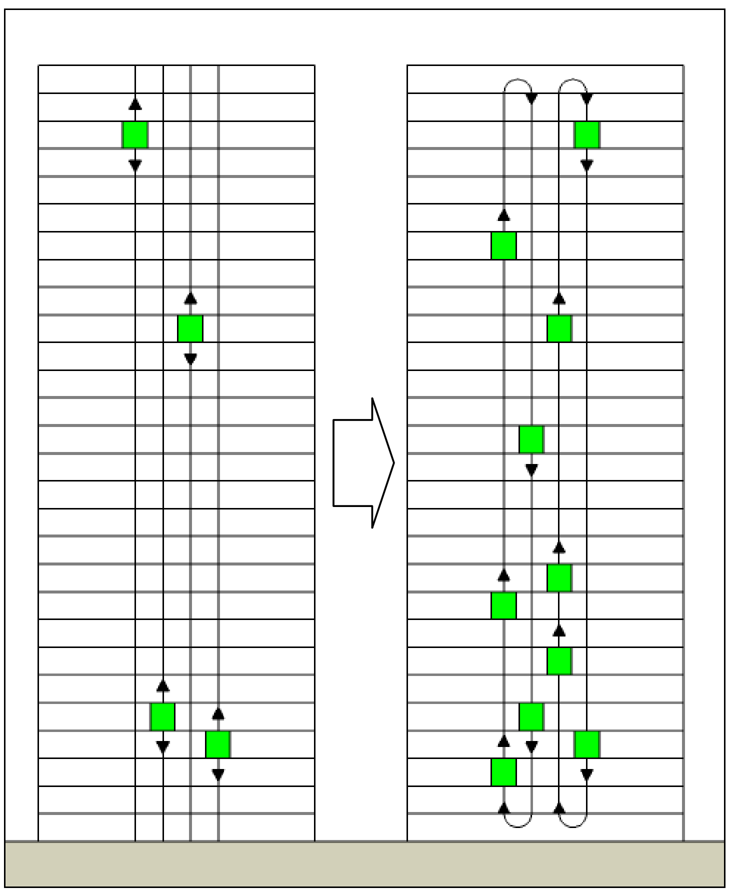

figure 5. (Basic) principle conventional lift system (left). Vertical loop transport principle (right)

Variations on the loop transport principle can be made, as shown in figure 6.

- Loop-in-loop principle.
  Some parts of the building may require more traffic than other parts. In this variation it is not necessary that cabins go entirely up or down.
- 3-1 principle.
  During the day there may be a transport peak upwards or downwards. In an office building for example, during the morning everybody will arrive and wants to go upwards. At the end of the day the people will go downwards. This variation makes it possible to use more shafts to go up than to go down or vice versa. This principle is not fixed to the ratio 3-1, it could be possible to have other ratios.
- Cabin-out-loop principle.
  When a cabin is loading or unloading at a floor, it blocks the shaft. So when the loading and the unloading is not in the shaft but outside of the shaft transportation in the shaft can continue. It should be comment that also the stopping places for the cabins uses floor space. This space must also be taken into account for the total floor space taken up by the vertical transport system.

The above mentioned variations of the loop transport principle can be combined. The three variations will be discussed in chapter 6.

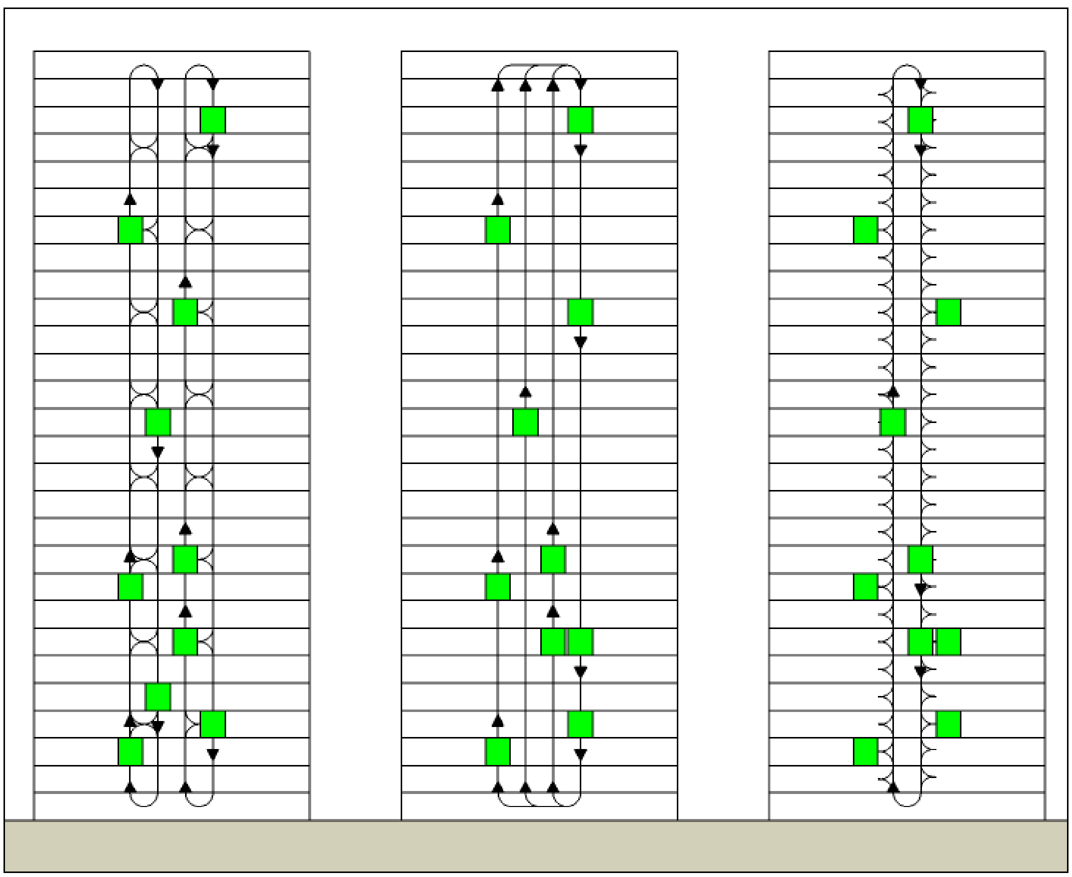

figure 6. Variations. Left, Loop-in-loop principle. Middle, 3-1 principle. Right, Cabin-out-loop principle

2.2 Research objectives

The objective of this Master project is to optimise the vertical transport principle of a high-rise building. The optimisation of the transportation principle for a building is the main objective, the development of the mechanical functioning is considered less important at this time. The final goal is to reduce the floor space used in a high-rise building for the vertical transportation to create more floor space which can be used as let-able floor space. This should be done without reducing the comfort for the user of the lift system. Waiting time inside (travel) and outside the cabin will be important assessment variables. The reduction of the number of shafts is an important issue.

The objectives of the Master project can be subdivided into a number of research questions. The main question can be directly distilled from the objectives:

- Is it possible to reduce the number of lift shafts by using the loop transport principle for a high-rise building?

Background questions will create a framework in which the main question will be answered:

- What are the basic assumptions and the boundary conditions for the loop transport principle?
- Which parameters influence the functioning, expressed in waiting time and ride time, of the loop transport principle and its variations?
- Which alternative shaft reducing methods are used nowadays?

This master project will investigate vertical transport systems. Vertical transport systems are part of a building, the control and the physical lift are parts of the vertical transportation system. This research will investigate for the loop-transport-principle, possible techniques for the physical movement of the lift and determine how the cabins must travel through the building ("control" and "lift"). This vertical transport system will be compared to existing vertical transport methods. In the figure 7 the relation of the different elements of a vertical transportation system is set down.

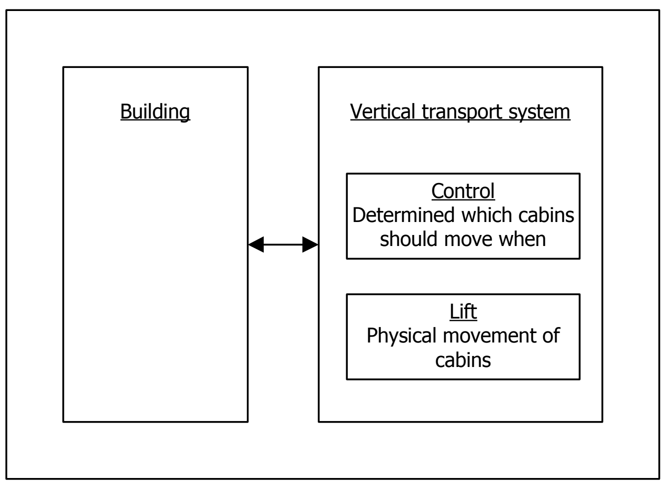

figure 7. The building related to the vertical transport system.

2.3 Conclusion

The described problem and objectives are the starting points for this master project. The described variations are for now considered complete, at this moment no other variations could be considered.

3 Aspects of vertical transportation within buildings

Vertical transportation in high-rise buildings is a very important aspect of the functioning of the building. Space taken by vertical transportation elements will influence the economic functioning of a building and the functioning of the transportation elements itself will be noticed by every day users of a building. Lifts are appliances for vertical transportation; staircases and stairs could also be used for vertical transportation but have their limitations. The lift system itself has to be reliable and it has to have enough capacity for the building in a theoretical and practical way; the purpose of the building will influence the capacity demand. Lifts will be used by human beings so there are also physical and psychological aspects which will influence the capacity of a lift system.

This chapter describes important aspects of vertical transportation within buildings. The focus will be on transportation with a lift. A lift as it is used nowadays corresponds to the loop transportation principle in many respects. However, the way cabins move through the shafts is different in the loop transport principle. Therefore there could be mechanical differences, but loading time, unloading time, door opening time and acceleration are all parameters which can be used as a starting point for the loop transport principle.

3.1 Human preferences

A vertical transport system has to be satisfactory for passengers. It has physical and physiological aspects. These human preferences will be discussed in this paragraph.

3.1.1 Stairs, escalators and lifts

Vertical transport in buildings can be done by several types of systems. Most common are stairs, escalators and lifts. More advanced buildings have different types of vertical transportation possibilities; if there is for example a low-rise and a high-rise part of the building it may contain a lift and a stair. But it is still the judgement of the user which kind of system will be used. The stair use depends on the number of floors which must be travelled; the distribution can be found in table 2. Stairs are also important in case of an evacuation

table 2. Stair usage, compared to lift or escalator use (Barney, 2003)

Floors travelled	Usage up	Usage down
1	80%	90%
2	50%	80%
3	20%	50%
4	10%	20%
5	5%	5%
6	0%	0%

Escalators are a common vertical transport system in low-rise buildings such as shopping centres, sports complexes, conference and exhibition centres, railway stations and airports. These are very useful to transport very high volumes passengers in a simple and comfortable way in vertical direction. However, the escalator has its limits when the bridgeable vertical distance becomes too long so the transport time becomes too long. So, based on the judgement of the passenger, passenger usage of escalators or lifts can be found in table 3.

table 3. Lift and escalator: distribution of traffic (Barney, 2003)

Floors travelled	Escalator	Lift
1	90%	10%
2	75%	25%
3	50%	50%
4	25%	75%
5	10%	90%

3.1.2 Physiological preferences

A point of interest is which movements are tolerable for the body of a passenger. Most unpleasant feeling is the changing of the gravitation forces during vertical acceleration or deceleration. The changing of the gravitation forces occurs if there is a vertical acceleration or deceleration. The general accepted level of acceleration is 1.5 m/s^2. This is about 1/8 of g (9.8 m/s^2) on earth. A (constant) speed is up to a particular speed not noticeable in an enclosed cabin, when the speed is more than 15 m/s (Liftinstituut, The Netherlands 2008) the pressure changes will become too high. Underneath this value speed is not a design criterion. Another unpleasant feeling is the rate of change of acceleration (jerk), a general accepted level is 2.0 m/s^3. The effect of the movements of the vertical transportation of the passenger depends on the condition and characteristics of the passenger itself, such as individual age, physical and mental health.

In figure 8 the physiological preferences of a passenger are shown, figure 8a shows the maximum accepted acceleration and jerk, figure 8b shows the coherent velocity set out against the time and figure 8c shows the associated travelled distance. The three figures a, b and c are dependent on each other. If the acceleration decreases the coherent velocity and travelled distance decrease as well.

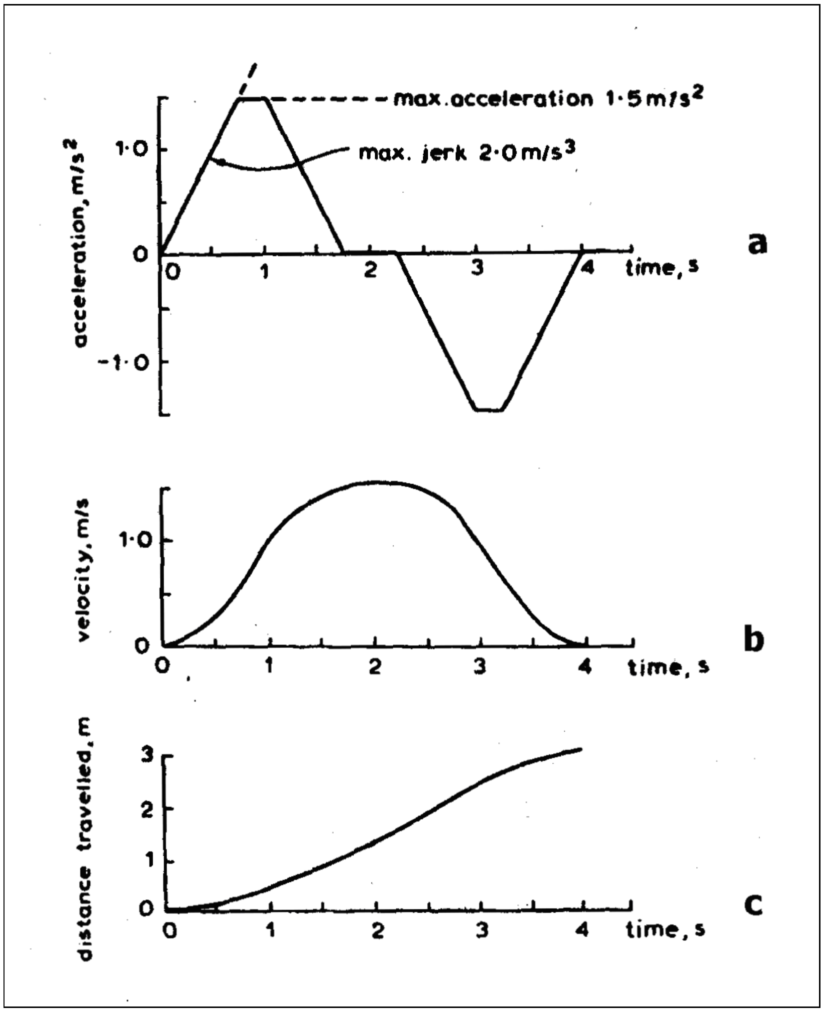

figure 8. (Barney, 2003)
(a) Acceleration profile (normative): maximum jerk(shock) 2.0 m/s^3 and maximum acceleration 1.5 m/s^2.
(b) Velocity profile (not normative): maximum speed 1.5 m/s.
(c) Distance travelled (not normative): total distance 3.0 m.

3.1.3 Psychological preferences

Psychological constraints are hard to quantify and are very subtle. These constraints depend on the location and time during the day. An office worker does not expect the same grade of service in his office as in a residential block. Waiting time in an office should not exceed 30s (Barney, 2003), while in the residential block it should not exceed 60s (Barney, 2003). Waiting time is the most important psychological constraint, so it is important to keep the waiting time as low as possible. It is also possible to make the waiting time more pleasant, e.g. by adding a mirror in a waiting area or adding a display with short movies. Adding a display with the location of the lift can also help; when you are informed and know where the cabin is it is less annoying to wait. The uncertainty of the waiting time is less and therefore less annoying. These influence parameters are hard to quantify.
Another important psychological constraint is the travel or transit time in the cabin. The duration of the transit depends on the number of people in the cabin and the number of calls on the different floors. The trip in the cabin becomes intolerable if it is longer than 90s (Barney, 2003). There are more psychological constraints, such as aesthetic appearance, doors, finishing, that can be blamed on the general impression or feeling of the lift.

3.2 Vertical transport traffic patterns

The traffic pattern of a vertical transport system depends on the use of the building. The most complex and intense pattern is the pattern of an office building. An office building has a large demand of upward calls at the beginning of the day (morning up peak) and a large demand of downward calls at the end of the day (evening down peak). During the day there is a continuous demand in both directions (two-way traffic), see figure 9. The demand is also influenced by the user (tenant = company) of the building. If there is a single tenant building the inter floor traffic during the day is larger than if it is a multi tenant building. The reason for that is that you need your colleagues and you have to visit them. In appendix 1 (Traffic patterns) traffic patterns can be found for other types of buildings.

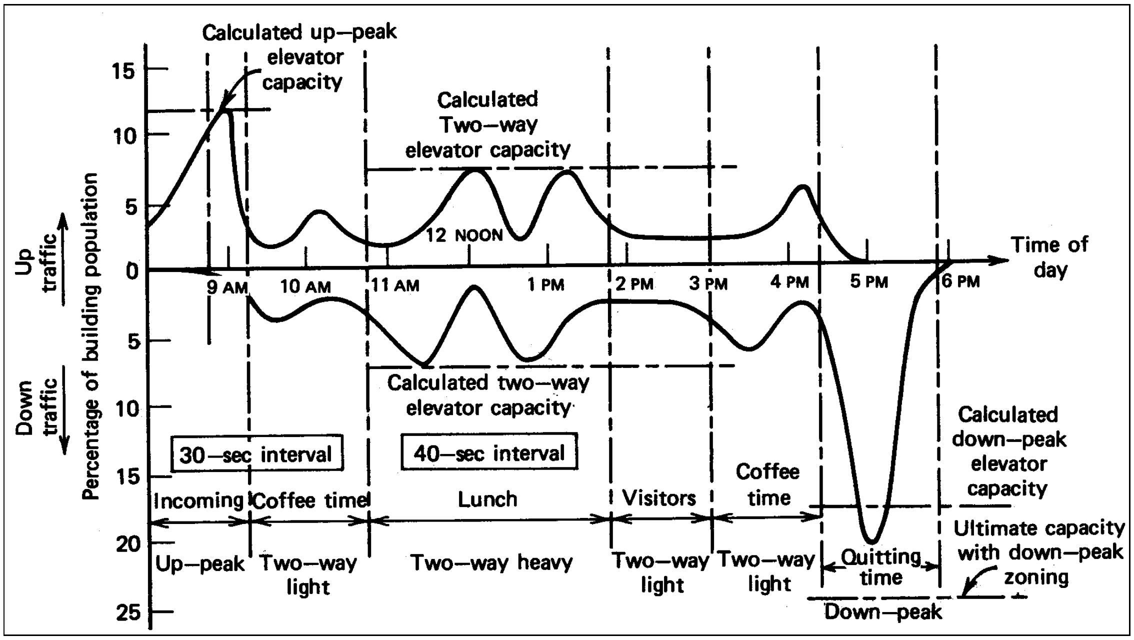

figure 9. Typical traffic flow- diversified office building observed on and off lifts at the main lobby (Strakosch, 1998)

3.2.1 Up peak traffic

An up peak traffic condition exists when the dominant, traffic flow is in upward direction, with all, or the majority of, passengers entering the lift system at the main terminal of the building. In the morning, up peak traffic conditions occur most clear. Office employees enter the building and go to their office. During the day there are more peaks, but the morning peak is the most intense. If the vertical transport system can cope efficiently with that up peak traffic condition, it will be able to cope with the other traffic conditions as well. In figure 10 the up peak is show in detail and is idealised by designers in terms of a 5-minute peak value taken as a percentage of the building population. The industry practice is to design a lift installation to handle the number of passengers requesting service during the heaviest 5 minutes of the up peak traffic condition. This is a sound recommendation. To design the lift system to handle the actual peak would require a large system, which would be very expensive and much of the equipment would be under utilised during large periods of the working day. The difference between the actual peak and the heaviest 5 minutes is that the actual peak can be larger than the heaviest 5 minutes peak. The heaviest 5 minutes are determined on the average of peaks so there are individual actual peaks that are larger. In appendix 2 (Spatial movements) a screenshot of spatial movements can be found of a lift system during up peak traffic conditions.

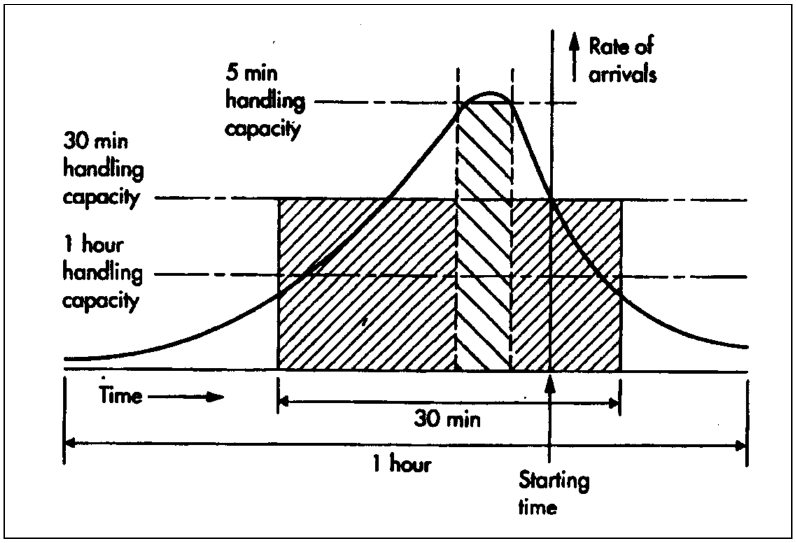

figure 10. Detail of up peak traffic profile (Barney 2003)

3.2.2 Down peak traffic

A down peak traffic condition exists when the dominant traffic flow is in a downward direction with all, or the majority of, passengers leaving the lift system at the main terminal of the building. The down peak traffic condition is the reverse of the morning up peak traffic condition and occurs most intensely during the end of the day, in case of an office building. The evening down peak is usually, depends on the function of a building, more intense than the morning up peak with higher demands and with durations of up to 10 minutes. Fortunately a lift system can be shown to possess 50% (Barney, 2003) more handling capacity during down peak than during up peak. This is because during down peak a lift cabin fills at three, four or five floors and then makes an express run to the main terminal. Passengers tend to leave in groups or with a partner, so lift cabins are sooner filled. Sophisticated lift cabins even detect if a cabin is full and do not have to stop on the way down. This reduction in the number of stops results in a shorter round trip time and hence a greater handling capacity during down peak. This can also be seen in the comparison of figure 72 and figure 73 in appendix b (Spatial movements). A detail of the down peak traffic condition is shown in figure 11.

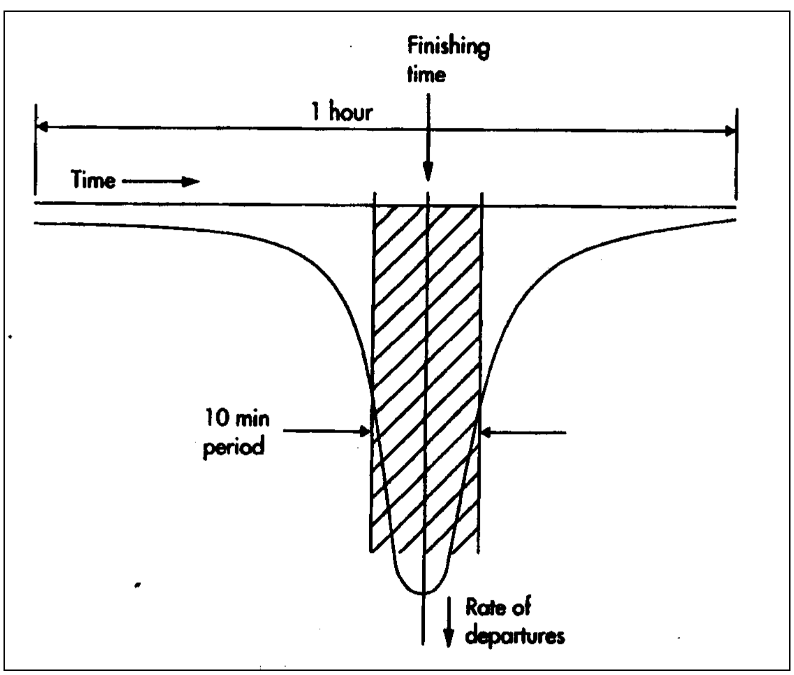

figure 11. Detail of down peak traffic profile (Barney 2003)

3.2.3 Two way and mid day (lunch time) traffic

A two way traffic condition exists when the dominant traffic flow is to and from one specific floor, which maybe the main terminal. This traffic can also occur if a canteen is in the middle floor of the building and all the office employees go there for lunch. The mid day lunch period often presents the heaviest demand on a lift owing to the simultaneous up, down and inter floor traffic to several floors. The inter floor traffic condition exists for most of the working day and therefore is very important. A mid day traffic condition occurs in the middle of the day and exhibits a dominant traffic flow to and from one or more specific floors. During lunchtime it could be usual to go outside to have lunch there.

table 4. Expected peak traffic periods, office buildings. (Strakosch, 1998)

	Percentage of population in a 5-min period		
	Peak arrivals	Up peak with 10% down traffic	Noontime or two-way
Diversified offices	10 to 11%	11 to 12%	10 to 12%
Diversified single-purpose	11 to 13%	12 to 15%	12 to 15%
Single-purpose	12 to 18%	13 to 20%	13 to 17%

3.3 Parameters influencing vertical transport

Parameters which influence the vertical transport system can be divided into three factors: building, lift system and passenger.

3.3.1 Building

Building parameters have a relation with the building itself and are determined in the design stage. The following parameters can be distinguished:

(a) Number of floors
(b) Inter floor distance
(c) Express jump

The express jump may be nothing more than a few extra meters between the main terminal and the first served floor and is not present in every building. The influence of these parameters on the functioning of the lift system can be qualified. Assumption in the qualification of the parameters is that all other parameters will be the same. The influence of the building parameters a, b and c are qualified underneath.

(a) Increasing the number of floors asks for more lifts (absolute) to serve all the floors with an acceptable quality of service.
(b) When the inter floor distance increases the lift will take longer to go from floor to floor. Increasing the inter floor distance has a negative influence on the transport capacity.
(c) When the express jump increases, the lift will take more time to go from the ground floor to the first floor. Increasing the express jump has negative influence on the transport capacity and on travel times.

3.3.2 Lift system

The parameters in this paragraph have a relation with the vertical transport system and can be divided in the lift parameters and the control system of the lift (together the lift system).

Lift system parameters

Lift parameters
(a) Number of cabins
(b) Rated car capacity
(c) Rated speed
(d) Acceleration and deceleration

(e) Door opening times (single slide, two speed or centre opening)
(f) Door closing times
(g) Miscellaneous times (such as car and door dwell times, etc.)

Control system of the lift
(h) Traffic control system

Parameter (a) and (b) are designed variables to meet the required passenger traffic demands and the quality of service. Items (c) to (g) can be established from the lift manufacturer.
When the lift parameter values increase the transport capacity may increase too. But it is too simple to say that when the transport capacity is not enough, the lift parameters should be increased. For example, if the transport capacity is not enough the rated cabin capacity can be increased, but when the rated car capacity increases the cars can make more stops per ride, so it could be better to have two smaller cabins. There is an optimum which depends on the type of building. The effect of the change of the cabin capacity and the associated number of stops can be found in the appendix e (Determination review criteria). Parameters (c) and (d) are limited by physical preferences of passengers as described in 3.1.2. Parameter (e) and (f) are limited by building codes. A closing door may not have too much energy, this to prevent that passengers get injured by a closing door. The energy of a closing lift door depends on the mass of the lift door, the speed of the lift door and the type of motor. Doors can operate faster if they are not allowed to touch a passenger. This involves the use of passenger detection and door control systems.
The effect of (h) cannot always be analysed in precise mathematical terms, but may be assessed empirically. The control system can also be adjustable to the time of day; this is done to optimise the capacity. For example in an office building during the morning up-peak all cabins are sent to the main terminal when cabins are empty (see appendix 4, technical description Maastoren).

3.3.3 Passenger
Parameters described in this paragraph have a relation with the passengers who uses the lift:L

(a) Number of passenger boarding at specific floors
(b) Number of passengers alighting at specific floors
(c) Traffic mode, i.e. unidirectional or multidirectional
(d) Transfer times for passengers entering and leaving cars
(e) Passenger actions

Items (a) and (b) are dependent on floor populations, which depends on the type of building. Items (c) and (d) are dependent on human behaviour and are not easily predictable but are also dependent on the type of building, for example the difference between a school and an office. Item (e) is included to cover passenger misbehaviour (door holding, excessive operation of pushbuttons, etc.) and could be minimized by a good information facility. This data set is the least well defined and is subject to considerable error in its estimation and depends on local situations.

3.4 *Quality of service*

There are several methods and indicators to measure the quality of a lift system. Passengers are mainly interested in waiting time, response time, ride time (travel time) and journey time. Project developers, owners of buildings and lift builders are more interested in capacity and the associated level of comfort and costs.

3.4.1 Quality of the transport system
Often used indicators for the quality of service for a lift system are the up peak handling capacity, round trip time, interval time and the up peak interval (Barney, 2003). These indicators depend on the used lift system, the type of building and time of the day. These indicators are discussed in the coming paragraph.

Up peak handling capacity (UPPHC)

The up peak handling capacity of a lift system is the total number of passengers that can be transported in a period of five minutes during the up peak traffic conditions with a specific average car loading.
The up peak is especially in an office building the most difficult traffic flow to cope with, so if the vertical transport system manages to deal with the up peak mostly the rest of the day will not be a problem.

Round trip time (RTT)
The round trip time is the time in seconds for a single car trip around a building from the time the car doors open at the main terminal, until the doors reopen, when the car has returned to the main terminal floor. The round trip time depends on the capacity demand for the lift system and therefore depends on the time of the day.

Interval (INT)
The interval is the average time between successive lift car arrivals at the main terminal floor with cars loaded to any level. The interval depends on the capacity demand for the lift system and is therefore dependent on the time of the day.

Up peak interval (UPPINT)
Up peak interval is the average time between successive lift car arrivals at the main terminal floor with cars loaded to 80% (proven by experiment) of rated car capacity during up peak traffic conditions.

3.4.2 Quality for passenger

Passengers want to have a reliable and safe system, they are mostly interested in waiting time, travel time and journey time. The physical and psychological levels of comfort are also qualities and have already been discussed in the first paragraph of this chapter.

Passenger average waiting time
The passenger average waiting time is the average period of time, in seconds that a passenger spends on average while waiting for a lift measured from the instant that the passenger registers a landing call (or arrives at the landing), until the instant the passenger can enter the lift.
Passenger waiting time would be the best indicator for the quality of service that an installed lift system could provide. The shorter the time the better the service. If the capacity of a lift system is far too less, the interval time still has the same significance compared to a lift system with enough capacity, but the average waiting time will be much longer. A queue will originate while cabins are full. The interval of car arrivals at the main terminal can be determined therefore more easily compared to average waiting time and is an adequate indication of service quality, if the capacity is sufficient. When considering office buildings, an interval of (Barney, 2003):

20s or less indicates an excellent system
25s would indicate a good system
30s would indicate a satisfactory system
40s would indicate a poor system
50s or greater would indicate an unacceptable system

In table 5 an indication is given for values of suitable intervals for different types of buildings.

table 5. Up peak intervals (Barney, 2003)

Building type	Interval (s)
Hotel	30-50
Flats	40-90
Hospital	30-50
School	30-50
Office	
regular	25-30
prestige	20-25

A simple rule of thumb has been to assume that the average waiting time is half of the interval. This would be so if passengers were to arrive with equal time spacing, so passengers arrive random without information about the time of arrival of the lift. This is a theoretical situation and it is only accurate when the cabins load half than full. Lightly loaded cabins are an unlikely situation for an up peak traffic condition. It has been shown (Barney and Dos Santos,1977) that a theoretical relationship exist between interval and passenger average waiting time depending on the actual percentage of the car load (passengers in the cabin). For cabin loads between 50% and 80% it is possible to develop an approximate equation for the Average Waiting Time (AWT) as:

$$AWT = \left[0,4 + \left(1,8P/RC - 0,77\right)^2\right] INT$$

With:
P = Average number of passengers present in a lift as it leaves the main terminal
RC = Rated car capacity (passengers)
INT = Interval (s)

Passenger average travel time to destination (ATT or Ride time)
The passenger average travel time (ATT) is the average period of time, in seconds, it takes for a passenger to travel from start floor to the requested destination floor, measured from the time the passenger enters the lift until alighting at the destination floor.

The travel time to destination would help to evaluate the suitability of a planned lift group, but it is a secondary quality of service design consideration after average passenger waiting time.

Average passenger journey time (AJT)
The passenger average journey time is the average period of time, in seconds, measured from the instant an average passenger first registers a landing call (or arrives at the landing), until alighting at the destination floor.

Average waiting time can be combined with average travel time to calculate the average journey time. The passenger average journey time is the sum of the average passenger travel time (ATT) and the average passenger waiting time (AWT).

AWT, ATT, AJT
The quality of service is particularly important for office buildings. The values given in table 6 indicate the performance times to aim for a traffic design and the maximum acceptable values.

table 6. Summery of times for office buildings (Barney 2003)

Time	Aim for	Poor
AWT	<20s	>25s
ATT	<60s	>70s
AJT	<80s	>90s

Where a passenger uses a shuttle lift (see chapter 5) to first reach the upper terminal floor and then uses another group of lifts to reach their final destination floor, the values obtained for AWT, ATT and AJT should be calculated separately for each journey (Barney ,2003).

Definitions in passenger service level, as mentioned in the paragraph above can be found in figure 12.

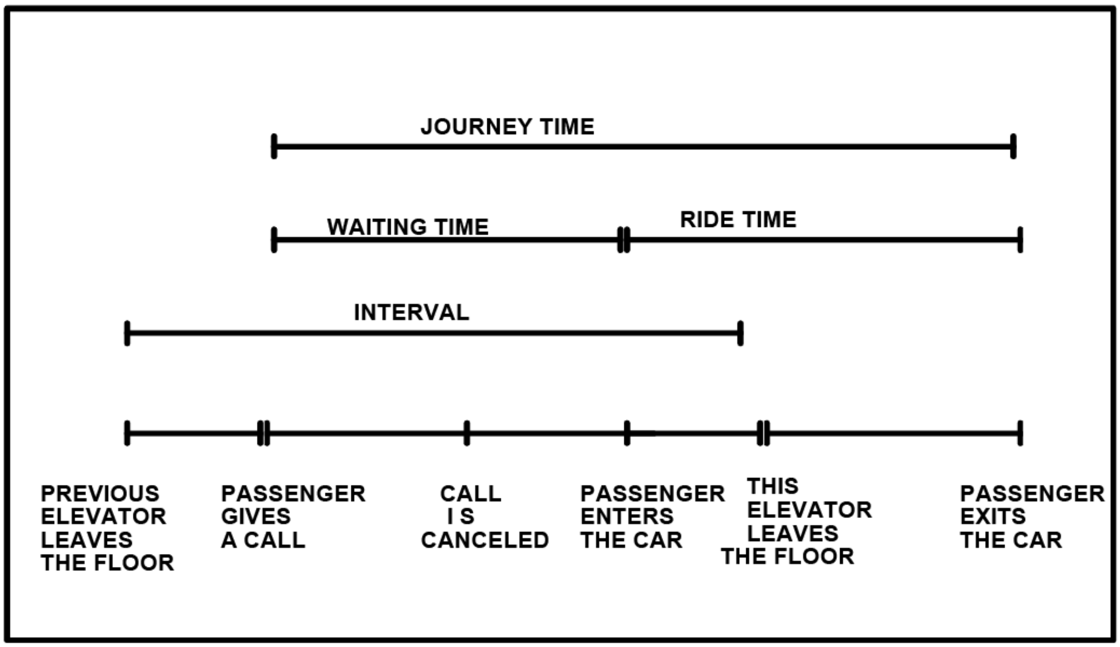

figure 12. Definitions of passenger service level (Siikonen, 1997)

3.5 Definitions for lift calculations

Starting point for the design of every lift capacity calculation is the number of passengers that have to be transported by the lift system. Also the level of comfort for the passenger needs to be determined. So when these factors are known the vertical transport system can be designed on these factors. This paragraph describes how the number of passengers which have to transported can be determined. Parameters which are used in lift design are also discussed.

3.5.1 Lift system

The lift system has properties such as passenger loading time, door opening time and flight time. All the factors are given in table 7 and are mainly dependent on the lift system; this means a combination of the physical movement of the lift and the control of the lift.

table 7. Definitions and terms for lift capacity calculations (Barney, 2003)

Time period	Symbol	Description
Passenger loading time	t_l	The average time for a single passenger to enter a car (boarding time, entry time)
Passenger unloading time	t_u	The average time for a single passenger to leave a car (alighting time, exit time)
Passenger transfer time	t_p	The average time for a single passenger to enter or leave a car: $t_p = t_l + (t_u/2)$
Door closing time	t_c	A period of time measured from the instant that the car doors start to close until the doors are locked
Door opening time	t_o	A period of time measured from the instant that the car doors start to open until the doors are 800mm. (Passenger transfer can begin when doors open > 800mm)
Door operating time	t_d	The sum of the door opening and closing times, i.e. $t_d = t_c + t_o$
Car call dwell time	t_{cd}	The period of time that the car doors remain open at a stop in response to a car call, provided no passengers cross the threshold
Landing call dwell time	t_{ld}	The period of time that the car doors remain open at a stop in response to a landing call, provided no passengers cross the threshold
Single floor flight time	$t_f(1)$	The period of time measured from the instant that the car doors are locked until the lift is level at next adjacent floor
Multi -floor flight time for a jump of n floors	$t_f(n)$	The period of time measured from the instant that the car doors are locked until the lift is level at nth adjacent floor
Single floor transit time	t_v	The period of time for a lift to travel past two adjacent floors at rated speed, i.e.: $t_v = d_f / v$ where d_f is the interfloor distance and v is the rated speed
Stopping time	t_s	A composite time associated with each stop, i.e.: $t_s = t_f(1) + t_c + t_o - t_v$
Performance time	T	The period of time between the instant the car doors start to close and the instant the car doors are open 800 mm at the next adjacent floor
Cycle time	t_{cyc}	The period of time between the instant the car doors begin to close until the instant that the car doors begin to close again at the adjacent floor provided no passenger have crossed the threshold

3.5.2 Up peak arrival rate (%POP)

The up peak arrival rate is the number of passengers that arrive, at the main terminal of a building, for transportation to the upper floors over the most crowded five minutes period expressed as a percentage of the building population.

table 8 . Estimation of population and peak arrival rate (Barney, 2003)

Building type	Population estimate	Arrival rate(%POP)
Hotel	1,5 -1,9 persons/room	10-15%
Flats	1,5 -1,9 persons/bedroom	5-7%
Hospital	3,0 persons/bed space	8-10%
School	0,8 -1,2 net area/pupil	15-25%
Office (multi tenancy)		
regular	10-12 m^2 net area/person	11-15%
prestige	15-25 m^2 net area/person	17%
Office (single tenancy)		
regular	8-10 m^2 net area/person	15%
prestige	12-20 m^2 net area /person	17-25%

3.5.3 Arrival rate

The building population per floor and the number of floors are important factors to determine the capacity of the lift system. The number of individuals per floor can be determined with the parameters given in table 8. These factors are guidelines and need to be checked per individual building. The lift system needs to transport a rate of the total population of the building during the morning five minute up peak. But it is unlikely that all the population is present on any day. The greater London council assumed attendance of 84% (Barney, 2003), in other countries this percentage is different but in the same order. The effective population considered during up peak period can be reduced to account for:

-Persons away on holiday
-Persons away sick
-Persons away on company business
-Vacant posts
-Persons who arrive before or after the peak hour incoming traffic

The total building population could be reduced by 15% to 20% to account for these factors.

3.6 Conclusion

The loop transport principle has similarities with vertical transportation of a conventional lift system. The traffic demand does not depend on the vertical transportation system; it is related to the function and purpose of the building. Some elements in vertical transportation that depends on the technique of the lift (i.e. door opening time), while other elements are maximized by human constraints (i.e. acceleration or speed above 15 m/s^2).
The loop transport principle will use a conventional lift as starting point, the loading and unloading of a cabin and the associated door opening and closing time are considered the same. Human constraints are also considered the same for the loop transport principle. For the development of the loop transport principle parameters which are the same and optimised by conventional lift designers, are taken from the conventional lift. The investigation of the loop transport principle can therefore be seen as an investigation of a conventional lift where cabins do not move in a conventional way, but in a loop through a building.
The evaluation of the quality of the loop transport system will be performed from the passenger point of view, expressed in waiting time and travel time. These passenger parameters have a relation with the capacity of the vertical transportation system.

4 SWOT analyses to reduce the number of shafts

In a SWOT analysis Strengths Weaknesses Opportunities and Threats are given to evaluate the viability of a project. It tries to find the positive and negative aspects in a project. In this case, what are the strengths, weaknesses, opportunities and threats if a vertical transportation system for a building can be found with at least the same transport capacity and comfort for passengers which uses less space within the building compared to a conventional lift system.
The transport capacity of a vertical transportation system and the associated level of comfort for the passenger are a starting point for this SWOT analysis. With an existing conventional lift it is very well possible to increase the capacity, but the level of comfort, expressed in waiting time and ride time get worse. The level of comfort in this SWOT analysis may not be less compared to the level of comfort of conventional lift used nowadays, only the used spaces within a building must be smaller.
In this master project the loop transport principle will be investigated. This SWOT analysis is not an analysis for the loop transport principle, but it is more general for vertical transportation. The level of comfort, expressed in the waiting time and ride time, may not be longer. The techniques to accomplish this must be developed, lift systems with one lift cabin in one shaft have reached the optimum in capacity and level of comfort after 150 years of improvements. This SWOT analysis will describe aspects if a more efficient vertical transport system can be found or whether it is useful to develop one.

Strengths

-Fewer shafts can result in more let-able floor space per floor.

-More flexibility for other functions for existing high-rise buildings. Buildings are designed for a particular purpose, this could change and with that the vertical transport system no longer satisfies. If the new function asks for a vertical transport system with a higher capacity, a system with more capacity and the same level of comfort can solve this.

-Higher level of comfort. Increase of vertical transport capacity without increasing the number of shafts. This can result in a higher level of comfort for passengers. One of the criteria to determine the quality of an (office) building is the quality of vertical transportation, expressed in waiting time and ride time. If this can set to a higher standard, the quality of the office building will be increased. There are opportunities for other functions within a building.

Weaknesses

-The mechanical requirements and the control of lift cabins are different and more complex compared to a conventional lift. The new system has to be developed so will be most likely therefore more costly. The direct cost for vertical transportation can therefore be higher. Once the new system is developed the control of the lift cabins stayed more complex compared to conventional lifts.

Opportunities

-Other architectural possibilities for a high-rise building are possible, because the space the vertical transport system takes up is reduced so less dominant and can be arranged differently.

-It is possible to build taller high-rise buildings. The higher the building is nowadays the more space the vertical transport system takes up (relatively) so taller buildings become more efficient, the relative let-able floor space is higher.

-The possibility to increase the height of existing buildings. Of course this depends on many more things, for example structure and installations. But not on every floor the used space for vertical transportation has to be increased.

Threats

- Until now none could be found.

In a lot of high-rise buildings the core (where all the shafts for vertical transportation are suited) can be an important element for the overall stability of the tower. If the number of shafts can be reduced, the core will become more slender. When the core should act as a stability element, a smaller core would influence the overall stability of the high-rise building. Other elements must be used, i.e. the outside wall (façade wall), of a building to facilitate the overall stability of a building. This fact can not directly be described to one of the four elements of the SWOT-analysis and does not need to be disadvantageous; it is more something that has to be taken into account in the early design stage of a high-rise building.

4.1 Conclusion

In the SWOT-analysis a vertical transport system within a building is shown to be a large potential, using less space than existing vertical transportation systems. To quantify the elements of the SWOT analysis, it must be known how much space will be gained with a sophisticated space reducing vertical transportation system. If the elements of the SWOT analysis are quantified, the benefits of the building with a new vertical transportation system can be quantified too. This quantification is not a part of this master project.

5 Existing shaft reducing methods for vertical transportation

A functionally effective building asks for a lift system which requires as little space as possible within a building. In this chapter existing shaft reducing methods will be discussed. Conventional lifts with one cabin in one shaft is the basic configuration of a vertical transportation system. This is a starting point for existing shaft reducing methods. These methods are in this chapter subdivided into three categories, related to the arrangement of a group of lifts, the type of lift and the control system.

The arrangement of a group of lifts. Lifts can serve a particular number of floors (zoning) or it can be possible that more than one lift must be used to reach your final destination (sky lobbies).

-Zoning (see paragraph 5.1)
-Sky lobbies (see paragraph 5.2)

The type of lift. Lift cabins which serve two floors per stop because the lift cabin has a double deck cabin. A twin lift system exists of two independent moving cabins in the same shaft which move as conventional lifts.

-Double Deck lifts (see paragraph 5.3)
-Twins system (see paragraph 5.4)

The control system. The control of the lift can be adapted on the way individuals ask for a lift. In case of destination selection passengers put a hall call by entering their final destination. The control of the lift knows earlier the final destination compared to a conventional lift.

-Destination selection (see paragraph 5.5)

This chapter will describe the methods and give a qualitative description of the positive and negative aspects of the shaft reducing methods described above.

5.1 Zoning

In case of zoning, each lift is usually not required to serve every level, since this would imply a large number of stops during each trip. The effect is an increase in the roundtrip time, which in turn increases the interval and passenger waiting time with passengers having to endure long journey times. The solution is to limit the number of floors served by the lifts. A rule of thumb is to serve a maximum of 15-16 floors successively with a lift or a group of lifts (Barney, 2003). This introduces the concept of zoning. Zoning is where a building is divided so that a lift or group of lifts is constrained to only serve a designated set of floors. There are two forms of zoning: interleaved (paragraph 5.1.1) and stacked (paragraph 5.1.2). Stacked zoning can also further be optimised (paragraph 5.1.3).

5.1.1 Interleaved zoning

Interleaved zoning indicates that the whole building is served by lifts, which are arranged to serve either the even floors or the odd floors. This has been a common practice in public housing and has been used in some office buildings. The effect is to reduce the number of stops a lift makes because there are fewer floors to be served. This also reduces the investment costs because there are fewer openings and landing doors to install. The service to passengers, however, is poorer than with a lift system serving all floors, because there is only one lift to take them to their floor. Tenants tend to solve this by calling both cars at the main terminal and if it is the "wrong" one, walking a flight of stairs to their floor (if they are able). Thus cars are unnecessarily brought to the main terminal. Interleaved zoning is therefore not recommended.

Positive aspects
- Reduce the number of stops per trip.

Negative aspects
- Passenger misuse. Passengers can give a request for both lifts, but use only the first arriving lift.

- Reduce the number of stops but compared to the stacked zoning principle a long (in distance and therefore in time) travel time.
- If a passenger is at the top region of a building and wants to travel to another region, he must travel via the ground floor. Psychologically, it can be strange that when you want to go up in the building, or you want to go to another floor, first you have to go down after that you can go up again. It would also be possible to take the stairs.

5.1.2 Stacked zoning

A stacked zone building occurs when a tall building is divided into horizontal layers, in effect, stacking several buildings on top of each other, with a common "footprint" to save ground space. It is recommended practice for office buildings and institutional buildings. Each zone can be treated differently with regard to shared or separate lobby arrangements, grade of service, etc. The floors served are usually adjacent, where the occupants of each region (zone) are associated with each other and can be expected to generate some inter floor movements. So it is recommended that a tenant rents office space in a region (zone), otherwise inter floor traffic requires travelling via the main terminal. The number of floors in a zone, the number of lifts serving a zone and the length of the express jump all affect the service times.

Positive aspects
- Reduces the number of stops per trip.
- Lifts will take less space at the higher region of the building.

Negative aspects
- Passenger misuse. Passengers can give a request for more lifts, but use only the lift which serve the destination floor of the passenger.
- If a passenger is at the top region of a building and wants to travel to another region, he must travel via the ground floor. Psychologically, it can be strange that when you want to go up in the building, or you want to go to another floor, first you have to go down after that you can go up again. It would also be possible to take the stairs.

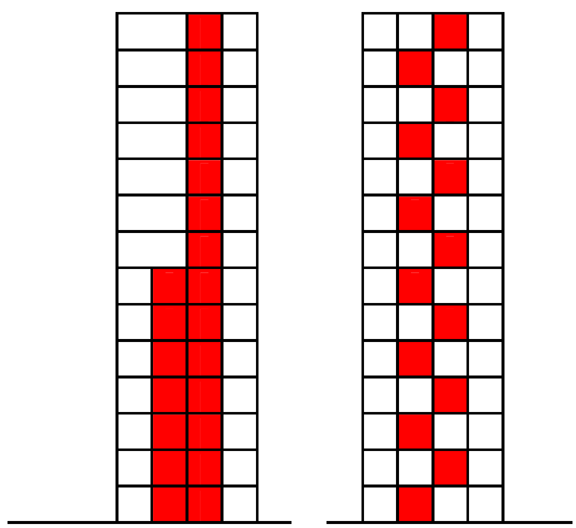

figure 13. Stacked zone principle (two zones) (left). Interleaved zone principle (right)

5.1.3 Optimised Zoning

Stacked zoning can be optimised by positioning the shafts close to each other. If the entrance at the main terminal is spread over different floors the entrances of the lifts are located above each other so entering at the main terminal of the lifts is possible (Wiersma, 2006). Because of the zoning principle not all the lifts have to go to the top, so at the landing places at the floors the exits (and entrances) are free. There are more space reducing solutions for lifts systems when the entrance of the lifts are spread out over more than one floor, for example a double deck lift, so this is not uncommon. The lift itself needs to have some attendance, so the lift pit can not be too deep and the machine room on top of the lift shaft can not be too high. There also has to be a special tool to enter the shaft in the middle in case of an emergency, with current techniques this is possible.

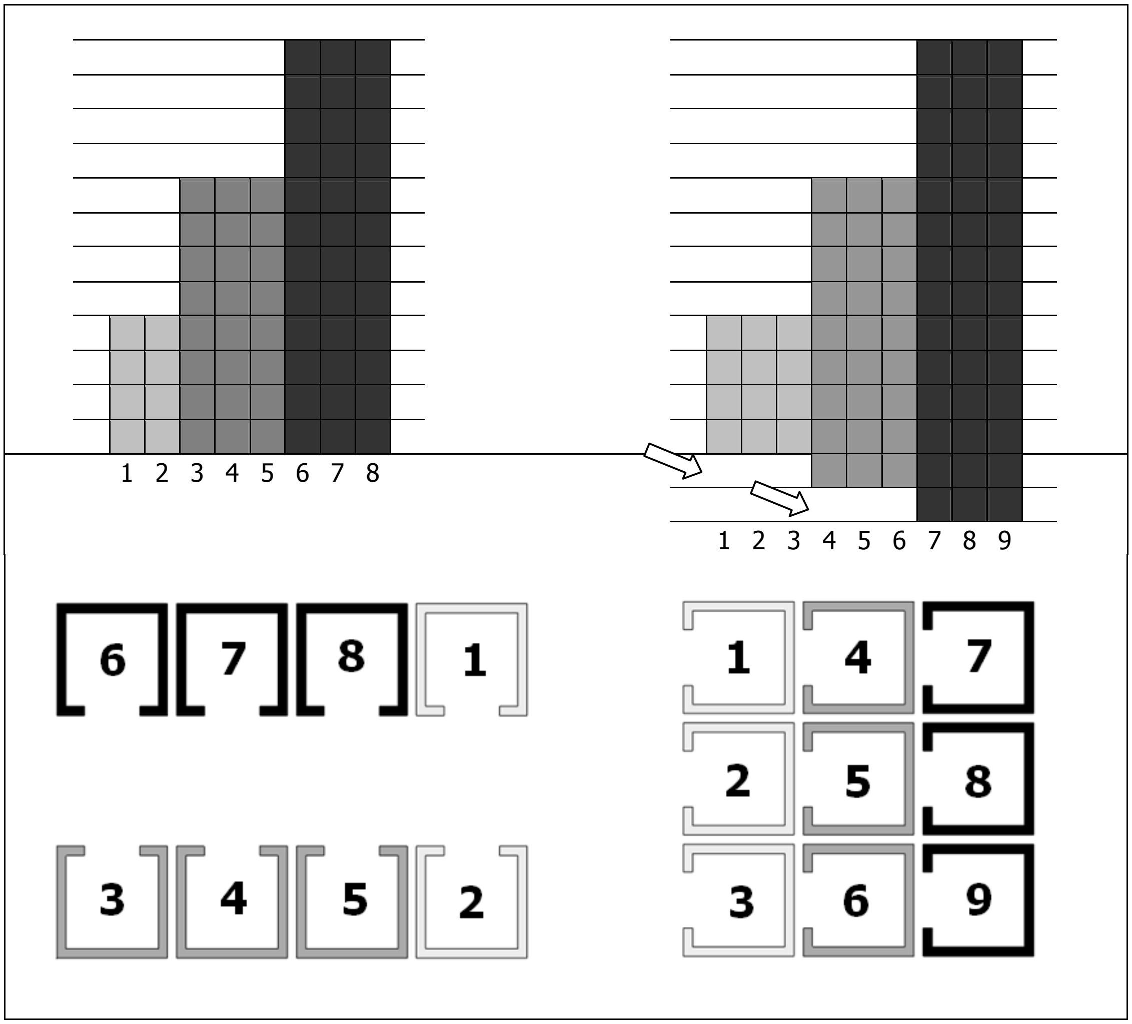

figure 14. Schematic scheme of Space reducing method for vertical transport in a high-rise building without reducing the number of shafts, Left stacked zoned principle with 8 lifts. Right, optimised stacked zoned principle with 9 lifts.

If the buildings become taller, more shafts are needed per zone. Not all the exits at the landing places at the floors are used on every floor; they are only all used at the main terminal. So at those floors where they are not in use, it is possible to give another function at that particular place, for example a toilet or a closet. This is shown schematically in figure 15.

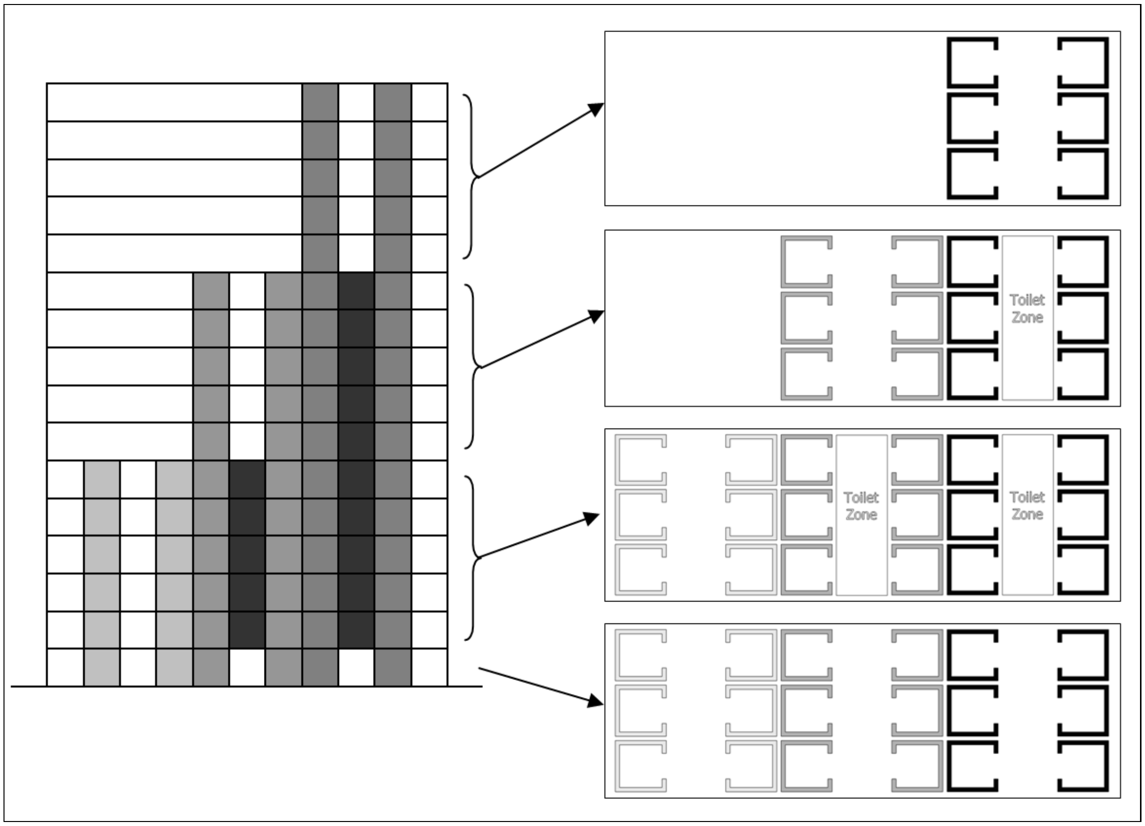

figure 15. Schematic scheme of other functions, for example a toilet, at places where the boarding area is not used. Drawing of a vertical cross-section (left), and plans (right)

The optimised zoning principle has the same positive and negative aspects as the stacked zoning principle addition to the following:

Positive aspects
- Space used more efficiently.

Negative aspects
- Lift requires attention. Smaller lift pit and machine room on top, otherwise the first floors above a lift can not be used.

5.2 Sky lobbies

Sky lobbies are used as transfer zones in vertical transportation, see figure 16. They partially overcome the problem of increased shafts in the lower portions of the project because all lifts do not have to serve the entry level. The upper local zones are stacked on top of one another, so the lift shafts, generally, occupy the same "footprint" as the local zones below. This group of lifts above the stacked zones below is served by a shuttle lift. A shuttle lift will stop at two places, at the main lobby and at the sky lobby. Unless the building tapers or steps back - the same number, arrangement, size and speeds of the local lifts are again duplicated in each stacked zone. A building can contain more than one sky lobby at different levels, so the vertical transportation is split up into smaller parts.

Positive aspects:
- Used space, especially at the bottom of the high-rise tower, is used efficient.

Negative aspects:
- Passengers must change lifts mid journey, hence increasing their total journey time. This is not the case for passengers with their destination in the lowest stacked zones (underneath the first sky lobby)

- Most of the time it is necessary to transfer, if you change your floor. This is not the case for inter floor traffic in the same zone.
- If a passenger is at the top region of a building and wants to travel to another region, he must travel via the ground floor. Psychologically, it can be strange that when you want to go up in the building, or you want to go to another floor, first you have to go down after that you can go up again. It would also be possible to take the stairs.

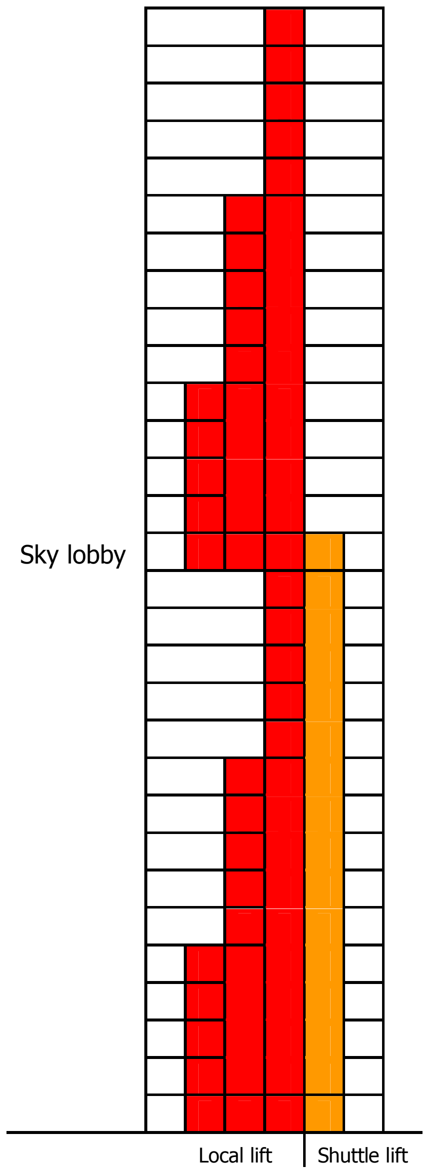

figure 16. Lift configuration stacked zoned configuration with a sky lobby and a shuttle lift

5.3 Double (and triple) deck lifts

Double-deck lifts comprise two passenger cars, one above the other, connected to one suspension/drive system. The upper and lower decks can thus serve two adjacent floors simultaneously. During peak periods, the decks are arranged to serve "even" and "odd" floors respectively with passengers guided into the appropriate deck for their destination. Special arrangements are made at the lobby for passengers to walk up/down a half flight of stairs/escalators to reach the lower or upper main lobby. Double-deck lifts, which are common in the U.S. and elsewhere, but unusual in Europe, are used in high-rise buildings. There are many advantages and disadvantages to double deck operation (Fortune, 1996) and special care has to be taken with the lobby arrangements. One advantage for double deck lifts is that handling capacity is improved, as effectively there are two lifts in each shaft. A disadvantage for passengers during off peak periods is when one deck may stop for a call with no coincident landing, or car call, required on the other deck. Fortune (1996) describes special control systems that are available during off peak periods, such as skip/stop, trailing deck and restricted deck service.

Positive aspects (Fortune, 1996):
- Fewer cabins, more people can fit in one cabin because passengers can stand above each other in same car.
- Smaller cabin size, passengers stand can stand above each other in case of behind each other.

Negative aspects (Fortune, 1996):
- Passenger misuse.
- Balanced demand from even and odd floors.
- Inter floor distance must be regular.
- Lobby exist need to be larger.
- Special facilities for disabled access to "other" floors.

5.4 Twin System

In the twin system, two cabins arranged one above the other can run independently, also at different speeds, in the same shaft, see figure 17. The cabins can move in a different direction, which means that they can also move toward each other. It is necessary to add a destination selection control (see also paragraph 5.5) on the group of lifts, so there can be calculated which shaft and which cabin can be used for the best and fastest journey. Without a destination selection control the twin system is less accurate.

Positive aspects
- Less core space.
- It is not necessary to shut down the whole system during maintenance work – one of the TWIN's cars can remain in operation (remark, it is not possible to serve all the floors).
- The distance between floors does not need to be fixed (compared to double deck lift).
- No connections are needed between access levels.
- The use of two conventional drives considerably simplifies installation of the drive unit in the machine room.

Negative aspects
- Lobby exist need to be larger.
- Not all the cabins can reach the upper and lower floor; only possible with special arrangements.

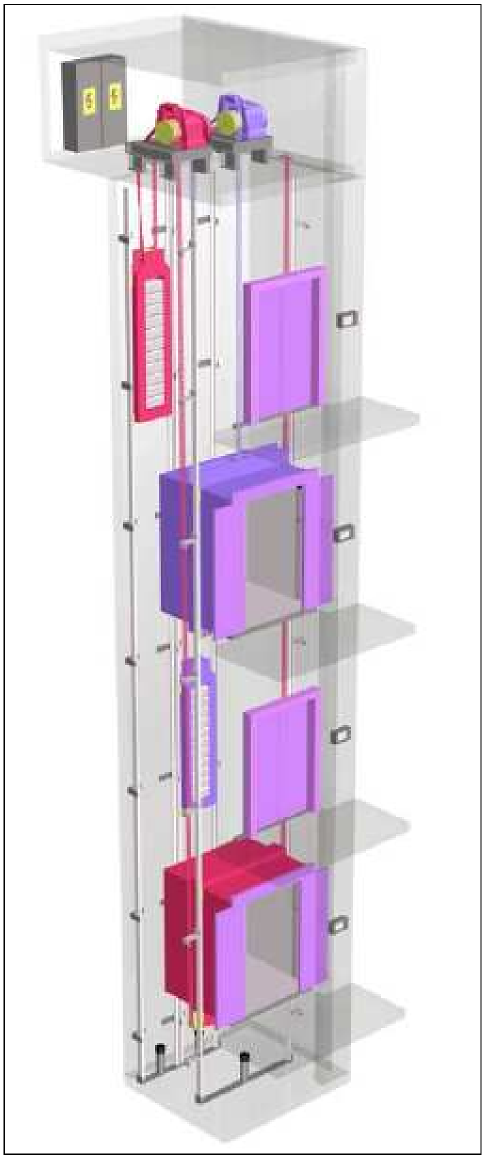

figure 17. Twin lift, Cabins operate separate (Image ThyssenKrupp)

5.5 Destination (Selection) Control

A destination selection control (DC) system is useful with a group of lifts. It is a system in front of the entrance of a group of lifts the final destination floor must be given. A computer determinse which lift cabin will give the fastest journey and the cabin will go to the given floor. This system has therefore no buttons inside the cabin, this can be unexpected if the system is used for the first time. In the cabin itself it is necessary that the system indicates at which floors the cabin will stop. Passengers will be grouped who have to go to the same region of the building, so the number of stops will be decreased. During up peak the main terminal will be less crowded because people know which cabin they have to enter and they do not want to enter all the same cabin. The system can be fit to the traffic pattern of the moment like up peak, down peak or two way demand.
The system knows much earlier than a conventional system the destination of the passengers and can anticipate on what is coming.

Positive aspects
- Reduces stops per trip.
- Reduces passenger waiting time.
- Reduces travel time.

- Organised passenger flow in the main terminal (see figure 18).

Negative aspects
- The system works different from conventional system, passenger confusion is possible.

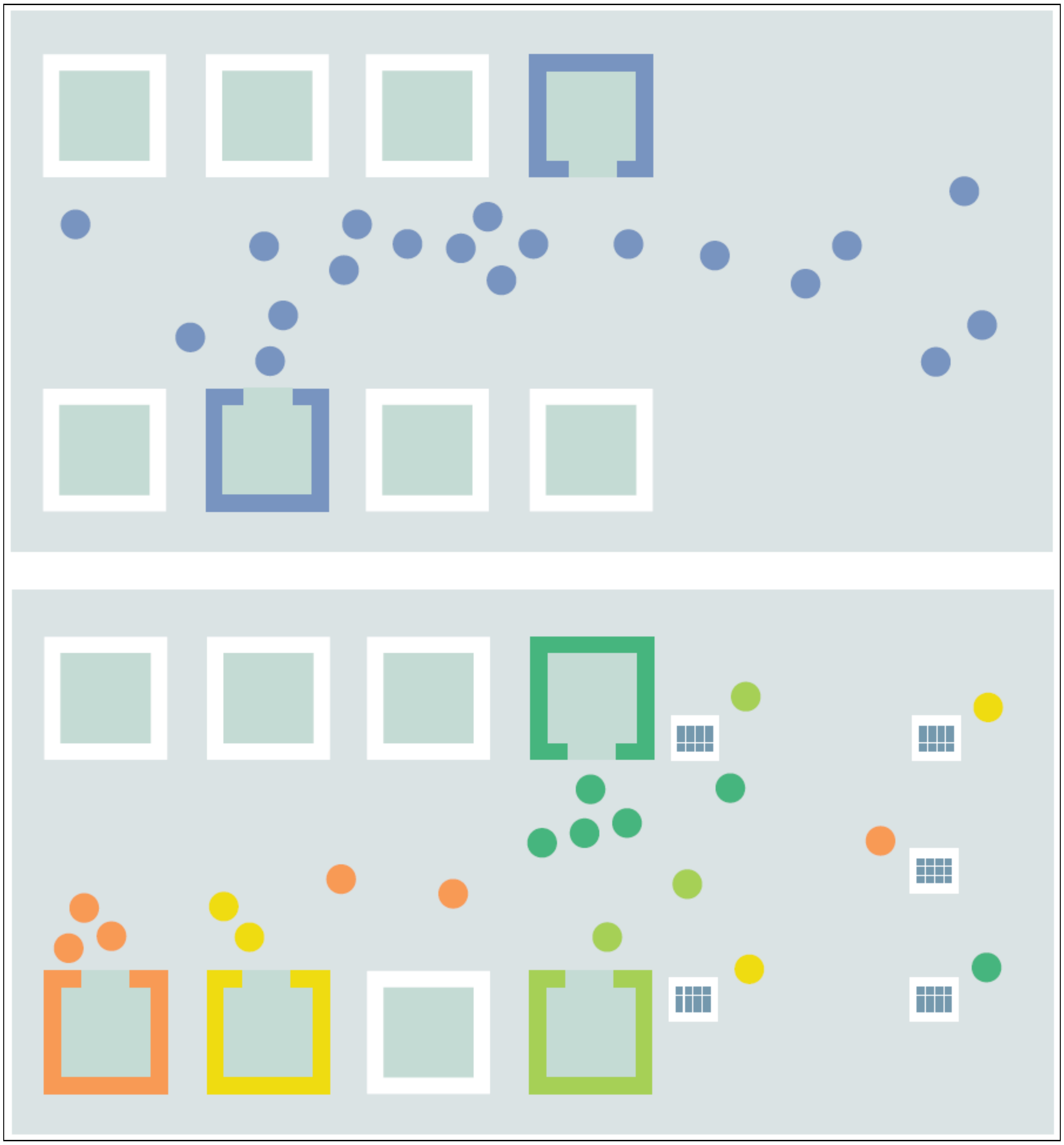

figure 18. Destination selection control, Above conventional system, Below Destination selection system. Passengers will be grouped per lift, by the destination selection control mechanism (Image Otis)

5.6 Conclusion

Several methods are developed to minimise the space used for vertical transportation within a building. When the discussed shaft reducing methods will be combined, for example a zoned double deck transport system with destination control, a better vertical transportation system can be obtained for a particular building.
The basic principle for the described shaft reducing methods are still all based on cabins that go up and down in the same shaft thus not maximising shaft use. This is not the case by the loop transport principle and is from an infrastructural point of view different and therefore interesting to investigate.

Combining aspects of existing shaft reducing methods with the loop transport principle could be an option to develop an optimal vertical transport system. Zoning and destination selection can be used for a vertical transportation system based on the loop transport principle. Within table 9 the previous mentioned positive and negative aspects for the different shaft reducing methods are given.

table 9. Positive and negative aspects of different shaft reducing methods

Shaft reducing method	Positive aspects	Negative aspects
Zoning		
Interleaved zoning	Reduce the number of stops per trip.	Passenger misuse. Passengers can give a request for both lifts, whether one lift is unnecessary.
		Reduce the number of stops but compared to the stacked zoning principle a long (in distance and therefore in time) travel time.
		If a passenger is at the top region of a building and wants to travel to another region, he must travel via the main terminal. Psychological can be strange that if you want to go up in the building, or you want to change your floor, first you have to go down after that you can go up. It would also be possible to take the stairs.
Stacked zoning	Reduces the number of stops per trip.	Passenger misuse. Passengers can give a request for both lifts, whether one lift is unnecessary.
	Lifts will take less space at the higher region of the building.	If a passenger is at the top region of a building and want to travel to another region, he must travel via the main terminal. Physiological it can be strange that if you want to go upstairs in the building, or you want to change you floor, first you have to go down after that you can go upstairs.
Optimised zoning	Space used more efficiently.	Lift requires attention. Smaller lift pit and machine room on top, otherwise the first floors above a lift can not be used.
Sky lobbies	Used space, especially at the bottom of the high-rise tower, is used efficient.	Passengers must change lifts mid journey, hence increasing their total journey time. This is not the case for passengers with their destination in the lowest stacked zones (underneath the first sky lobby).
		Most of the time it is necessary to transfer, if you change your floor. This is not the case for inter floor traffic in the same zone.
		If a passenger at the top region of a building wants to travel to another zone, he must travel via the main terminal. Psychologically it can be strange that if you want to go upstairs in the building, or you want to change your floor, first you have to go down after that you can go upstairs.
Double (and triple)deck lifts	Fewer cabins, more people can fit in one cabin because passengers can stand above each other in same car.	Passenger misuse.
	Smaller cabin size, passengers stand can stand above each other in case of behind each other.	Balanced demand from even and odd floors.
		Inter floor distance must be regular.
		Lobby exist need to be larger.
		Special facilities for disabled access to "other" floors.
Twin lifts	Less core space.	Lobby exist need to be larger.
	It is not necessary to shut down the whole system during maintenance work – one of the TWIN's cars can remain in operation (remark, it is not possible to serve all the floors).	Not all the cabins can reach the upper and lower floor; this is only possible when there are done special arrangements.
	The distance between floors does not need to be fixed (compared to double deck lift).	
	No connections are needed between access levels.	
	The use of two conventional drives considerably simplifies installation of the drive unit in the machine room.	
DC (Destination (Selection) Control)	Reduces stops per trip.	The system works different from conventional system, passenger confusion is possible.
	Reduces passenger waiting time.	
	Reduces travel time.	
	Organised passenger flow in the main terminal.	

6 Vertical loop transport principle (developed within thesis)

As described in the chapter 2, Problem and objectives, the loop transport principle and the variations (figure 19) are investigated in this master project and are compared by their influence of a building, main issue is the used space of the transport system and the associated level of comfort. This chapter will describe the loop transport principle more into detail.

The capacity optimisation is approached from the building's point of view. The optimisation of a high-rise building is the focal point. This is not possible without looking at the mechanical possibilities of a vertical transport system. But first it is necessary to know what this system must be capable of, how and when cabins move through the building and how the cabins move in respect to each other. This must be known before the design of the mechanical transportation system can be continued. The mechanical system will not be developed into detail in this master project; focal points for the mechanical system will be developed.

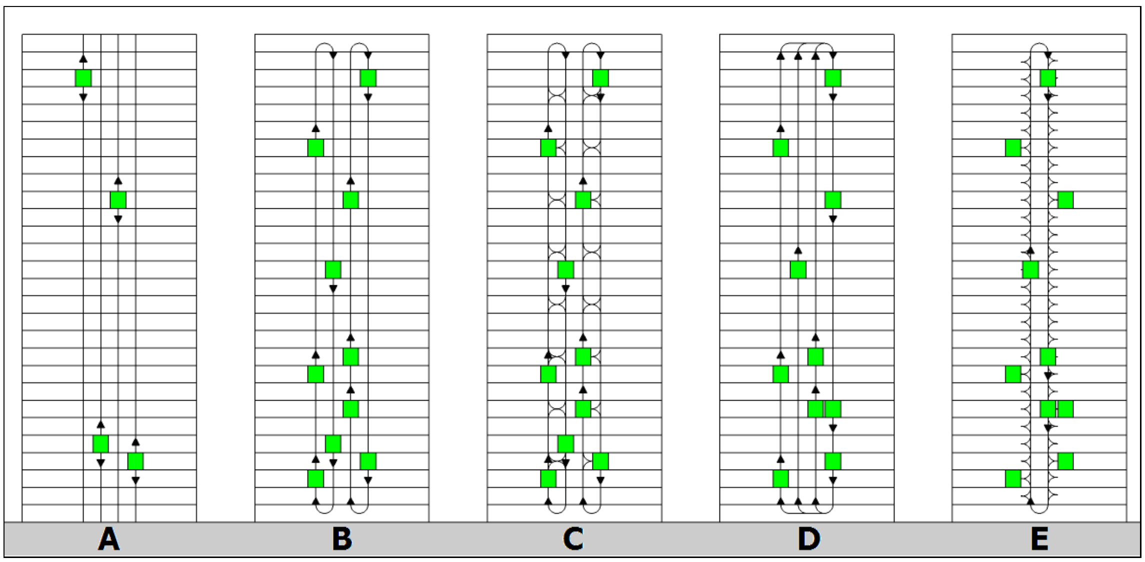

figure 19. A: Conventional lift, B: Loop-transport-principle, C: loop-in-loop transport principle, D: 3-1 loop transport principle, E: Cabin-out-loop transport principle

The loop transport principle and the variants given in figure 19 will be discussed in paragraph 6.1 to 6.4. The variants are discussed theoretical, in practice lift system should also fit into a building. For now this is not taken into account.

6.1 Loop principle (figure 19 b)

The loop transport principle is based on a track where lift cabins can move independently through the shaft. Cabins must travel behind and in succession independently. Within the shafts there will be one-way-track traffic. At several places but definitely at the top and at the bottom cabins must be able to switch shafts, in order to change their vertical direction.
Starting point for the loop transport principle is that it has to work for users of the system more or less the same compared to a conventional system. A passenger has to push a button at a hall call location, then a cabin has to stop and bring the passenger to his/her destination floor. In the loop transport principle it will be possible that a cabin filled with passengers moves horizontally, this has to be done in a smooth way.

6.1.1 Examples of loop principle in vertical transport

The loop-transport-principle is not totally new in vertical transportation. Three other systems can be found: Paternoster lift, Goods lift and ski lifts. These three transportation systems will be shortly cited in the following three paragraphs.

6.1.1.1 Paternoster lift

The paternoster lift is a lift with open cabins. Cabins can fit one or two passengers and are attached to a continuously moving chain which makes a loop from the bottom to the top of the building. The chain moves slowly, so it is possible to enter or exit a cabin easily at every floor. It is possible to say that a paternoster lift is some sort of vertical escalator. These kinds of lifts have some disadvantages; disabled people in a wheelchair cannot use the paternoster and elderly people who do not walk very well can also have problems to enter or exit the lift. There is also a high risk for accidents, passengers can be flattened or fall when they enter or exit the lift, when this occur the whole system temporarily useless. In many countries it is therefore no longer allowed to construct paternoster lifts.

The paternoster lift is from an infrastructural point of view a good solution but in practice there are too many and too large disadvantages. Improvements to the concept could help to eliminate the disadvantages.

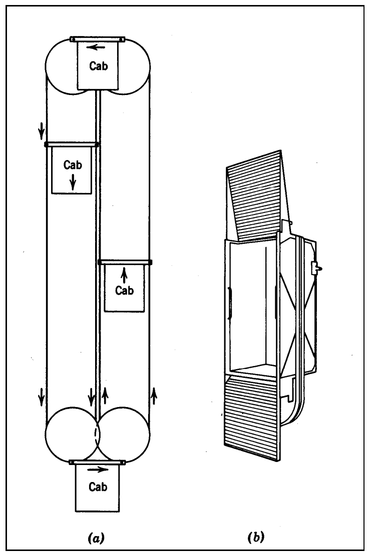

figure 20. "Paternoster lift" (a) Schematic; (b) paternoster car (Strakosch, 1998)

6.1.1.2 Goods lift

There are many types of goods lifts (freight lifts). Goods lifts can be large or small, they could be only for goods or for goods accompanied by an employee. Mostly goods lifts are comparable to the usual lifts. Loop principles in goods lift are only known for not too heavy goods; for example postal services within a building. An example of a good lift can be found in figure 21.

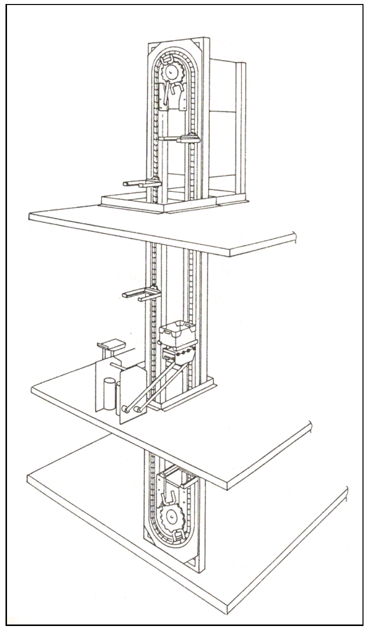

figure 21. Cutaway of a selective vertical conveyer system, goods lift for postal services (Strakosch, 1998)

6.1.1.3 Ski lift

A ski lift with chairs, benches or cabins is an inclined loop transport system; in fact it is a horizontal and vertical transport system. There are ski lifts where the cabins can be uncoupled from the cable so it is easier to enter or exit the cabin and the cable can travel faster. The comfort standards for a ski lift are different than for a lift in a building because it is (often) not necessary to deal with disabled and wheelchairs as a building lift has to do.
There are ski lifts which do not use the loop transport principle, these lifts are usually quite larger and travel with a pulley over a pre-stressed cable and are moved back and forth by another cable.

figure 22. Ski lift (image www.seilbahntechnik.net)

6.2 Loop-in-Loop principle (figure 19 c)

In the loop-in-loop principle the cabins have the possibility to change shaft at several places. It is therefore not necessary for cabins to go entirely up or down. This can be positive when some parts of the building have more traffic (than other parts). This is for instance the case in a high-rise tower with various functions, for example apartments combined with offices. Offices have much more traffic than apartments.
Another interesting situation arises when there is one floor which requires a lot more traffic than others it is possible to use two stopping places for cabins which arrive from the same direction. They can both stop at the top (or bottom) of a loop, see figure 23.

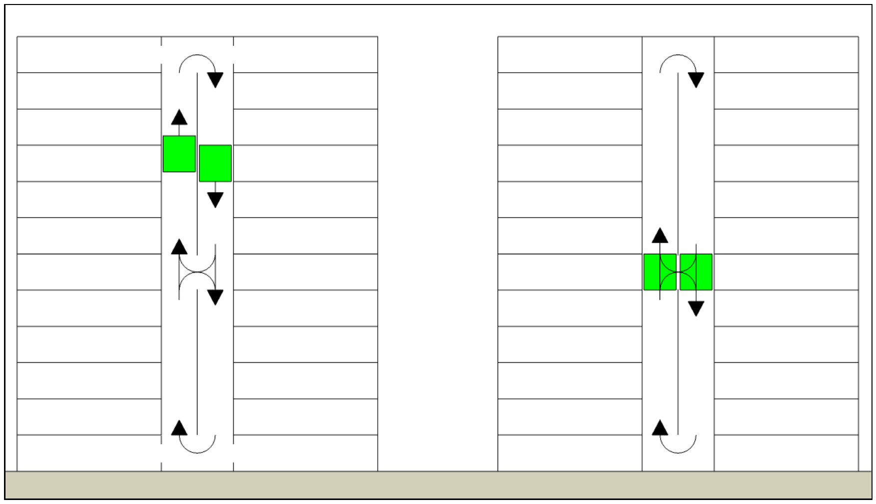

figure 23. Left: Loop in loop principle. Right: Loop in loop principle option for two cabins which came from the same direction it is possible to stop at the same floor

6.3 3-1 Loop principle (figure 19 d)

The 3-1 loop principle can be effective during an up or down peak. In the 3-1 principle there are more shafts in use for traffic in downward or upward direction. As we have seen in the example of the shuttle lift, a limiting factor in a loop system is that cabins have to stop for passengers to enter or exit. Therefore it is impossible to pass the cabin with a cabin because it blocks the shaft. During up peak there is much more demand for upwards traffic so if the number of shafts for upward traffic increases the possible number of stopping places increases as well. The number of stops for downward traffic is much less compared to upward traffic, so the decrease in possibilities for stops for downward traffic is not limiting. The system must be able to invert to facilitate the down peak in the afternoon.

The configuration of 3-1 is flexible; it is also possible to have a 2-1, 3-2 or other configurations, only limited by the number of shafts. The chosen configuration depends on the traffic demand. An advantage of the 3-1 configuration is that there is an even number of shafts so it is easy to switch to loop principles. On the other hand, with an odd number of shafts there is always one extra shaft for upward or downward traffic, which can facilitate the asked traffic demand.
In the figure 24 the 3-1 principle is drawn as a formation of up-up-up-down and up-down-down-down this is not fixed. An up-up-down-up configuration is for instance a more efficient system in relation to the horizontal movement of the lifts. This configuration will give a maximum necessary horizontal movement of two shafts. Since the horizontal movement of the lifts is fairly inefficient it should be reduced to a minimum. Horizontal movement for a passenger is much simpler than horizontal movement for a cabin, the less horizontal movement for cabins the better.

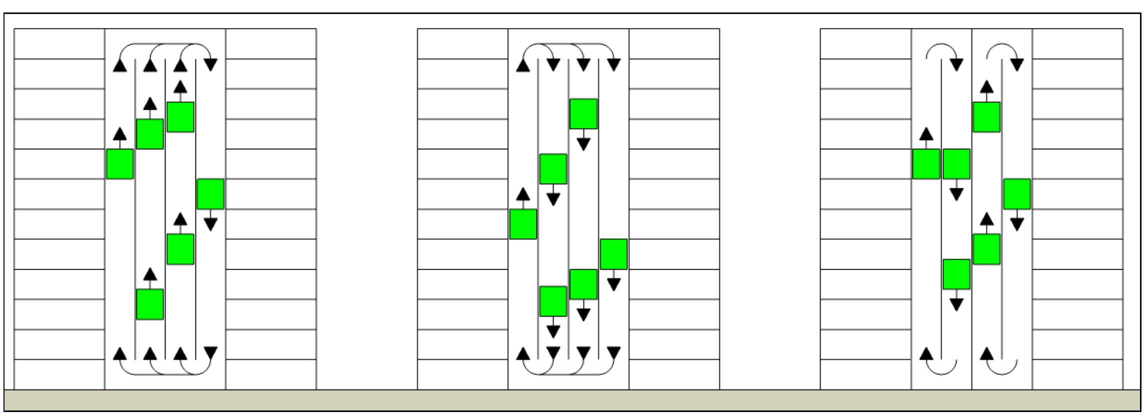

figure 24. 3-1 loop principle. Configuration for up-peak traffic (left). Configuration for down-peak traffic (middle). Configuration for two-way- or midday traffic (right).

6.4 *Cabin out loop principle (figure 19 e)*

Starting point for the cabin out loop transport principle is to keep the shaft free for moving cabins and use stopping places for stops. The gain is that the shafts are free for continuing traffic and cabins can pass each other. It must be said that these stopping places also took place, this must also be taken into account in it. The configuration of this principle can be done in several ways; firstly the principle of a cabin which went temporarily out of the shaft can be applied on a conventional lift. A cabin will use the same shaft for up and downward movements (figure 25, left). If the loop transport principle is applied there are two options, the cabins move outside the loop for stops (figure 25, middle) or the cabins move inside the loop for stops (figure 25, right). The principle where the cabins move inside the loop for stops is an interesting variation because it creates a loop in loop principle.

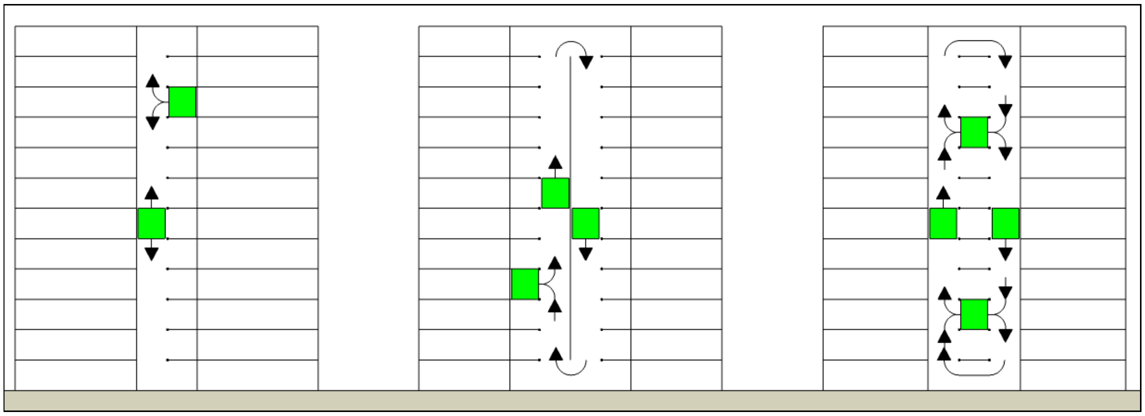

figure 25. conventional lift cabin out shaft (left). Cabin out loop principle "outside" (middle). Cabin out loop principle "inside" (right)

6.5 *Points of interest for loop transport principle*

Controlling the cabins is an important aspect, to prevent collision of cabins. Intelligent computers and software, combined with sensors for precise determination of the location of the cabin, must make this possible.

Horizontal movements and the changing of movement from vertical to horizontal have to be smooth. A similar movement can be found by the Schmid Peoplemover© (figure 26) and is used to pass roads or railways in a clever way. The maximum horizontal speed is in the Schmid Peoplemover© is 2 m/s.

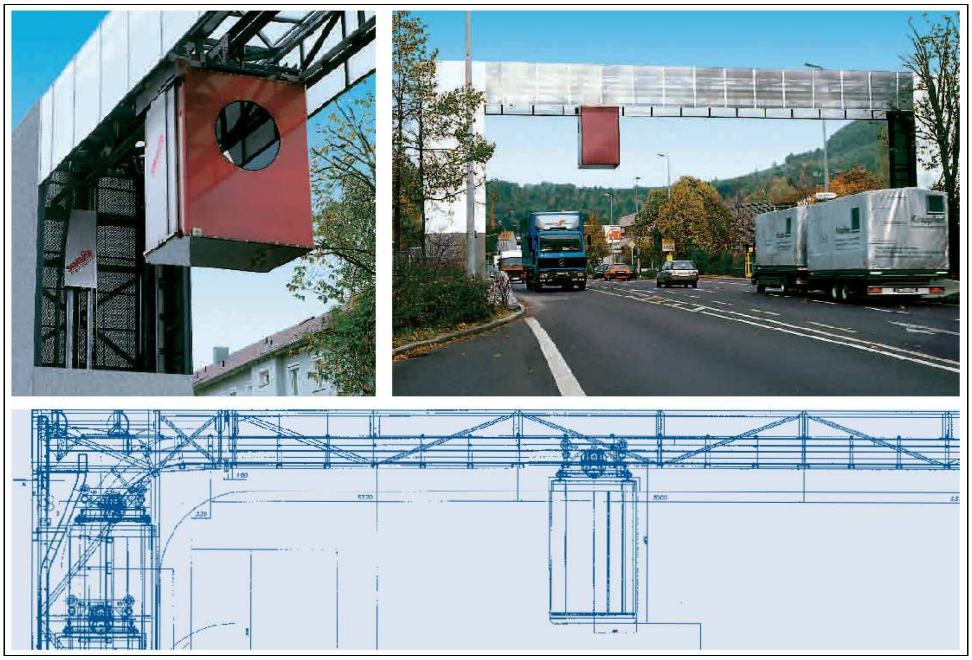

figure 26. Schmid Peoplemover (ThyssenKrupp)

The maximum horizontal acceleration or deceleration acceptable for a lift is 0.2g (Liftinstituut, The Netherlands). When inclined lifts must make an emergency stop the acceptable value for horizontal acceleration is between 0.2g and 0.4g (Liftinstituut, The Netherlands). In case of an emergency, higher values are acceptable because of the exceptional situation.

The control system is an important aspect in the functioning of a group of lifts. The way a passenger calls a lift at a landing place influences the control system and therefore the capacity of the lift system. There are 4 options to register a call at a landing place; Non directional collective, Down collective, Directional collective and Destination selection collective registration.

-Non directional collective
A single call button at each landing place; when the button is pushed the system knows that a passenger is waiting, but the system does not know what the direction and the final destination of the passenger is. Passengers must enter their final destination inside the lift cabin. Therefore it is possible that a passenger is transported first in a wrong direction before the cabin is moved in the right direction to the final direction. This type of collective is most suitable for short travel lifts. By non directional collective the system knows that there is a passenger waiting at a landing place where a button is pushed. The system has to wait until the passenger has pushed their final destination button inside the cabin to know the direction.

-Down collective
Assuming very little inter floor traffic; this is the case if there is no (or a few) traffic needed between floors, for example in an apartment complex or an office building with a single tenant at every floor. The control system can assume that all the calls at landing places have the intention to go downwards to the main terminal. If a lift is going upwards to deliver a passenger it is not needed to stop and pick up the waiting passenger. When the lift is moving downwards again the lift can stop and bring the waiting passenger to the main terminal. Summarizing it can be said that by down collective the system is told when a passenger is waiting at a landing place and the system assumes that passengers want to go down. Only if the landing call is at the main terminal the direction is assumed upwards.

-Directional collective
At each landing place, except from the bottom- and top floor, there are two buttons; one button is for upward directions and one button for downward directions. The system knows the direction of the

passenger and can adapt the system to the most efficient trip for the passenger. It is not possible, if the system is programmed well, that passengers first will be transported in a wrong direction. Passengers must enter their final destination floor within the cabin. By a directional collective the system knows the direction of the passenger before he entered the cabin.

-Destination selection collective (Destination selection control)
This type of collective is also discussed in chapter 5.5 (Shaft reducing methods). A destination selection control system is a system where not in the cabin itself but just before the entrance of a group of lifts the final destination floor must be given. The system can determine which lift cabin will give the fastest journey and the cabin will go to the given floor. Passengers will be grouped by region of the building, so the number of stops can be decreased.
The system knows much earlier than a conventional system what the destination of the passengers will be and can anticipate what is coming.

The four options show that there are three options a passenger can call a lift at a hall call location:
- One button. *Non directional collective* and *Down collective.*
- Two buttons. One button for upward movements and one button for downward movements. The top and bottom floors will have one button at the hall call location, because at these places there is only one direction possible. *Directional collective.*
- At a panel, the destination floor must be given at the hall call location. *Destination selection collective.*

The sooner the system knows the destination of the passenger the better the system can determine the fastest (average) trip. Therefore the total capacity can be optimised. Non directional- and down collective are more suitable for short trips and therefore less interesting for investigation in this master thesis.

6.6 Technical requirements

The described loop-transport-principles ask for a lift system where cabins can travel independent. They must travel above each other and in succession and there must be a possibility that cabins can change shaft. The horizontal movement has to be smooth, because passengers must feel comfortable if they are in a horizontal moving cabin that is changing from shaft.
Acceleration and jerk are determined by physical constraints of passengers, these requirements are therefore the same as for a conventional lift. Other lift parameters, like door opening and closing time and speed must be at least the same as in a conventional lift. These parameters are already minimized for conventional lifts.

The most important thing for the loop transport principle to succeed is the reliability of the system; it needs to be at least as reliable as a conventional lift. This is, however, hard to express in a technical requirement so it is more a general comment than a technical requirement. Passengers and people who make the decision for a lift system must trust the system and must want to use it. This is largely dependent on the technical accomplishment of the system, a system can work in a theoretical way but it has to work in practice too.

Conventional lift cabins use a cable to pull the cabin up- and downwards or a hydraulic system to press the cabin up- or downwards. In conventional lifts there is always a cable above or a hydraulic system underneath the cabin, so it will be difficult to let the cabins travel behind and in succession because the cable is in the way. TWIN lifts, were two cabins travel in one shaft, have overcome this problem to put the cable not in the movement field of the other cabin which moves in the same shaft.

Lifts which travel higher will have a maximum for a cable system, on a given moment the steel cable will become too heavy due to its own weight. This will occur at a height of about 700 meters. There are alternatives for the material of the cable in conventional lifts, like Kevlar, where the self weight is less dominant (compared to steel). These techniques are in an early development stage.
As shown in the example of the shuttle lift (paragraph 5.2), taller buildings will make the loop-transport principle more efficient compared to a conventional lift system. It will also be hard to let

several cabins move behind each other when a cable is used. A lift system without a cable would be a very good option for a loop-transport-system and for the future of high-rise buildings.

When it is physically possible to let different cabins travel above each other as the loop transport principle describes, it is very hard to attach a communication cable or an electrical cable against the cabin. The cables can become a knot. Cabins always need electricity and need to communicate with the main control system. Therefore there must be worked with a guiding rail for electricity (or a battery which has to be filled) and communication is needed. Another option for communication could be a wireless connection. These techniques are available for lift builders.
When it is no longer possible to use a cable for instance in the case where a number of independent cabins travel behind each other, it will become very difficult to make use of a counterweight. A counterweight is normally used to make the transportation of the passengers and the cabin more efficient, from an energy consuming point of view. The counter weight in current conventional lifts is also necessary to gain enough traction onto the traction blade and the steel cable, this to prevent a slipping cable.

Physical transmission
Lifts that uses a cogwheel transmission, for example a building lift. With these kinds of lifts it will be possible to travel behind each other, but horizontal movement and shaft-changing of the cabins and the energy consuming need to be investigated. Travel comfort for passengers also needs to be optimized; a smooth journey without shocks is eminent.

Magnetic transmission
Magnetic transmission in lift industry is not new but it is a stating discipline. Magnetic transmission works with a LIM (Linear induction motor). The cabin is moved due to the change in magnetic field and therefore it is pulled forward. Examples of vehicles driven by a LIM are the Shanghai maglev train in Shanghai and the Transrapid in Germany. These trains “float” over a rail and trains do not use wheels; the magnetic field carries the train. This minimises the friction between rail and train so high speeds can be gained.
There are also metro systems where the trains are moved by a LIM, they use wheels as guiding but the transmission is a LIM (example: AirTrain JFK (New York, USA, 2003).

Lifts with a linear induction motor (LIM) are used since April 1990, and firstly installed in a Tokyo office building belonging to Bansei construction Co (Fujisawa, Norihiko, 1990). The lift still use a cable; the LIM is built in the counterweight. The reason to use the LIM transmission is that there is much less direct contact of moving elements so the will be less wear. The Linear Induction Motor moves the counterweight and with that the cabin. A break is needed, which is attached to the counterweight, so the cabin can stop. In Europe there is one LIM lift installed at the office of Konhef in Belgium, Antwerp. Konhef is a company for external service for technical control of lifting gears. Lifts with this type of transmission (LIM with a cable) are no longer used in Europe because they are too expensive compared to the gained benefits.

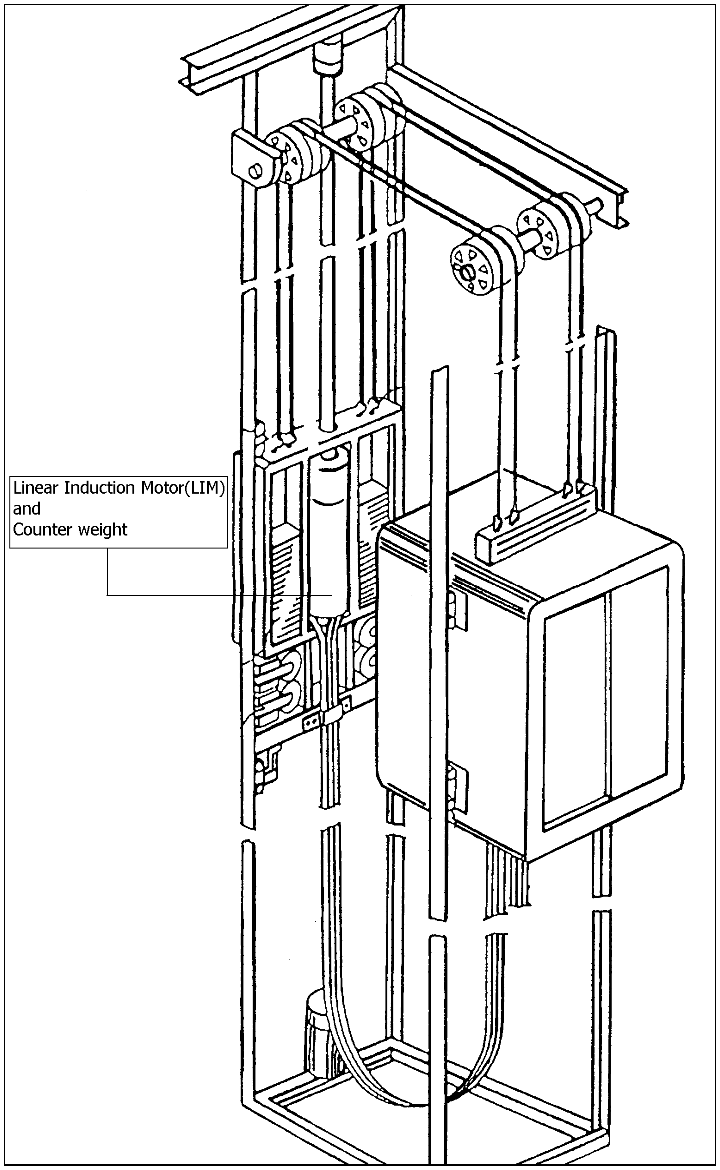

figure 27. Lift with a Linear Induction Motor (LIM). (Image: United States Patent: 5,074,384)

When the LIM is attached against the cabin the cable can be loosed, which would be very positive for the loop transport principle. There are two options for a lift using a linear induction motor. The magnetic field of the track (shaft) changes so the cabin will be pulled by the magnetic field of the track, or the magnetic field of the motor attached to the cabin changes and the cabin pushes itself through the shaft.
It will be difficult to make use of a counterweight when the cabins are self-propelled, this means that the energy efficiency of the system will need to be improved in a different way. Energy for down going cabins needs to be regained, which is possible with a linear induction motor. Cabins which move upwards will then use energy and down going cabins will produce energy. When considering vertical transportation in a building in a theoretical way, only the friction forces need to be overcome; since cabins and passengers are on a specific height, they have potential energy.

At the time of writing, there are no systems known where a cabin is self-propelled by a linear induction motor, but already several patents have been requested:

1. August 30, 2007
   Title: *Elevator installation with a linear drive system and linear drive system for such an elevator installation*

2. January 10, 2002
   Title: *Elevator comprising a linear motor drives*
3. February 6, 1998
   Title: *Linear motor for driving an elevator car*
4. August 10, 1993
   Title: *Rope less linear motor elevator system*

These patents can be found in the appendix c, “Patents of lift systems with linear driven systems”. More patents about this subject are available but these are the most relevant ones.

The techniques described in the patents can be used for the loop transport principle. One of the things that have to be solved is how the cabins can change their shaft in a smooth way.

When the cabins are self-propelled it is very well possible that not all the cabins are used the whole day long, this depends on the capacity demand. The loop transport principle therefore requires temporary storage for cabins.

The system can be optimised when the system knows whether the cabin is full or empty. This way the cabin does not have to stop for hall calls, only to show to the waiting passengers that the cabin is full. If a balance is installed, combined with sensors it would be very good possible to estimate the number of passengers in a cabin. This will only be effective when cabins are filled at several floors, which will occur during down peak and mid day traffic pattern. During up peak the capacity of the total vertical transportation system will not be influenced that much, since the cabins are filled at the main terminal. Techniques to estimate the number of passengers in a cabin are available for lift builders.

6.7 Safety requirements

Safety is a very important aspect for every (vertical) transportation systems. Safety, in case of a loop transport system, needs to have, at least, the same standards as conventional lifts. Safety is important for all the persons who are involved in the lift system. Below some points of interest are set out concerning safety for different persons involved in the lift.

Safety for passengers, users of the lift

-The cabin must never fall through the shaft. When a lift would fall it could take along other cabins. That is why a fall protection and also a back-up fall protection for the cabins are essential.
-Cabins are not allowed to hit each other. (Twin lifts uses a safety of six meters (approximately two floors) between moving cabins)
-Stagnated cabins must be prevented.
-A cabin must be able to be cleared safely in case of stagnation.

Safety for maintenance-, service- and installation engineers

-Installation of the system needs to be safe.
-Self-powered cabins can break; in this case a service engineer has to repair the cabin. It will be interesting if a cabin can be removed from shaft and repaired outside the shaft. The service engineer will then not have to repair the cabin inside the shaft, and all parts of the cabin can be easily reached.
-It must be possible to safely perform periodical checks.

Safety for users of the building

-In case of the magnetic lift, the magnetic field may not be uncomfortable for users working in the building.

Safety in case of an emergency (like fire)

-A positive aspect of a self-propelled cabin is that transportation does not depend on a cable. In case of a calamity, for example in the top part of the building, self propelled cabins can still move up and down under the fire. In case of a conventional lift, the transportation cable might already damaged.

When the system proves to be unsafe or when, in whatever case, accidents occur the system will loose people's trust for a large part. Safety is therefore a very important aspect for a new vertical transport system to succeed. If an accident occurs and measures are taken to avoid similar accidents, it will still be difficult to convince people that the system is, due to the taken measures, reliable and safe.

6.8 Fire lifts

Evacuation of a high-rise building asks for special attention, lifts and especially fire lifts play a dominant role in the evacuation plan of high-rise building. Regulations for lifts and the use of fire lifts are layed down in building codes. In the European Union this is standard EN 81-72, Safety rules for the construction and installation of lifts - Particular applications for passenger and goods passenger lifts - Part 72: Fire fighters lifts.

It would go too far to discuss the whole standard in this master project; the reader is referred to the standard itself for more information. Aspects of the standard which are relevant for this master project are stated below:

- In principle lifts do not function as an emergency route.
- A fire lift is a lift which serves every floor and can be switched by the fire brigade. When the fire brigade does not have to use the lift the lift can be used by the tenant of the building for other purposes.
- A building can be evacuated by lifts if the lifts are under supervision of the fire brigade and the lifts satisfy to special requirements stated in the building code (In The EU EN 81-72).
- To prevent smoke inside the shaft and cabins there has to be an overpressure inside the shafts and at the hall call location. The overpressure is necessary at both locations for the safety of the passengers. Also the way of refuge must be free of smoke.
- The number of fire lifts depends on the height of the building and its purpose. Buildings with a floor which in use higher than 20 meters above ground level need to have a fire lift every 90 meter distance (horizontally), for offices this is 75 meter(horizontally). These values are present in the Dutch building code, values in building codes in other countries may be different.
- The size of the fire fighters lift shall preferably not be less than 1.100 mm wide and 1.400 mm deep with a rated load of 630 kg. The minimum clear entrance width to the cabin shall be 800 mm.

Where the intended use is to include evacuation, with the need to accommodate such items as a stretcher or bed or designed as a dual entry fire fighters lift, then the minimum rated load shall be 1.000 kg and the dimensions of the car 1.100 mm wide by 2.100 mm deep.

6.9 Conclusion

The loop principle has been used in vertical transport before, but in a different shape. In existing loop transport principles consist of continuously moving chains to which cabins are attached. The difference with the loop transport principle which is investigated in this master project is that cabins move independently.
Further research will be focused on other assumptions and boundaries for the loop transport principle and the associated benefits and disadvantages.
Nowadays there is, as far as could be investigated, no loop transport principle in use with independent moving cabins. Magnetic propelled cabins could be a very good option for the loop transport principle because with that technique there is a possibility that a transportation cable is not needed anymore and cabins can move independent and in succession. There are several techniques already patented where cabins can move independent and in succession with magnetic propelled cabins. These techniques should be adapted for the loop transport principle to make it possible for cabins to move as the loop transport principle describes. If that is physically possible the control system for the loop-transport principle must be developed.
Safety is an important aspect in the yes or no succeeding of the loop transport principle. Safety for all the people who are involved in the loop transport principle, these are not only the passengers, must be guaranteed

Fire lifts are, especially in taller buildings, important elements of the total vertical transportation system. In a later stadium the used floor space for vertical transportation of a building will be investigated, the fire lifts has to be taken into account too.

7 Modelling the loop transport principle

This chapter describes the modelling of the loop transport principle. The final model runs simulations for the basic loop transport principle. At this model algorithms and mathematical models are based which depend on which aspects are taken into account for the final model (§ 7.2). The basis for the model of the loop transport principle is an in this master project developed model for a conventional lift (§ 7.3 & § 7.4). The functioning of the model for a conventional lift is validated with an existing lift simulation program (§ 7.5). The model of the conventional lift is rebuilt for the loop transport principle. Necessary changes are done on the conventional model to model the loop transport principle (§ 7.6). After testing the model, the influence of different parameters values on the functioning of the loop transport principle is assessed (parameter sensitivity analysis) and compared to the functioning of a conventional lift which occupies the same floor space within a building (§ 7.7).

7.1 Aim of the model

The aim of the model is to answer the following question: how does the loop transport principle function compared to a conventional lift system? So, what will be the capacity of the loop system on a particular floor space? It has to be determined which parameters to which extent influence the used space within the building for the loop transport principle and with that the associated capacity and level of comfort (expressed in waiting time and travel time). Passenger misuse translated to the robustness of the system will be discussed in a qualitative way.

7.2 Aspects for the vertical transportation model

For the model of the vertical transport system different aspects can be taken into account. The importance of the aspects depends on the type and function of a building. The aspects described in this chapter are mainly related to the control algorithm. The control algorithm describes in which order passengers will be served by the vertical transport system. This control algorithm can also be changed during a specific period, so that the vertical transport system can operate differently during the day and cabins are controlled differently. When a vertical transportation system has to be designed, the aspects that are taken into account have to be determined. Using all the aspects is not possible because some aspects are optimised at the cost of other aspects. The function and type of the building determines which aspects are more important than others. In the design stage of a vertical transportation system some aspects get more priority than others. The aspects, which can be taken into account are described in figure 28. For the design of a vertical transport system, the aspects have to be determined. These aspects can be translated to different blocks of figure 28 and provided with a value to determine its importance (of the aspect). In figure 28 the aspects are given that could be considered, not all the aspects are taken into account in the final model. Aspects that are used for the simulations are described in the paragraph where the simulations are done for the final model, paragraph 7.7.

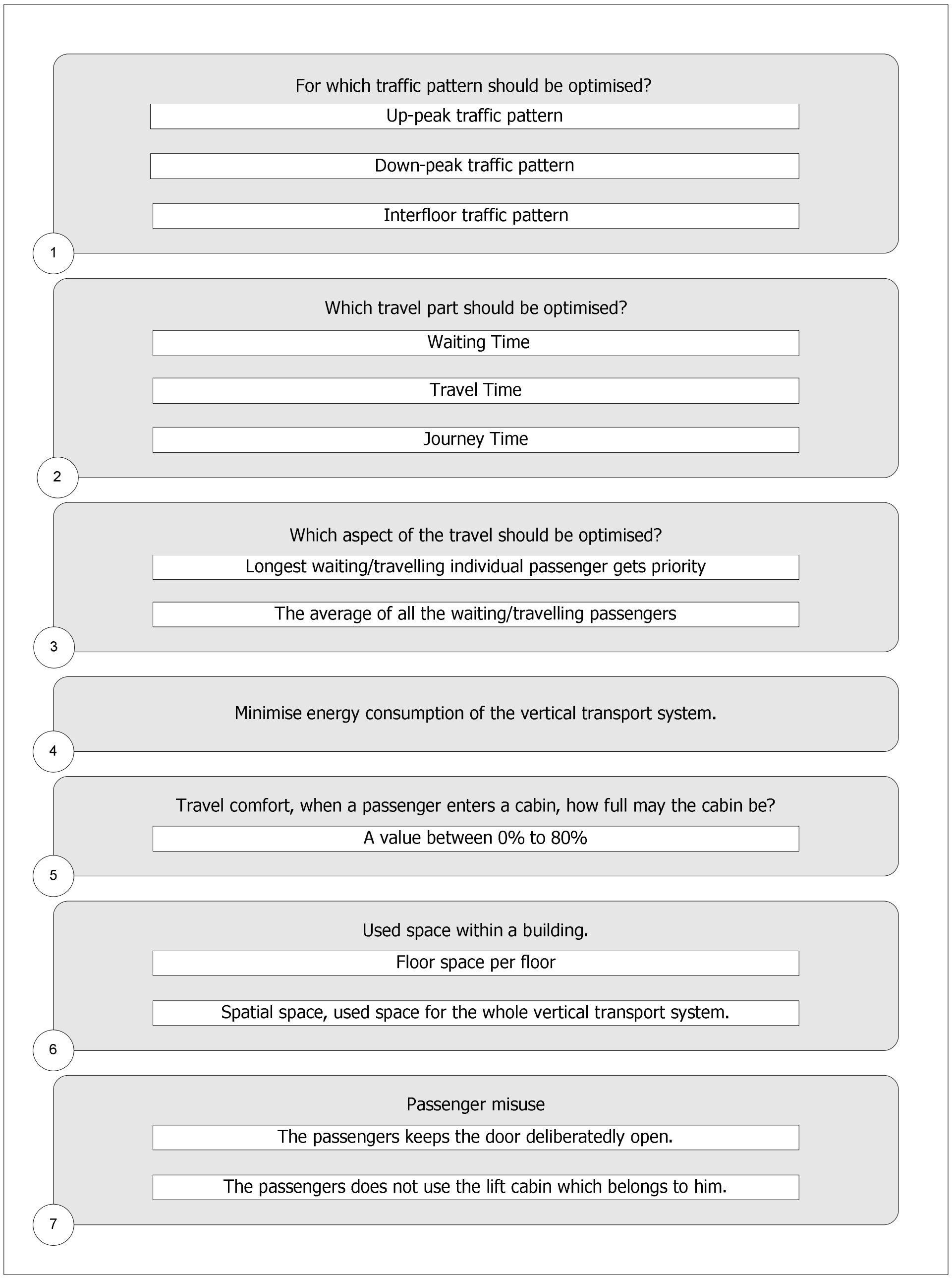

figure 28. Aspects for a vertical transportation system (not in order of importance).

The various optimisation aspects are described, the number on the left bottom of every block refers to the number below.

1. Traffic pattern
Various traffic patterns can be optimised and taken into account in the control algorithm of the model.
2. Travel part
A journey with a lift exists of different parts. Waiting time, this is the time waiting in front of a lift door at a hall call location. Travel time, time which is spent inside the cabin. Journey time is a summation of waiting time and travel time.
3. Distribution of waiting/travel/journey time
The distribution of the waiting/travel/journey time can be used as a decision parameter. It can be desirable that the average of waiting/travel/journey time is the only parameter which matters; this

average time can have a relatively high standard deviation. A large average time, with a lower standard deviation can have advantages in some circumstances.

4. Energy consumption

When one assumes that the movement of cabins will cost energy, cabin movements should be minimized. The energy consumption of a moving cabin is also dependant on the weight of the cabin.

5. Travel comfort

A cabin will never fill for more than 80% (see chapter 3). A trip with a lift can be more pleasant when it is not necessary to enter a cabin which is already full for a large part. Entering a emptier or complete empty cabin will result in a higher level of travel comfort.

6. Used space

The used space can be expressed in floor space per floor or spatial space, the amount of space needed for the total vertical transportation system. With a loop transport principle it can be desirable that the system needs some sort of premise to store cabins (comparable with a premise for trains) which also consumes space. This space can be allocated in an unattractive part of the building but it will still use spatial and floor space. Which part gets the highest priority, the floor space per specific floor or the total space used by the vertical transport system? At the moment, it is not known how much space the entire loop transport principle will occupy (in spatial space) and therefore hard to quantify.

7. Passenger misuse

The robustness of vertical transportation system will among other things be determined by the way it can cope with passenger misuse. It is interesting to investigate the influence when a passenger uses the lift in a wrong manner or wilfully blocks the door. Of course it is very difficult to design a system that is not sensitive for passenger misuse. As much as possible has to be done to reduce the chance on misuse or make it as small as possible. The influence of individual passenger misuse on the rest of the passengers must be minimised, but some systems can be more robust compared to others.

7.3 The model description

This paragraph describes the model of the basic loop transport principle. Assumptions and properties of the model are described to show to which level of detail the model is built up.

7.3.1 The advancement of the model

It is chosen to establish the model of the loop transport principle in smaller steps and to check the accuracy of the model at intermediate steps. These steps can be found in a diagram in figure 29.

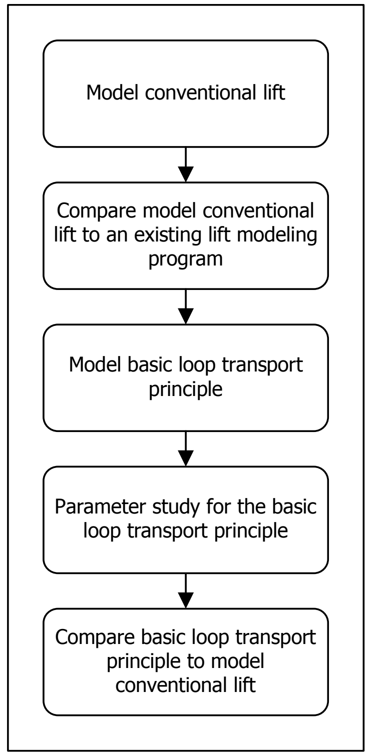

figure 29. The establishment of the model for the loop transport principle.

The modelling starts with a model of a conventional lift. The model simulates a lift with a single deck cabin and can comprise one or more lift shafts. All the cabins in each lift shaft can serve all floors. The quality of the modelled conventional lift must be determined. This validation will be done with an existing lift modelling program, the software of the existing lift modelling program is Elevate©. After this the model of the conventional lift will be converted to fit the basic loop transport principle. Parameters that influence the functioning of the loop transport principle and to what extent will be figured out. To what extent this will happen is also interesting. When this parameter study has been executed, it is possible to assess the optimal functioning of the loop transport principle. When both conventional and loop model function well, the basic loop transport principle will be compared to the conventional lift.

7.3.2 The determination of the computational modelling program

There are two options, which can be used, to model the loop transport principle;

-Adapt an existing lift simulation program with the loop transport principle.
-Program a completely new model.

Adapting an existing program could be a good option because a lot of program work has already been done. Actually there was no decent lift simulation program available that could and might be used. Programming a completely new model would mean that really everything needs to be programmed and figured out. Therefore a much better insight in the functioning of the model is obtained.
To program a completely new model was therefore a logical step. The program which is used to model the lift is MatLab© R2007b. MatLab© is a numerical computer environment and a program language, which is available at Delft University of Technology and extensively used worldwide.

7.3.3 Assumptions of the computational model

In this paragraph assumptions for the model are discussed. The model describes how simulations for the vertical transportation system are structured. The model is a theoretical model, assumptions have to be made. Assumptions must be made for both passengers the system.

Assumptions for passengers
Every passenger will behave according to the rules, e.g. they will enter the cabin which belongs to them and they will exit the cabin at the right floor. Passengers will not keep the door open too long to

let another passenger in or out. Passenger pushes the right buttons, so cabins do not make unnecessary rides. To reach this goal in practice it is very important that there is an adequate signposting for passengers, this is not an issue for the model.

Assumptions for the system
-Every passenger is known (after signing in) by the system (model), the system knows at every random moment where each passenger is. This only applies for passengers who are transported that have requested a hall call. This also implies that every passenger makes a hall call, so the system knows the number of waiting passengers. In reality it may occur that one passenger puts a hall call, while multiple passengers enter the cabin.
-A passenger is not transported in the wrong direction, if a passenger wants to go up he is not transported downwards first.
-The system does not stop, in practice this can take place because of mechanical failure.
-A cabin never fills for more than 80% (Barney, 2003 / Strakosch, 1998).
- The results can not directly be implemented in a building; the parameter study is a theoretical approach of both systems.
- Fire lifts are not taken into account in the system.

A small comment has to be made. A lot of optimisation techniques can be used to optimise the control of a lift. The optimal solution for conventional vertical transportation is hard to establish because the system must cope with a dynamic supply of passengers. It would go too far and it would not be interesting for the predetermined goals of this master project to enter into details of optimisation techniques.

7.3.4 Properties of the computational model

Parameters which have been included in the model are described in table 10. The parameters can be divided into four groups; building data, passenger data, lift data and simulation data. All the parameters for the modelling of the loop transport principle and the conventional lift have been assembled in the table. Parameters which are not relevant for the conventional lift will not be included for the simulations of the conventional lift, for example more cabins in one shaft. The values which are chosen for the simulations are described in the parameter study in paragraph 7.7. The model is structured in a way that the parameters can be altered. The parameters are inserted in a separate document.

table 10. Parameters of the model for the vertical transport system

Building data	unit
Floor height[1]	(m)
Number of floors	
Number of people per floor	
Passenger data	
Passenger mass	(kg)
Passenger loading time	(s)
Passenger unloading time	(s)
Capacity factor[2]	%
Stair factor[3]	%
Lift data	
Number of cabins[4]	
Time to move one shaft (horizontal)	(s)
Door opening time	(s)
Door closing time	(s)
Acceleration	(m/s^2)
Deceleration	(m/s^2)
Max. speed of lift cabin	(m/s)
Cabin capacity	(kg)
Simulation data	
Duration of the simulation	(s)
Percentage of the building population assumed attendant	%
Percentage of the attendant people in the building which will be transported during the simulation	%
Traffic pattern[5]	
Way of making a hall call[6]	
Time step for simulation	(s)

1. Constant over all floors
2. Value indicates up to which level a cabin will fill.
3. Value indicates how many passengers will use the stair.
4. In a conventional lift every cabin has its own shaft. In the loop transport principle, two shafts can suit more than two cabins.
5. Traffic pattern can be Up Peak, Down Peak or Inter floor.
6. Can be done via direction selection or destination selection.

The parameters operate as a starting point for the simulations, the way the actual simulations are done depends on the way the model is structured. The structure of the main model is given in figure 30. The basis of the model can be described as follows; Input parameters determine which and how the simulations have to be done ("Input parameters"), after which the traffic pattern is described ("Generate OD-Matrix"). The simulations start and the cabins start moving and bring the passengers to the requested floors ("Time loop"). Then, when all the passengers are transported, the waiting time for the passengers can be calculated ("Calculate Waiting time, Travel time, Journey time), this results in an output per individual passenger ("Passenger Output per individual passenger"). The main model is similar for both conventional and loop transport principle, the difference is confined in the "Time loop".

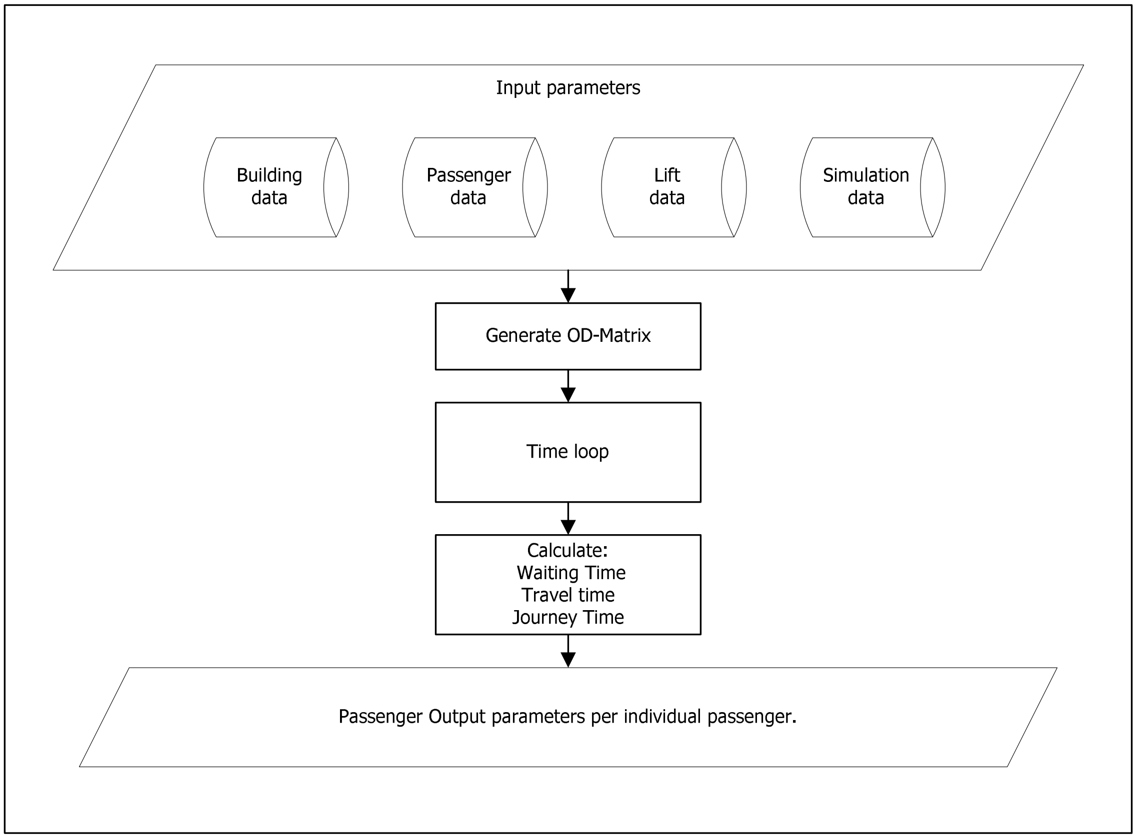

figure 30. Flowchart diagram of Main model

General explanation of flowchart

A flowchart is a schematic representation of an algorithm or a process and is used in this master project to describe the processes and algorithms. The items within a flowchart represent a particular function. There are Input/Output, Data, Process and Decision boxes with distinctive shapes, the arrows describe the direction of the flow of the algorithm/process. The interpretation of the flowchart has to start from the top of the figure, for an explanation of the shapes in a flowchart diagram see appendix " f. General explanation of flowchart".

OD matrix

An OD- matrix describes for a particular number of individuals their original floor (O) and destination (D) floor at particular time period. This matrix gives the arrival floor, destination floor and the time of arrival per individual passenger as input during the simulation. In table 11 the parameters of the OD-matrix can be found.

table 11. Parameters of the OD-matrix, per individual passenger

OD Matrix
Passenger ID
Arrival floor
Destination floor
Time of arrival

The composition of the OD-Matrix depends on the requested traffic pattern, determined in the input parameters. The composition of the OD-matrix and the associated traffic pattern can be found in table 12.

table 12. Composition of OD-matrix and the associated traffic pattern

Traffic pattern	Arrival floor	Destination floor
Up-Peak	Main terminal	Random (uniformly distributed) floor
Down-Peak	Random (uniformly distributed) floor	Main terminal
Inter-Floor	Random (uniformly distributed) floor	Random (uniformly distributed) floor

Modelled characteristics of cabins and passengers

The passengers and the lift cabins are dynamic objects during the simulation; the building is a static aspect. This means that the conditions of the building do not change during a simulation but some of the conditions of the passengers and the lift do change. Passengers move through the building via the lift cabin, so passengers and lift cabin change their location over time. The characteristics of the lift cabin and the passengers can be found in table 13 and table 14. In the table the type of the characteristics is indicated, being one of the following;

-Fixed during time loop *(FDTL)*
-Change during time loop *(CDTL)*
-Result during time loop *(RDTL)*
-Result after time loop *(RATL)*

The three characteristics that will be obtained after the time loop and thus got the status "result after time loop" are Waiting time, Travel time and Journey time and can be calculated as follows (per individual passenger) :

Waiting time = | Time of arrival – Time of departure |
Travel time = | Time at destination - Time of departure |
Journey time = Waiting time + Travel Time

table 13. Characteristics of lift cabin during simulation.

Characteristics lift cabin	quality	property
Cabin ID	number	(*FDTL*)
Height above ground	number	(*CDTL*)
Speed	number	(*CDTL*)
Acceleration	number	(*CDTL*)
Moving direction of cabin	number	(*CDTL*)
Future stopping places	row	(*CDTL*)
Number of people entering cabin at future stop places	row	(*CDTL*)
Direction of passengers who entering cabin at future stop places	row	(*CDTL*)
Number of people exit cabin at future stop places	row	(*CDTL*)
Number of passengers in cabin	number	(*CDTL*)
Lift shaft	number	(*CDTL*)[1]

[1] For a conventional lift a lift shaft is fixed to one cabin

table 14. Characteristics of passenger during simulation.

Characteristics passenger	quality	property
Passenger ID	number	(*FDTL*)
Arrival floor	number	(*FDTL*)
Destination floor	number	(*FDTL*)
Time of arrival	number	(*FDTL*)
Time of departure	number	(*RDTL*)
Time at destination	number	(*RDTL*)
Status[1]	number	(CDTL)
Cabin	number	(RDTL)
Waiting time	number	(*RATL*)
Travel time	number	(*RATL*)
Journey time	number	(*RATL*)

1. Possible status; 1 = not yet a hall call placed, 2 = hall call placed and waiting, 3 =Cabin is at hall call location, but passenger still hasn't pushed the location button. 4 = on the move inside cabin, 5 = Cabin was full, finding new cabin, 6 = cabin came along but was full, finding new cabin, 0 = passenger at destination floor

An important aspect of a lift system is the selection of the cabin which will serve which passenger in which hierarchy. This is called the control algorithm of the lift (group). The control algorithm can be optimised on different aspects mentioned before. The allocation of a cabin to a passenger and associated with that the order of serving floors can be done in two different ways, namely static or dynamic.

In case of static allocation, the model calculates, when the hall call is given, which cabin best serves the passenger. The algorithm, described in §7.4 for a conventional lift and §7.6 for the loop transport principle, determines which cabin is best for the waiting passenger. It depends on the chosen optimisation aspects as described in figure 28. In case of dynamic allocation a cabin is assigned to the passenger with the same criteria as static allocation. Different form static allocations is that by dynamic allocation after every time step, or change in the traffic demand for the system, a recalculation is performed to decide if the predetermined cabin is still the best one, based on the planned optimisation aspects.

Dynamic allocation can only improve a model made with static allocation. The dynamic allocation options can be interesting for a vertical transport system because the supply of passengers can and will change during time. In the time between a hall call and the moment that the cabin reaches the hall call location changes may occur. The information calculated at a certain moment can be superseded after a short time span.
In the development of the model static allocation is used because the programming of the model will be less complex and for a first indication for the benefits of the loop transport principle it will be accurate enough. With a dynamic allocation the results can be improved, the quantification of this improvement is not done is this master project.

7.4 The model of a conventional lift

The first step has been to model a conventional lift. The conventional lift is characterised by a lift cabin which can travel vertically within a building and can pick up or let individuals off at every floor it passes, see figure 31. The model of a conventional lift contains the parameters as described in table 10, which are varied to include stochasticity in the model.

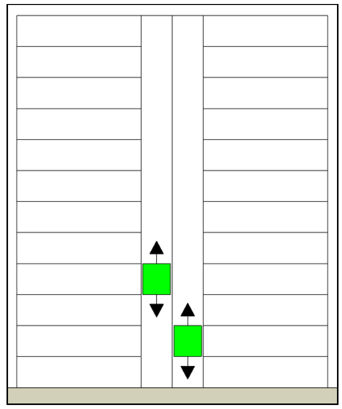

figure 31. Principle of a conventional lift, starting point for the model of the conventional lift.

The hierarchy in which the cabin of a conventional lift has to serve waiting and travelling passengers must be determined, this is called the control algorithm. A lift cabin can travel up and down in the same shaft, the control of the lift must therefore determine when it must travel up or down and with that which passengers must be picked up or let off. The algorithm describes the basis for the movements of the cabins through a building. In this master project the following well accepted algorithm for a conventional lift has been used:

Algorithm for a conventional lift
The lift cabin continues to travel in its current direction (up or down) until empty, stopping only to let individuals off or to pick up new individuals heading in the same direction.

It is interesting to see how much the different aspects contribute to an optimal functioning, i.e. the differences of direction vs. destination selection of the loop transport principle. It is chosen to start with the modelling of a lift resembling lifts that are used nowadays; this is direction selection. This lift will be adapted and optimised for the loop transport principle.

Flowchart of "Time loop" for conventional lift
In figure 30 the flowchart of the main model is given. As discussed before the process "Time loop" within the main model needs to be determined for the conventional lift. The process "Time loop" is shown as a flowchart diagram in figure 32.

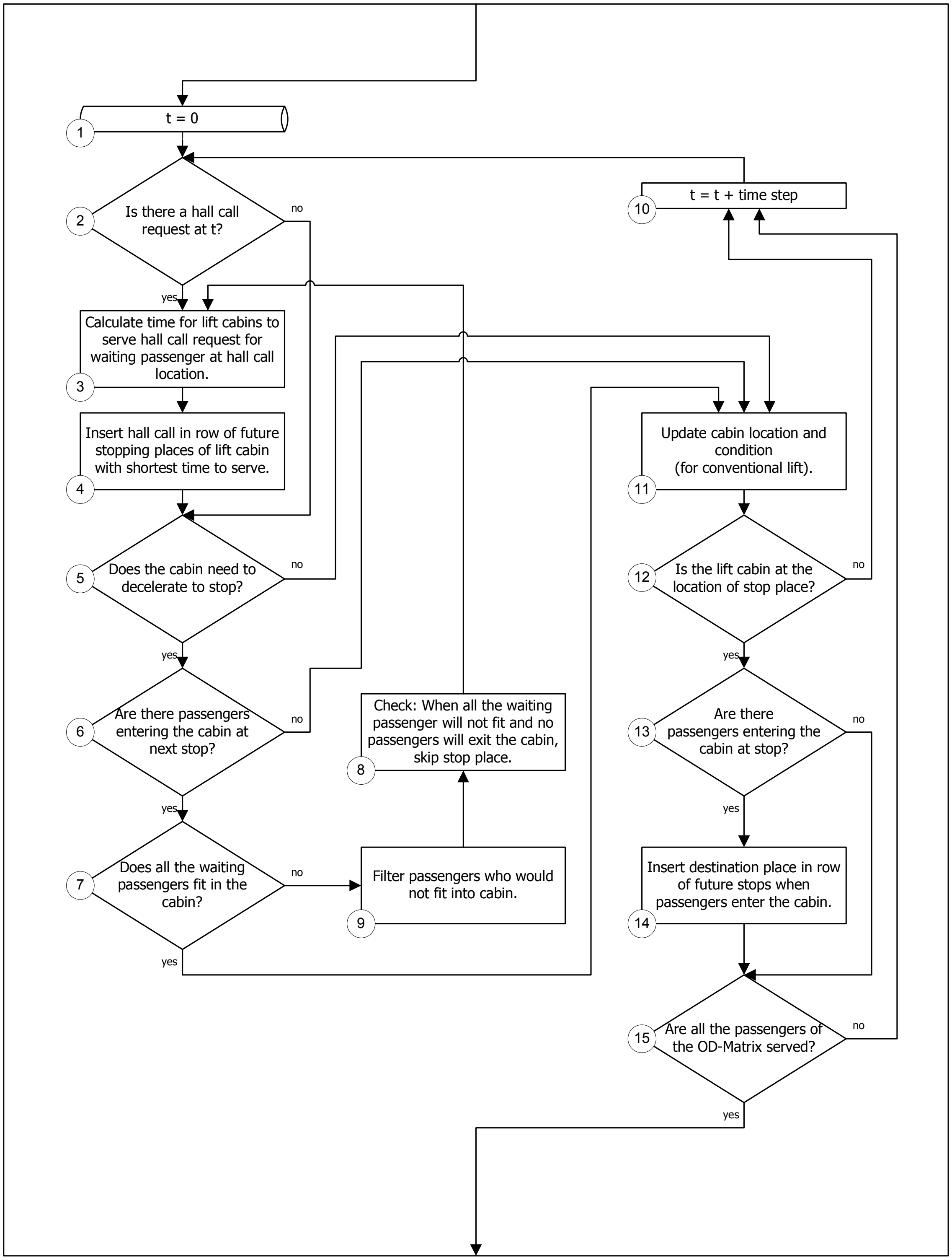

figure 32. Flowchart of process "Time Loop" within main model (figure 30) for conventional lift

The flowchart of figure 32 contains process and decision parts. The process will be explained in the next paragraph. The number represents the reference number in the flowchart of figure 32.

3. This process determines on the basis of the previously described algorithm which cabin will serve a particular hall call, assuming that there is more than one cabin. When a vertical transportation system

has only one cabin, every passenger will be served by this cabin. So within this process the time it takes for a cabin to reach the hall call location is calculated. It has to be noticed that the calculated waiting time can change between the moment of placing a hall call and the moment the cabin will arrive at the hall call location. This can occur because during this period other passengers can give requests for the system. When a cabin is assigned to a passenger, that cabin will serve the hall call. A recalculation is made and the passenger can be transported by another cabin when the cabin has reached its maximum capacity and the cabin arrives at the hall call location.
4. This process is based on the predetermined algorithm for a conventional lift at which location in the row of future stop locations the stop for a hall call will be positioned. In figure 33 this process is described more into detail.

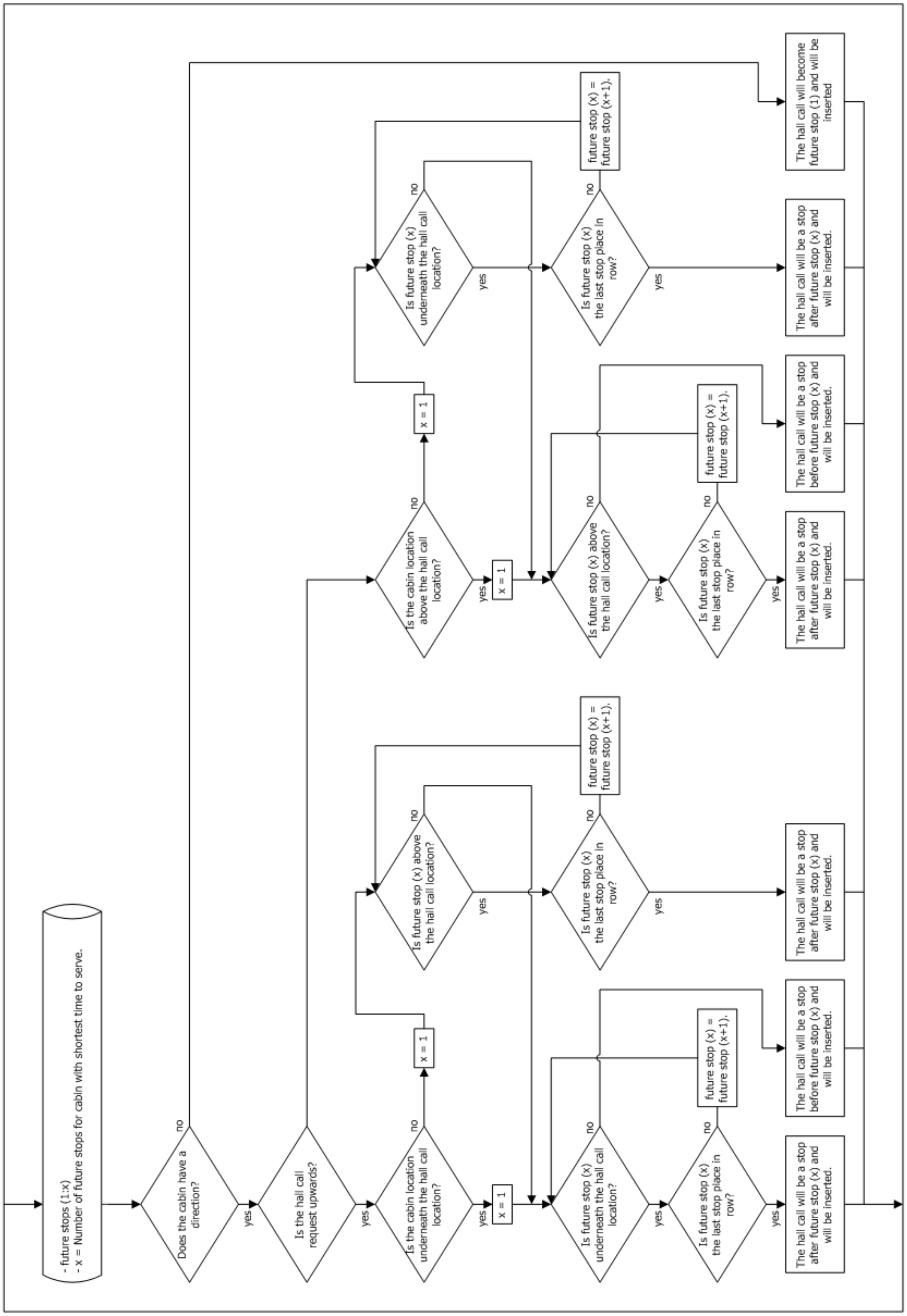

figure 33. Flowchart of process (4) "Insert hall call in row of future stopping places of lift cabin with shortest time to serve" within flowchart of "Time Loop" (figure 32)

8. When a cabin is full and has to stop at a particular floor to let a passenger enter the cabin, this is not possible (because it is full). Full in this case means that the cabin is occupied up to an in the parameters determined value. The cabin should only stop to show the waiting passenger at the hall call location that it is full. This stop would give a delay and these stops do not occur in the model. The process skips the stop of the cabin and places a new hall call for the waiting passenger(s) at the hall call location.
9. Passengers who are waiting at the hall call location but will not fit into the cabin must be informed that a new hall call is placed.
10. The time will be updated with the predetermined time step.
11. This process updates the location and the conditions of the cabins. Cabins which can accelerate, must decelerate or can keep a constant speed are updated. When a cabin arrives at the hall call location the cabin must open its doors and time should be reserved for passengers to enter or leave the cabin. The actual movement of cabins is described in this process.
14. When a cabin is at a hall call location the passenger enters the cabin and inside he/she indicates his/her final destination. This destination is translated into a stop in the list of future stops for the specific cabin.

With this model simulations can be executed. In appendix "g. Simulations conventional lift" (with a link to http://looptransportprinciple.googlepages.com) various simulations with different parameters can be found of the conventional lift model.

7.5 The comparison of the model of the conventional lift to an existing lift simulation program

The model of the conventional lift is compared with the existing lift simulation program Elevate®. Elevate® is a dynamic elevator simulation program to execute simulations for conventional lifts. In appendix "i. Overview features Elevate®" the main features of Elevate® are described.

For the validation of the model for the conventional lift model a building with two lift shafts is modelled, being a common situation. The number of floors will be varied between six and eighteen. The values of the other parameters can be found in table 15.

table 15. Parameters used for the comparison of the model for a conventional lift with Elevate®

Building data	unit	**Passenger data**	unit	**Lift data**	unit
Floor height	3,8 (m)	Passenger mass	75 (kg)	Number of cabins	2
Number of floors	6-18	Passenger loading time	1,2 (s)	Time to change shafts	- (s)
Number of persons per floor	50	Passenger unloading time	1,2 (s)	Door opening time	1,8 (s)
		Capacity factor	80 %	Door closing time	2,9 (s)
		Stair factor	0 %	Acceleration	1,5 (m/s^2)
				Deceleration	1,5 (m/s^2)
				Max. speed of lift cabin	6 (m/s)
				Cabin capacity	750 (kg)

Simulation data	unit
Duration of the simulation	300 (s)
Percentage of the building population assumed attendant	100 %
Percentage of the attendant people in the building which will be transported during the simulation	12,5 %
Traffic pattern	Up peak
Putting a hall call	Direction sel.
Time step for simulation	0,1 (s)

Ten simulations of 300s have been performed for each scenario to deal with stochasticity. For each scenario the average waiting time will be calculated after which the average waiting time per individual passenger over all the simulations is determined. The results of the simulations, expressed in average waiting time, for the model of a conventional lift and Elevate® can be found in figure 34.

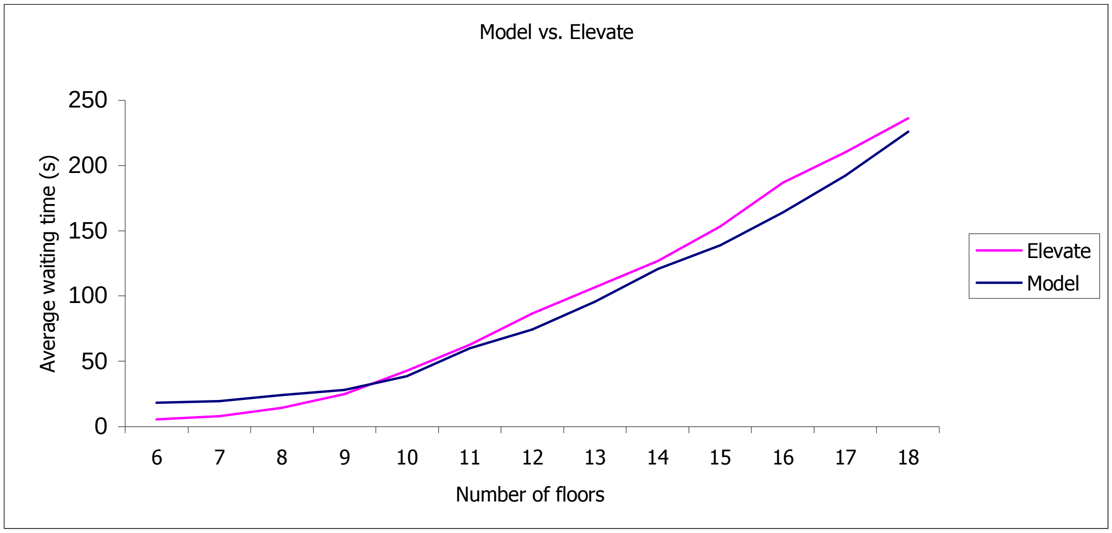

figure 34. Comparison of the model for a conventional lift to Elevate®

Discussion of the results
- The order of magnitude and the shape of the diagram are similar.
- The model produces a higher average waiting time for the scenarios with less than ten floors. This can be explained, because in the model passengers can enter the cabin at just one moment in time and within Elevate® passengers can enter the cabin in a period of time. A period of time means that passengers can enter the cabin other passengers entering the cabin. It is hard to see exactly how the control algorithm of Elevate® is set up, but it is most likely that when passengers enter the cabin and together with others also want to get in the doors will stay open longer to let the other passengers in. So for Elevate® it is possible to have an individual waiting time of zero for more than one passenger. In the model it is always more than zero, except for the situation that a cabin stays idle at the hall call location, when a passenger arrives.
When the total number of passengers is relatively small, which is the case in a building with fewer floors, the difference described above is more dominant.
- When the number of floors increases, the average waiting time of the model decreases. This is most likely because cabins within the model move less smoothly compared to the cabins within Elevate®.
- Very likely there are subtle differences in the control algorithms. It is hard to find the exact control algorithm within Elevate®. It is not visible and embedded within the simulation program. These differences in control result in different simulation results.
- The number of transported passengers is the same, the destination of the passengers is determined randomly (uniformly distributed), so the generated traffic patterns are not exactly the same. This can result in small deviations in waiting time. With enough simulations, for both models 10 simulations, these differences should be eliminated.

The model of the conventional lift may be assumed reliable enough to be used it as a starting point and reference for the basic loop transport principle.

7.6 The model of the basic loop transport principle

The basic loop transport principle is characterized by two one way shafts. Cabins can change between shafts at the top and at the bottom of the building. It is possible for cabins to stop at every floor to let passengers in or out; for the principle see figure 35. The model of the basic loop transport principle contains the parameters as described in table 10. It should be possible to vary these parameters to run simulations.

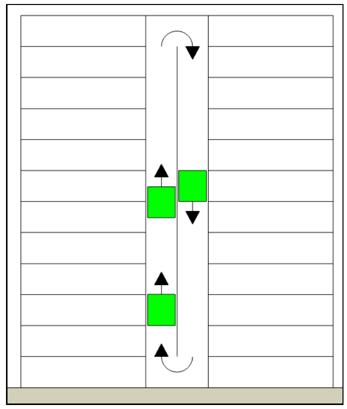

figure 35. Principle of the basic loop lifts, starting point for the model of the loop transport principle.

The control of the basic loop transport principle, the allocation of the passenger to a cabin, is performed with the idea that, when the nearest cabin can serve a hall call it will do so. With this the following algorithm is determined.

Lift algorithm for loop transport principle:
The first lift cabin that comes along the hall call location, in same direction as the travelling direction of the passenger, will stop to pick up this waiting passenger. When the first arriving cabin is full the next cabin will serve the hall call. When this cabin is also full, the next cabin will serve the hall call and so on. The cabin will stop when passengers either want to leave the cabin or to enter a cabin with transport capacity; passengers with the longest waiting time at the stop place get the highest priority.

Varieties for a better performance will be suggested and discussed in paragraph "7.8 The improvement of the basic loop transport principle and its variants."

The model of the conventional lift is used as a starting point for the basic loop transport principle. The structure of the model has a lot of similarities. The main model described in figure 30 is the basis for this model. The deviation is only in the process "Time loop". The process "Time loop" for the loop transport principle is described as a flowchart diagram in figure 36.

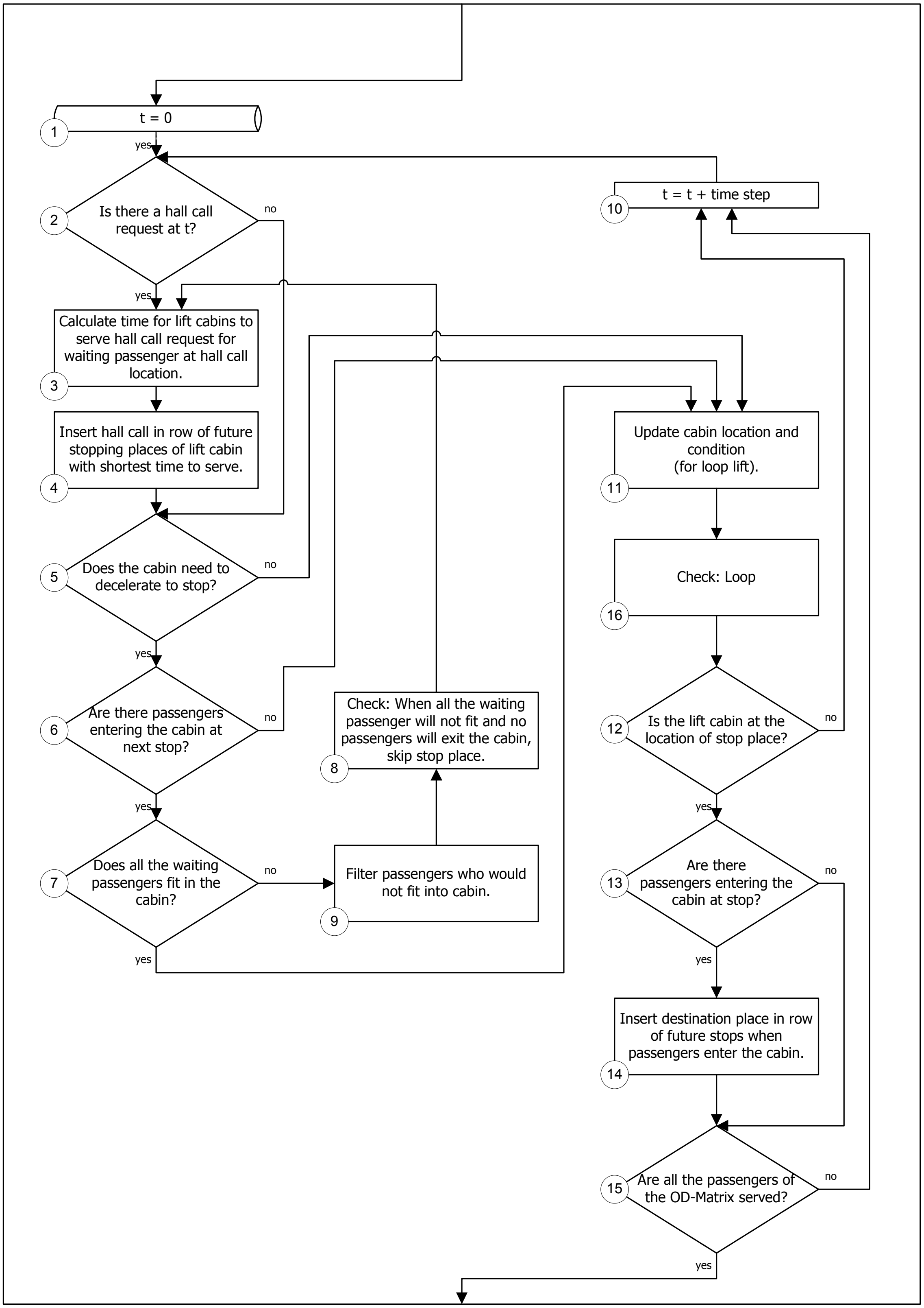

figure 36. Flowchart of process "Time Loop" within main model (figure 30) for loop transport principle

The flowchart of figure 36 contains process and decision parts. The processes will be explained in this paragraph. The number represents the reference number of the flowchart of figure 36. Attention is paid to the differences with the time loop of the conventional lift and new elements. The difference with figure 32. Flowchart of process "Time Loop" within main model (figure 30) for conventional liftfigure 32 is the process "check loop" with reference number 16.

3. This process determines on basis of the predetermined algorithm which cabin serves a particular hall call. As the algorithm describes, the first cabin that comes along the hall call location with transportation space will serve the hall call.
4. New future stops must be placed at the correct location in the list of future stopping places. The route a cabin will follow is fixed (this not the case with a conventional lift). The order of stops per cabin is the same compared to the chosen algorithm for the conventional lift. The only difference is that when a cabin has to change direction, it must go entirely to the top or to the bottom of the shaft.
8. This check is the same as for the conventional lift, skips stops when the cabin is full and no passengers want to exit the cabin. Waiting passengers at the hall call location must be assigned to another cabin.
9. This check is the same as for the conventional lift; passengers who will not fit into the cabin must be assigned to another cabin.
10. This process is the same as for the conventional lift. The time will be updated with the predetermined time step.
11. This process updates the location and the condition of the cabins. The distance between the cabins has to be checked to determine if the cabin can accelerate, must decelerate or can keep a constant speed. The minimal distance between two cabins is two floors (parameter value). This value is derivated from the twin lifts where two cabins have a minimum distance of two floors. It is assumed that when one cabin is moving horizontally and another one is already in the shaft, the minimum distance allowed is one floor. When a cabin arrives at the top or at the bottom of the building this process transfers the cabin to the other shaft. It is possible for a cabin to stay idle, but it blocks the shaft. This cabin must then be sent up or down so that there is no unnecessary stagnation. Cabins which block the shaft are sent four floors away before the other cabin will arrive at the location of the cabin that blocks the shaft is sent to the bottom or the top of the building.
14. This process is the same as for a conventional lift. Insert the destination floor of the passenger as new stop in the row of future stops.
16. The process "Check: Loop" is not present in the flowchart diagram "Time loop" of the conventional lift. This process will insert an "up loop", a "down loop" or both in the row of future stopping places. An "up loop" or "down loop" is a stop where a cabin can change shafts, see figure 37.

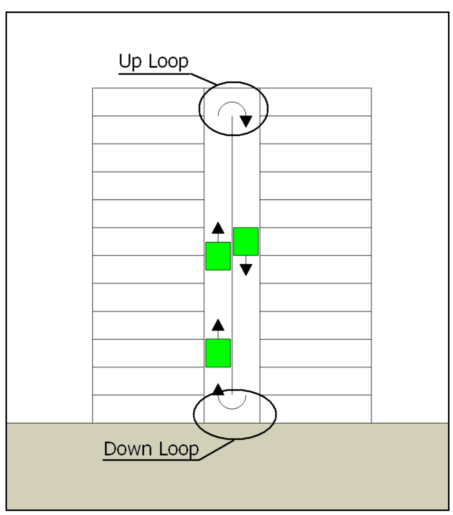

figure 37, Position of Up loop and Down loop

This process will only insert the need for shaft changes of the cabin in the list of future stopping places. The translation of the "up loop" or "down loop" into an actual shaft change is done in process (11), Update cabin location and condition. The flowchart of the process "Check: Loop" can be found in figure 38.

The model is applied for one loop with two shafts.

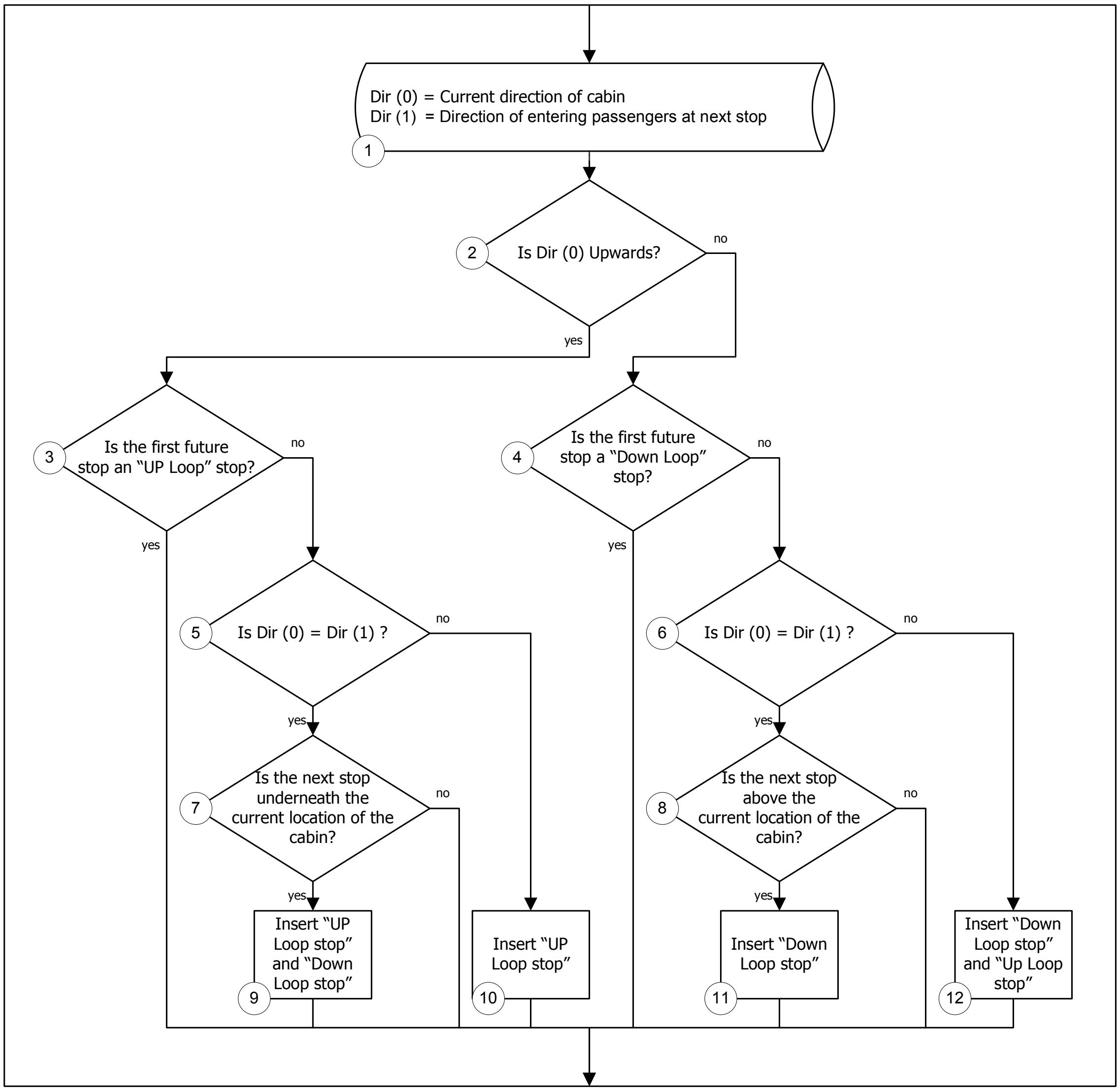

figure 38. Flow chart of process (16) "Check: Loop" within flowchart of "Time Loop" of loop transport principle (figure 36)

With this model simulations can be performed. In appendix "h. Simulations loop transport principle" (with a link to http://looptransportprinciple.googlepages.com) various simulations with different parameters can be found for the loop transport principle model.

7.7 A parameter study for the basic loop transport principle and the conventional lift

In this paragraph the performance of the programmed model of the loop transport principle is discussed. It is assessed how the loop transport principle performs compared to a conventional lift and also which parameters influence the performance of the vertical transport systems related to the space.

Included aspects for simulations

Optimisation will be performed on waiting time per individual passenger. In addition the associated travel time and journey time will be reviewed. The investigated traffic pattern is the up peak traffic pattern. In figure 28, different possible optimisation aspects are presented. For this parameter study, the optimisation aspects of figure 39 are taken into account.

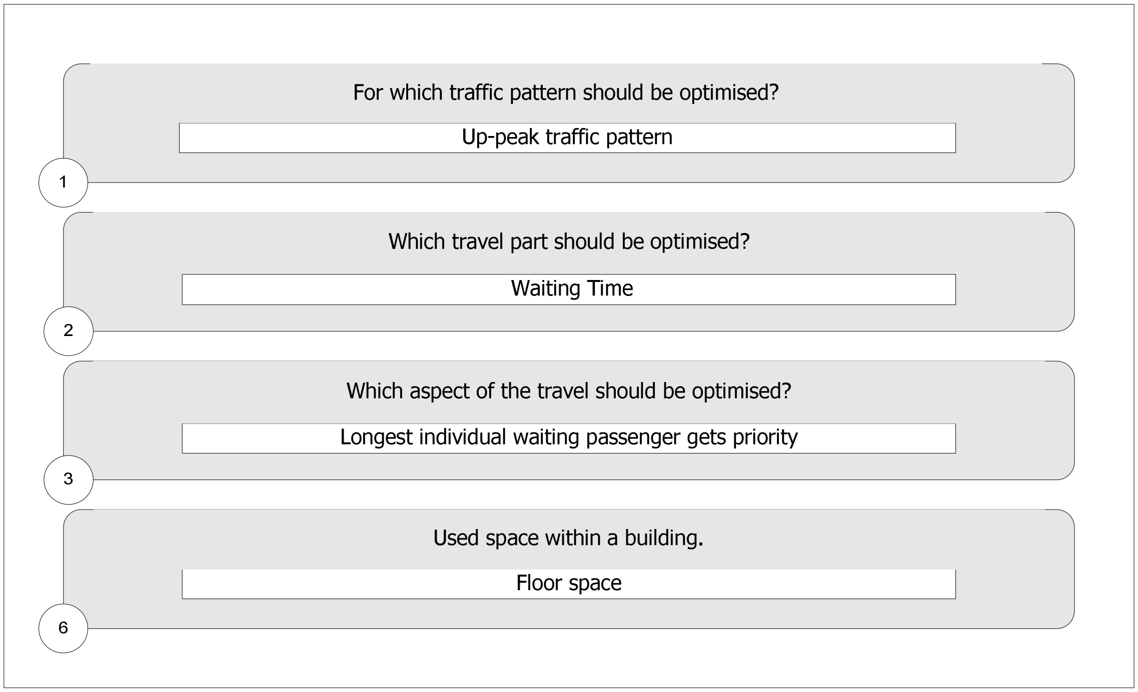

figure 39. Optimisation aspects for parameter study.

The aim of this parameter study is to get more insight into the parameters which influence the performance of the loop transport principle, related to the used space within the building. The model of the loop transport principle can simulate two shafts, that number is fixed. The rest of the mentioned parameter values can be varied. This means that the space taken up by the model of the loop transport principle is fixed (except that smaller cabins can take up less space). It is chosen to compare a conventional lift with two shafts to the loop transport principle with two shafts, so the used floor space is the same. Investigation will be done to a given floor space taken up by the vertical transport system and the performance of the vertical transportation is reviewed for a representative building.

Parameters which will be varied and their range
Varying all the parameters in this parameter study would give too many and unnecessary results, also from a practical consideration this would be undesired. The parameter values which are already minimised by lift manufacturers or human preferences are used as default values. The parameters which influence the space taken up by the lifts, the cabin capacity, are varied. The number of shafts is fixed to two. The number of cabins used in the loop transport principle is taken into account to distinguish the number of cabins which are necessary for an optimal functioning of the loop transport principle; more cabins within the loop transport principle do not take up more floor space. The number of cabins within the loop transport principle can therefore be varied. The number of cabins for a conventional lift is fixed at two. More cabins would occupy more shafts and therefore more floor space. To investigate when the loop transport principle performs better than a conventional lift, the number of floors is varied.

In table 16 the parameter values used for the parameter study are presented. Bold parameters are varied.

table 16. Parameter values for parameter study. Bold parameters will be varied.

Building data	unit	**Passenger data**	unit	**Lift data**	unit
Floor height	3,8 (m)	Passenger mass	75 (kg)	**Number of cabins**[1]	**2-12**
Number of floors	**5-30**	Passenger loading time	1,2 (s)	Time to change shafts	3 (s)
Number of persons per floor	50	Passenger unloading time	1,2 (s)	Door opening time	1,8 (s)
		Capacity factor	80 %	Door closing time	2,9 (s)
		Stair factor	0 %	Acceleration	1,5 (m/s^2)
				Deceleration	1,5 (m/s^2)
				Max. speed of lift cabin	6 (m/s)
				Cabin capacity	**600-1125** (kg)

Simulation data	unit
Duration of the simulation	300 (s)
Percentage of the building population assumed attendant	100 %
Percentage of the attendant people in the building which will be transported during the simulation	12,5 %
Traffic pattern	Up peak
Putting a hall call	Direction sel.
Time step for simulation	0,1 (s)

[1]The number of cabins for the conventional lift is two. The number of cabins for the loop transport principle varies between two and twelve.

The parameters that are varied and the range of variation are discussed below:
-Lift data, Number of cabins
Starting point for the maximum number of cabins is a minimum mutual starting distance of five floors. A building with e.g. five floors will have a maximum of two cabins and a building with e.g. eight floors will have a maximum of three cabins. This does not imply that it is not possible to have more cabins, but for now the minimum mutual start distance is set to five floors. The maximum number of floors is thirty, this results in a maximum number of cabins of twelve.
-Lift data, Cabin capacity
The cabin capacity is varied for four cabins, see table 17. The number of passengers for a cabin is the starting point.

table 17. Cabin capacity and the associated maximum number of passengers used for the parameter study (theoretic).

Cabin capacity (kg)	Associate maximum number of passengers
600	6
750	8
950	10
1125	12

-Building data, number of floors.
The range of data used for the number of floors is between 5 and 30. Within the loop transport system the minimum for two cabins is set to five floors. A rule of thumb, but depending on many parameter values, is to serve a maximum of 15-16 floors with a conventional lift or a group (can be more than two) of conventional lifts (Barney, 2003).

7.7.1 Results parameter study conventional lift

Simulations have been performed using the parameter values of table 16 for the conventional lift. The number of runs to calculate the average waiting time, travel time and journey time is set to 10 per parameter series,. The results of the runs for the conventional lifts can be found in the following figures. The associated result values are given in appendix "j. Results parameter study".

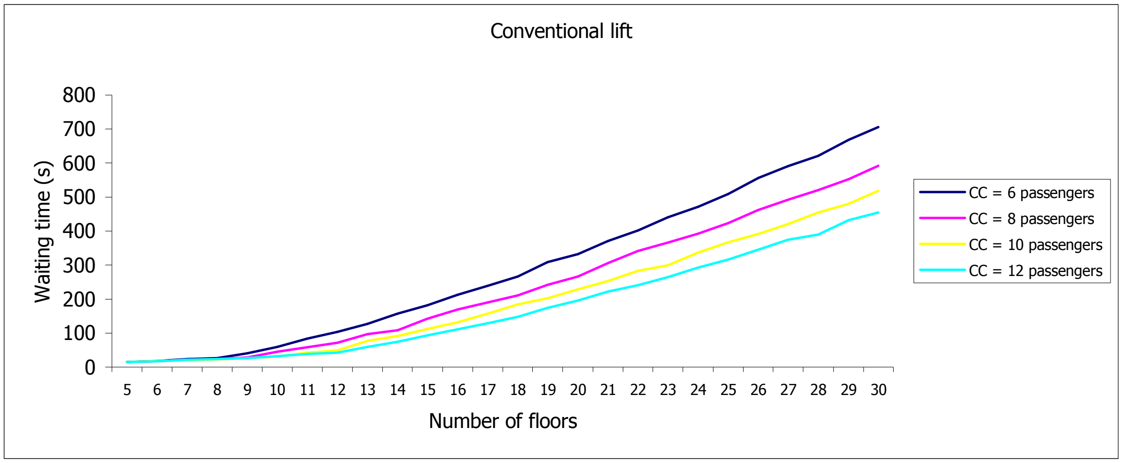

figure 40. Conventional lift, average waiting time (s) for different cabin capacities

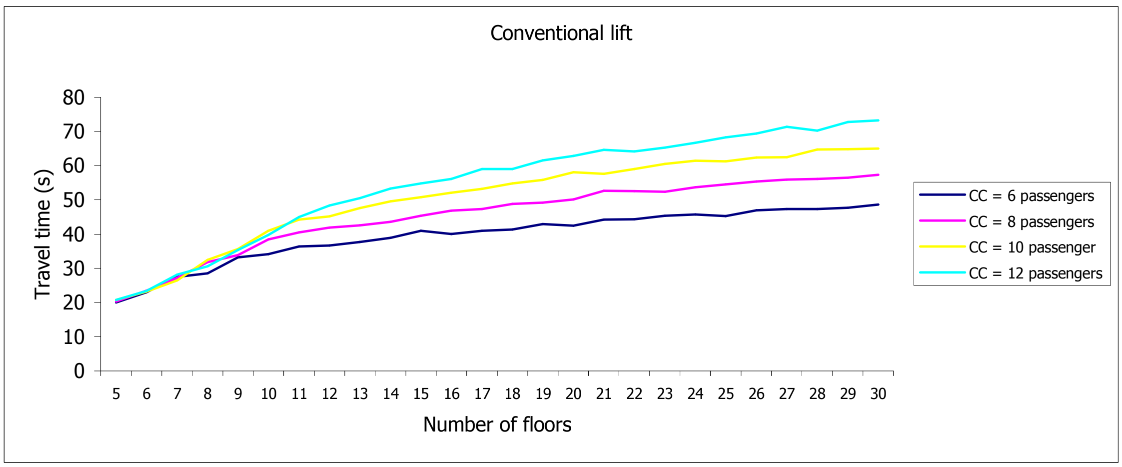

figure 41. Conventional lift, average travel time (s) for different cabin capacities

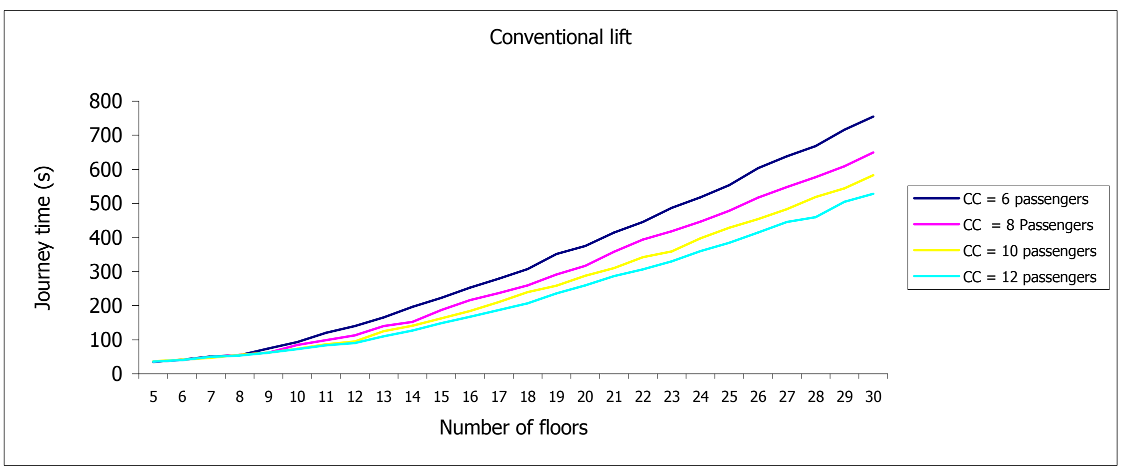

figure 42. Conventional lift, average journey time (s) for different cabin capacities

With increasing number of floors the calculated times become very high. The results in the regions with a smaller number of floors are more relevant, showing more desirable values for a vertical transport system. The results of the simulations (same results as the figures above but with a more relevant number of floors) can be found in the coming figures.

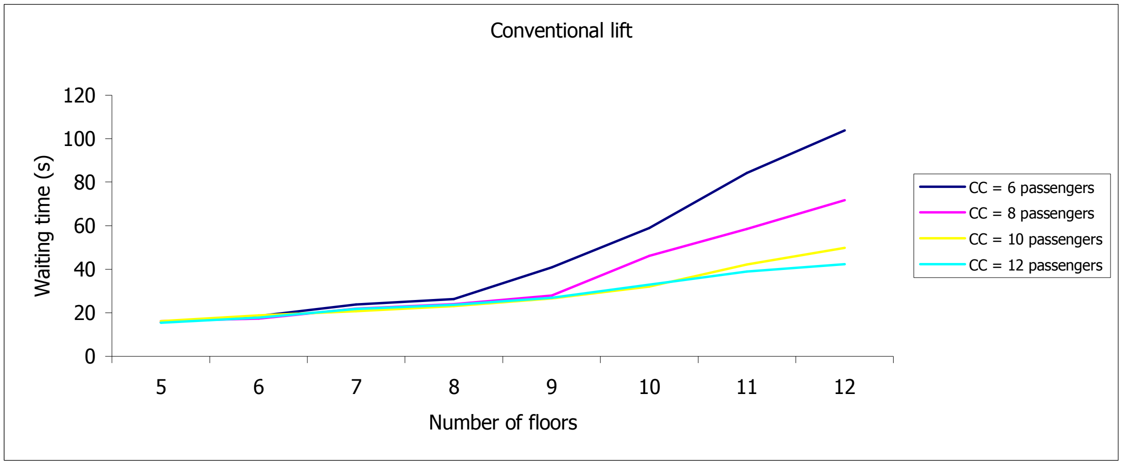

figure 43. Conventional lift, average waiting time (s) for different cabin capacities

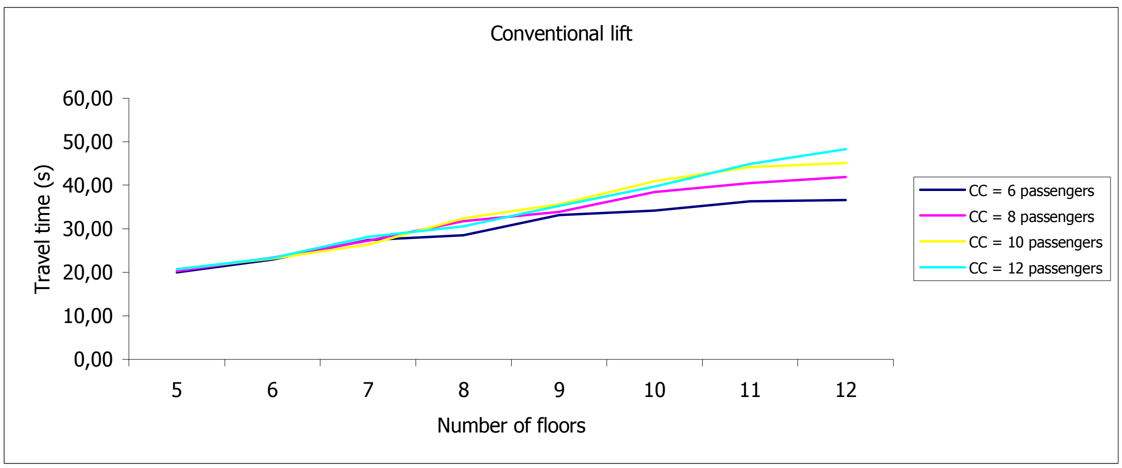

figure 44. Conventional lift, average travel time (s) for different cabin capacities

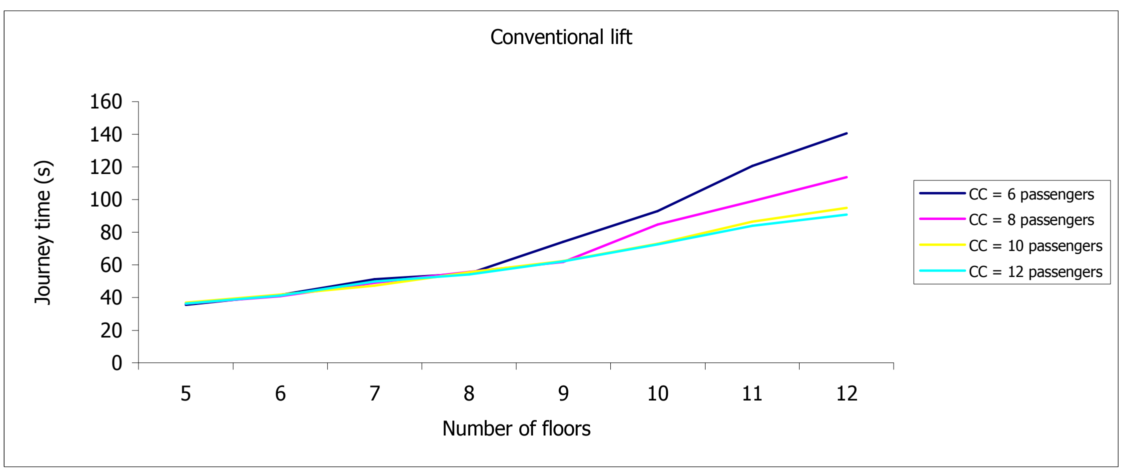

figure 45. Conventional lift, average journey time(s) for different cabin capacities

The maximum waiting time for a satisfactory vertical transport system is 30 seconds (Barney, 2003). When this waiting time is taken into account, the maximum number of floors related to the cabin capacity can be derived, see table 18.
The average travel time does not exceed the maximum value of 60 seconds (Barney, 2003).

table 18. Conventional system, cabin capacity related to the maximum number of floors with parameter values of table 16 for satisfactory transportation system

Cabin capacity (passengers)	Maximum number of floors	Associate average waiting time (s)	Associate average travel time (s)	Associate average journey time (s)
6	8	26,23	28,53	54,76
8	9	27,95	33,89	61,84
10	9	26,68	35,65	62,33
12	9	26,95	35,25	62,20

Remarks about the results of the parameter study for a conventional lift
- The maximum number of floors for this parameter study and a satisfactory transportation system is eight or nine floors.
- Using cabins with a high capacity gives a shorter waiting time compared to using cabins with a small capacity.
- Using cabins with a high capacity gives a longer travel time compared to using cabins with a small capacity.
- The average waiting time is governing for the maximum number of floors and a satisfactory vertical transport system.

7.7.2 Results parameter study loop transport principle

Within the loop transport principle the number of cabins is also taken into account. This will lead up to a less convenient arrangement of the simulation results. For every parameter value of the cabin capacity figures can be produced for waiting time, travel time and journey time, as can be found in figure 46, figure 47 and figure 48. The figures for the other cabin capacity values and tables with the associated result values can be found in appendix " j. Results parameter study". The figures underneath show the results for a cabin capacity of 12 passengers, figures for 6, 8 and 10 passengers can be found in the appendix. The tables with the result values in the appendix can clarify the figures. All the results are done with ten runs per parameter series (same as for the conventional lift).

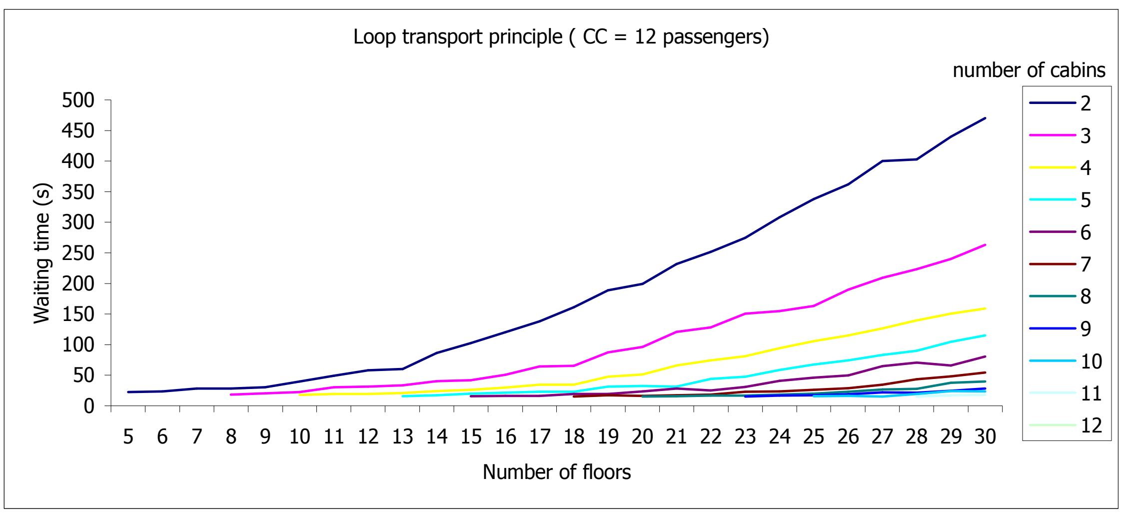

figure 46. Loop transport principle, average waiting (s) time with a cabin capacity (cc) of 12 passengers for a different number of cabins

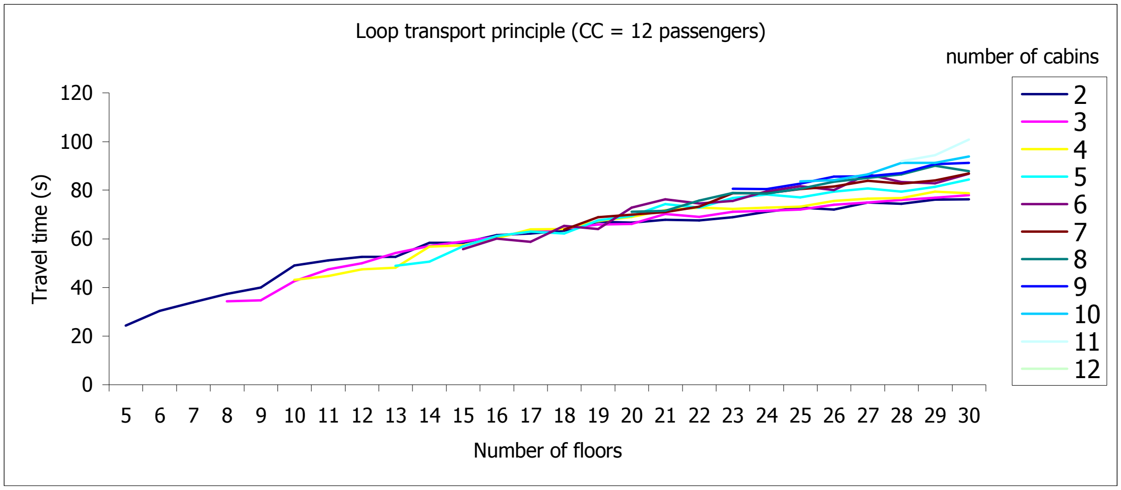

figure 47. Loop transport principle, average travel time (s) with a cabin capacity (cc) of 12 passengers for a different number of cabins

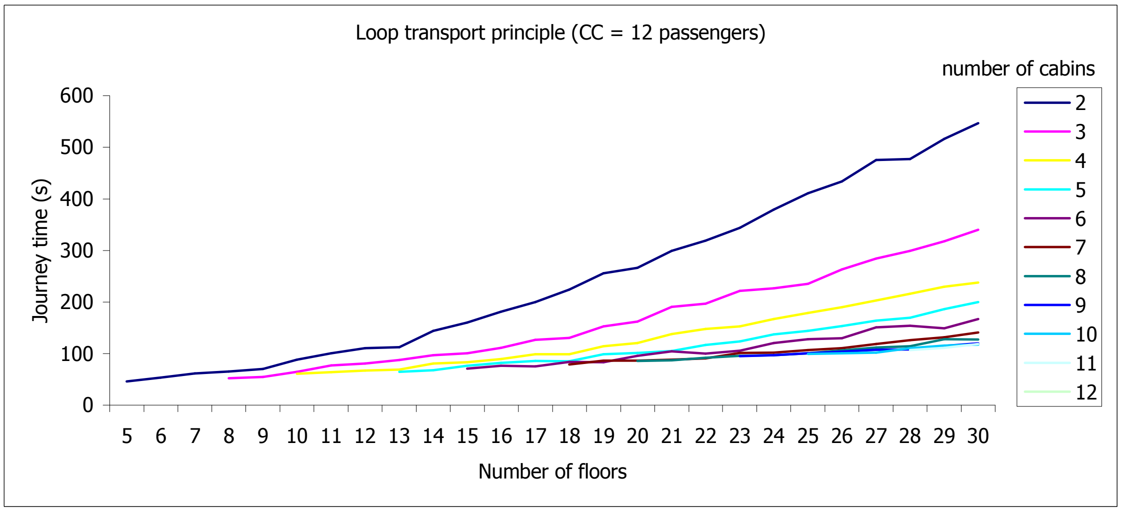

figure 48. Loop transport principle, average journey time (s) with a cabin capacity (cc) of 12 passengers for a different number of cabins

It is important to get more insight into how the loop transport principle performs depending on the used space within the building, one of the predetermined optimisation aspects. The number of cabins is less interesting because they do not influence the floor space taken up by the vertical transport system. The capacity of the lift cabin is related to the used space taken up by the vertical transportation system because larger cabins take up more floor space.
Another starting point was the optimisation of the waiting time. In figure 49 the minimum possible waiting time over the number of floors is given. Not all the values within this figure are obtained with the same number of cabins, the used number of cabins can be found in simulation data in the appendix. The figure displays the minimum average waiting times that are possible within the predetermined range in number of cabins.

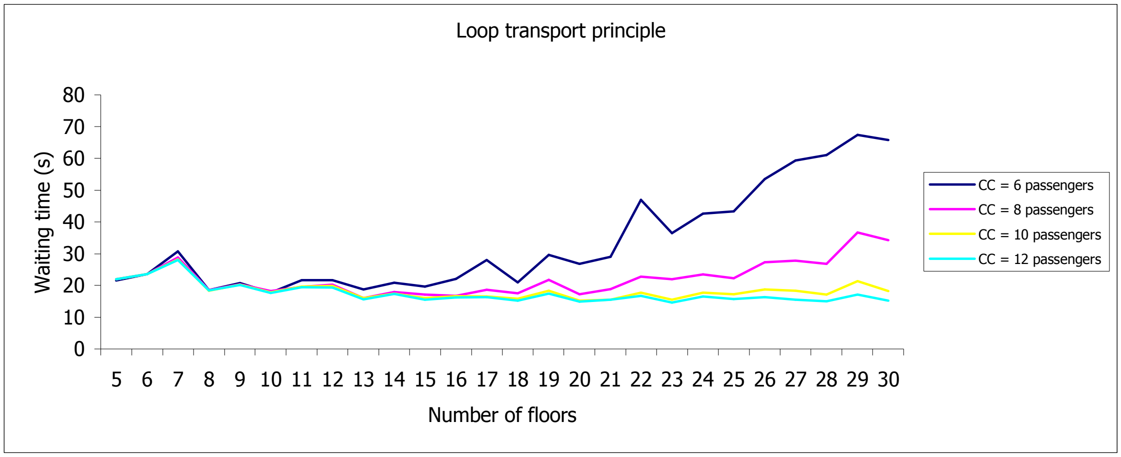

figure 49. Loop transport principle, minimum average waiting time (s) for different cabin capacities

The associated travel time and journey time can be found in figure 50 respectively in figure 51.

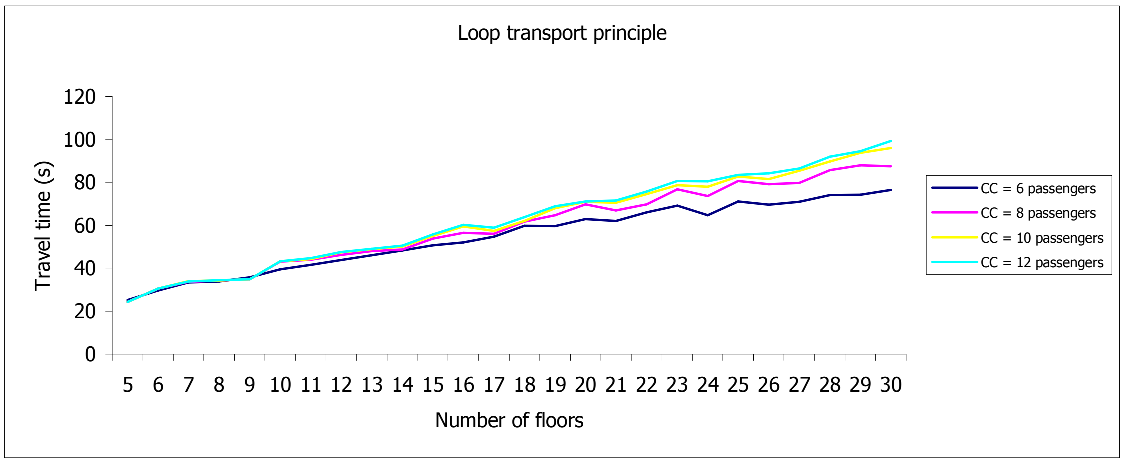

figure 50. Loop transport principle, minimum average travel time (s) for different cabin capacities

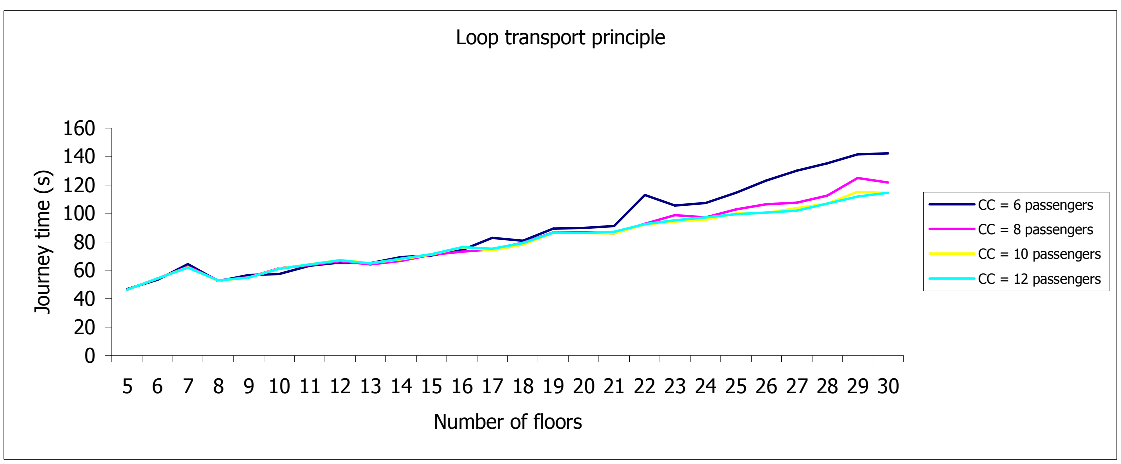

figure 51. Loop transport principle, minimum average journey time (s) for different cabin capacities

In appendix "j. Results parameter study" a table with the result values of the three figures above can be found.

The loop transport system must have a satisfying waiting time and travel time, the same satisfying times as used for the conventional lift. The average travel time for the loop transport principle is governing, not the average waiting time. This is interesting because in the model of the conventional lift waiting time is governing. When the average waiting time and average travel time are taken into account the maximum number of floors related to the cabin capacity can be found in table 19.

table 19. Loop transport system, cabin capacity related to the maximum number of floors with parameter values of table 16 for a satisfactory transportation system

Cabin capacity (passengers)	Maximum number of floors	Associate average waiting time (s)	Associate average travel time (s)	Associate average Journey time (s)
6	19	29,61	59,66	89,27
8	17	18,59	55,96	74,55
10	17	16,47	57,45	73,92
12	17	16,32	58,79	75,11

Remarks about the following results of the parameter study for the loop transport principle
- The maximum number of floors for this parameter study and a satisfactory transportation system is seventeen, eighteen or nineteen floors
- The results of figure 49, figure 50 and figure 51 are capricious; this is because not all the values are calculated with the same number of cabins.
- Using cabins with a high capacity results in a shorter waiting time compared to using cabins with a small capacity.
- Using cabins with a high capacity results in a larger travel time compared to using cabins with a small capacity.
- The average travel time is governing for the maximum number of floors and a satisfactory vertical transport system.

7.7.3 Comparison conventional lift to the loop transport principle

When the results of the previous paragraphs are combined, a comparison between the loop transport principle and the conventional lift can be made. Starting point is that both systems take up the same floor space. The number of cabins for the loop transport principle can be varied because more cabins do not take up more floor space. The number of cabins for the conventional lift is two, more cabins would take up more floor space. In the next three figures the results of the simulations of the loop transport principle and the conventional lift are plotted in the same figures.

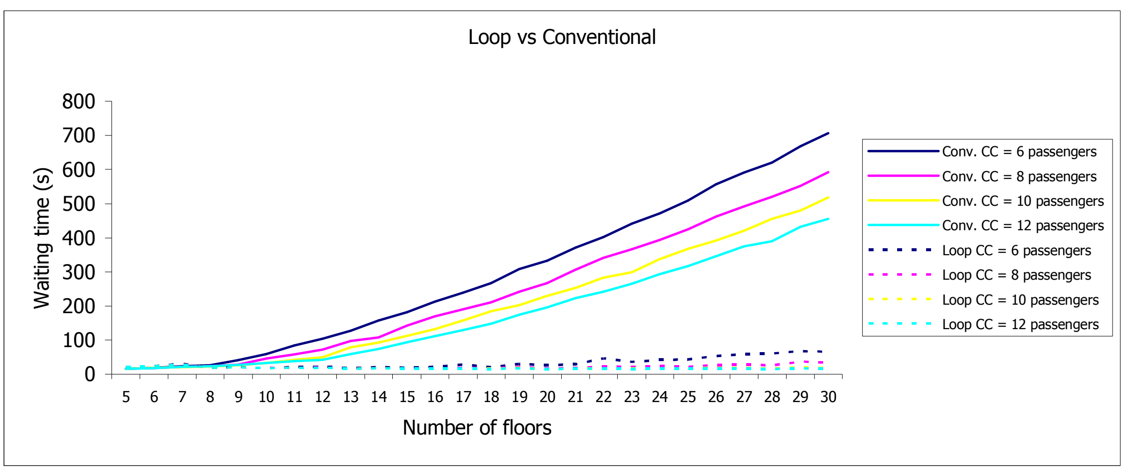

figure 52. Comparison Loop transport principle to conventional lift on average waiting time (s) for different cabin capacities

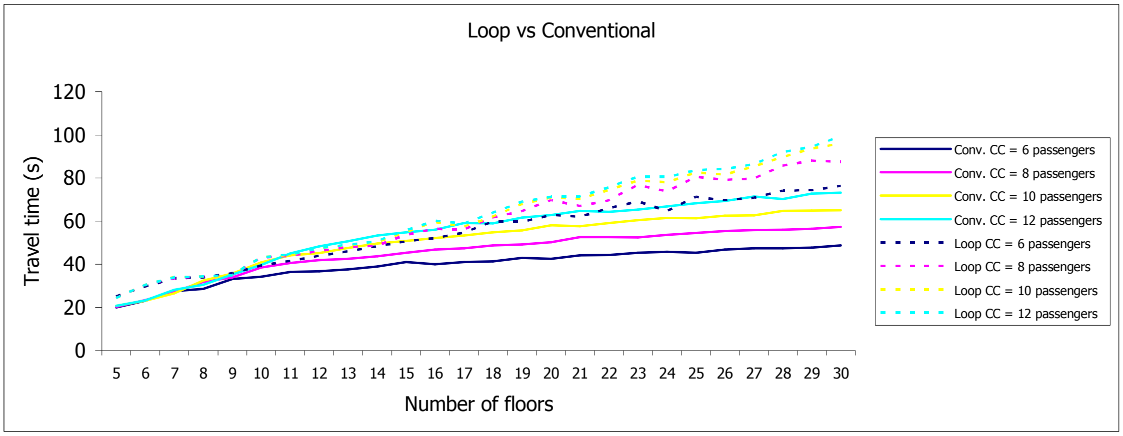

figure 53. Comparison Loop transport principle to conventional lift on average travel time (s) for different cabin capacities

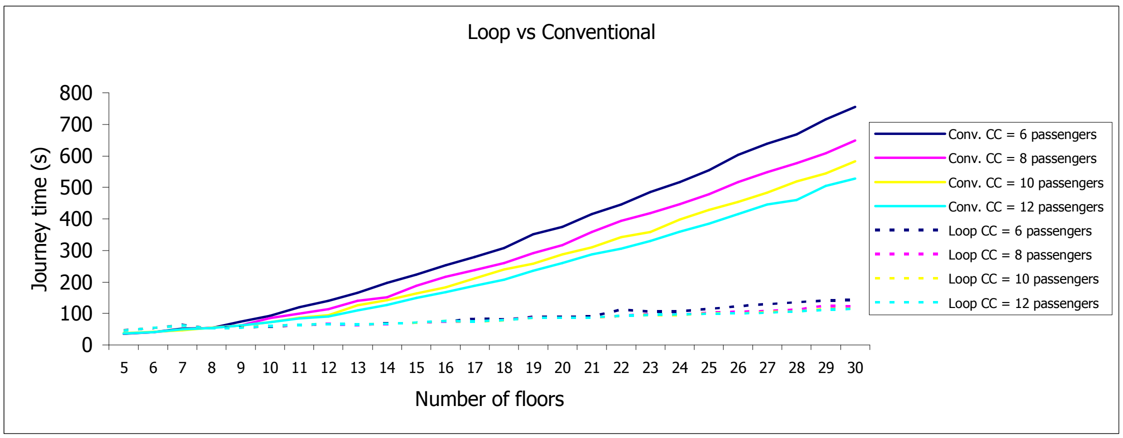

figure 54. Comparison Loop transport principle to conventional lift on journey time (s) for different cabin capacities

Remarks about the comparison of both systems in this parameter study

Waiting time:
When the number of floors increases, waiting time increases less rapidly for the loop transport principle than for the conventional lift. The use of larger cabins results in shorter waiting times, for both systems. Waiting time is leading for conventional lift (not travel time). When the number of floors increases the waiting time first exceeds the maximum waiting time for a satisfactory vertical transport system. This happened before the average travel time exceeds the maximum travel time for a satisfactory vertical transport system.

Travel time
When the number of floors increases, travel time increases less rapidly for the conventional lift than for the loop transport principle. The use of larger cabins results in larger travel times, for both systems. Travel time is leading for loop transport principle (not waiting time). When the number of floors increases the travel time first exceeds the maximum travel time for a satisfactory vertical transport system. This happened before the average waiting time exceeds the maximum waiting time for a satisfactory vertical transport system.

Journey time
When the number of floors increases, journey time increases less rapidly for the loop transport than for the conventional lift.

General

The loop transport principle is less sensitive to changes in supply. With a larger supply, larger than the system can transport for satisfactory travel and journey times, the waiting time and travel time for the loop transport principle will decrease less rapidly than for the conventional lift. The investigated traffic pattern is up peak, it should be investigated how the systems perform on other traffic patterns.

7.8 The improvement of the basic loop transport principle and its variants

The basic model of the loop transport principle shows some properties and the associated advantages and disadvantages of the loop transport principle. It demonstrates that the loop transport principle can be used to develop a vertical transportation system which takes up less floor space. The functioning of the loop transport principle can be further optimised. The aspect of the vertical transportation system which can be improved will be discussed below, control algorithm, cabin movements and safety assumptions.

Control algorithm
When the control algorithm does not function optimally it is possible that a cabin blocks the shaft while this would not have been necessary if a sophisticated control algorithm had been used. Two options for a better control and more efficient control of the lift system are: dynamic instead of static allocation and destination selection instead of direction selection.
The model uses a static allocation. When a passenger gives a hall call the system determines which cabin will transport the passenger (static allocation). There is some time between the moment of placing a call and the time a cabin arrives at the call location. Within this time period it is very well possible that the determined cabin for the passenger is not the best one anymore (based on the optimisation aspects). After every time step it should be assessed if the predetermined cabin (to a passenger) is the best one (dynamic allocation), or whether another cabin should take over.
The model uses direction selection to indicate a hall call is given. If destination selection is used, the system knows in advance what the final destination of the passengers is and it can adapt the system onto this information earlier. The more the system knows in an early stage the better it can anticipate on the information.

Cabin movements
Within the model of basic loop transport principle the cabins have to move entirely to the top or the bottom of the building to change their direction. The variant on the loop transport principle described in chapter 6 can be used to improve the vertical transportation system by the optimisation aspects. The path for the cabins within the basic loop transport principle is fixed; it is only possible to stop. The path for cabins in the variants is not fixed, at some points cabins may choose to stop or change their direction. As a result of this the control has to be adapted to the variants.

Safety assumptions
Safety is a very important aspect for the success of a (new) vertical transport system. Within the model it is assumed that the minimum vertical distance between two cabins is two floors and when one cabin is moving horizontally and the other is moving vertically the minimum distance is assumed to be one floor. If it would be possible to prove that it is safe to reduce the minimum distance between two cabins at the bottom of the building, it is possible to enter or exit cabins simultaneously, which may result in a shorter waiting times (see figure 55). With a destination selection it would be possible to group passengers for different areas of the building.

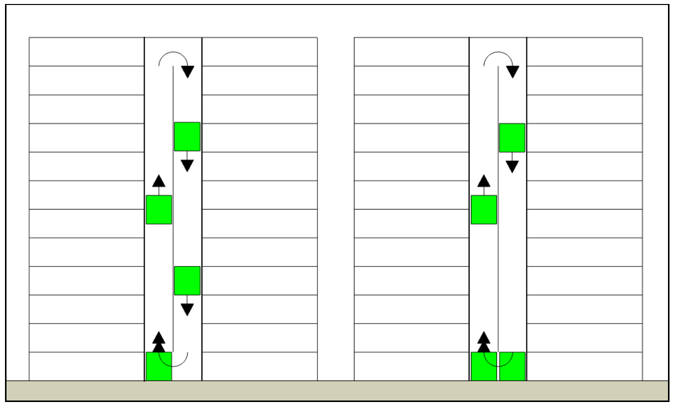
figure 55. Enter or exit two cabins simultaneously at the main terminal (right)

7.9 Passenger misuse for the loop transport principle

In the model it is assumed that passengers use the system as intended. In practice this is not always the case. Passengers can open the doors too long, they can enter a cabin which is not intended for them, they can leave the cabin too early or they can stay in their cabin too long. It is known that situations like this occur, but how often is hard to say, especially because the loop transport system is a new system. It is therefore very hard to implement passenger misuse in the model. Yet it is interesting to know how passenger misuses influence the functioning of the loop transport principle.
A passenger may hold the door wilfully open too long. This may also occur in current conventional lifts. Lift manufactures may implement a "Nudging device". This device is a gentle way of persuading a person not to hold the door open for too long. This device should also be present in the loop transport principle, to avoid passengers form opening the door too long. It may happen that a cabin stays too long at a particular location. If this is known by the control of the lift the system can anticipate on this stagnated cabin. In case of a stagnating cabin, the other cabins move differently and have to be controlled differently. This can be achieved in different ways. How cabins can move in case of a stagnated cabin depends on the number of shafts and when and where a stagnated is detected. In figure 56, the basic loop transport principle is shown. In case of a stagnated car (cabin with a shape of a cross) there are two options. The rest of the cabins move as a conventional lift (figure 56 B) or either they make a loop and pass the stagnated cabin (figure 56 C).

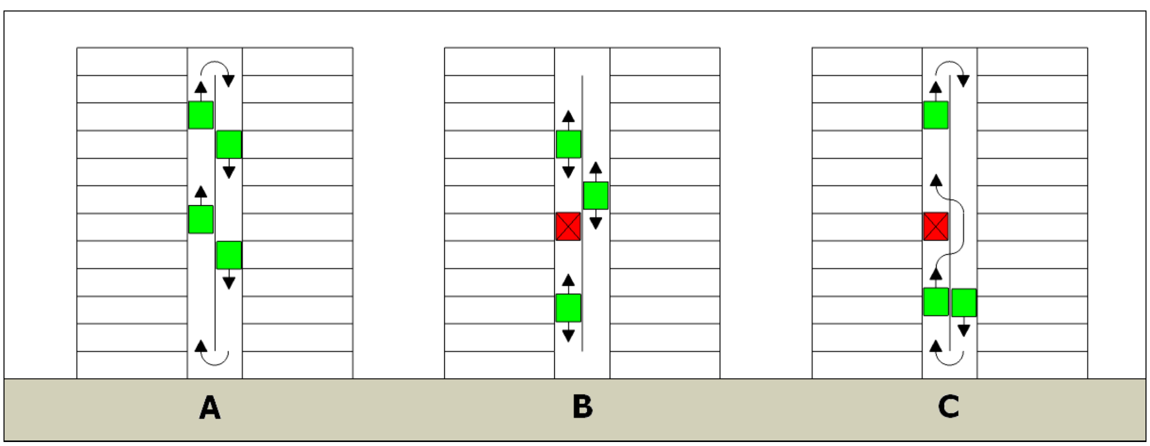

figure 56. A. Basic loop transport principle. B. Stagnated cabin, rest of cabins moves as conventional lifts. C. Stagnated cabin, cabins can pass the stagnated cabin.

When the number of shafts is larger than two (figure 57) it is possible to keep the loop with one shaft closed (figure 57 B). The loop then keeps functioning and above and under the obstacle, cabins can move as conventional lifts (figure 57 C) or cabins can pass the stagnated cabin. The advantage of this configuration compared to a two shaft configuration is that it is possible to pass the cabin through a shaft where cabins move in the same direction (figure 57 D). This is not possible in a two shafts configuration.

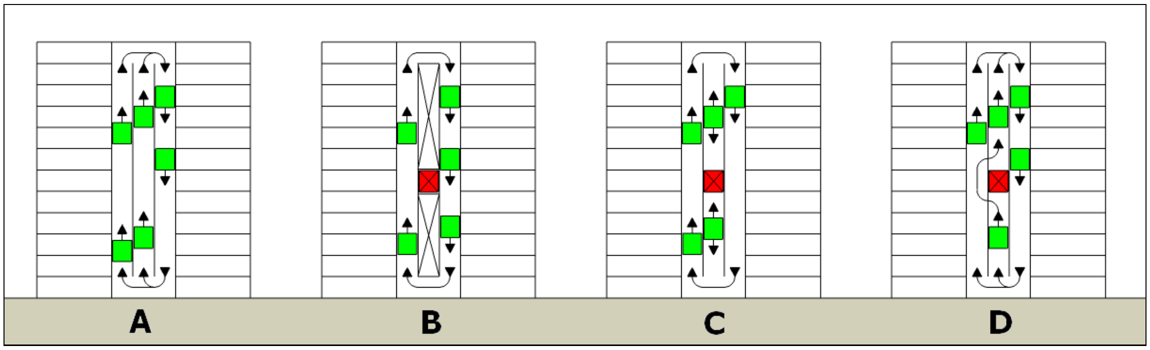

figure 57. A. Basis loop transport principle (2-1 configuration). B. Stagnated cabin, all the other cabins moves via the loop transport principle. C. Stagnated cabin, cabins move as loop transport principle and as conventional lifts. D. Stagnated cabin, all the cabins moves via the loop transport principle and pass the stagnated cabin.

The quantitative influence of a stagnated cabin on the transport capacity or waiting time is not investigated in this master project. When it is physically possible and safe to move cabins as described above, possibilities to cope with a stagnated cabin are achievable. The transport capacity will decrease in case of a stagnated cabin but compared to a conventional lift it is not necessary to close an entire shaft. Vertical transportation system with more than two shafts will be less influenced by a stagnated cabin.

7.10 Conclusion

The aim for the model was to gain more insight in the functioning of the loop transport system. Before the optimisation of a vertical transportation system can be achieved, the optimisation aspects must be clear and determined.
The parameter study determines, with simulations of an up peak traffic pattern, what the maximum height of a building with two shafts is for the loop transport principle and for the conventional lift. The investigated fictitious office building accommodates 50 individuals per floor, the rest of the used parameters are default parameters (see table 16). As a result of the simulations the maximum height of a building for a satisfactory transportation system can be found in table 20 (combination of table 18 and table 19). In this case a building could be twice as high when a loop transport principle with two shafts is present compared to a conventional lift with two shafts.

table 20. Max. number of floors for a satisfactory vertical transportation system with two shafts, (used parameters see table 16)

Cabin capacity (passengers)	Maximum number of floors for conventional lift	Maximum number of floors for loop transport principle
6	8	19
8	9	17
10	9	17
12	9	17

A well functioning loop transport principle results in a system which acts more as a taxi whereas a conventional lift acts as a bus. Conventional lifts fill and after that they will stop several times to deliver passengers. The loop transport principle has a more individual functioning so smaller cabins can be used to gain the same transport capacity. This can also be seen in the table above where smaller cabins result in a larger maximum number of floors.
The model shows that the loop transport principle can result in a vertical transportation system which uses less floor space. The model investigates the basic loop transport principle. Improvements for an optimisation of the loop transport principle can be achieved with a more sophisticated control of the system and another way of putting a hall call, destination selection instead of direction selection. The system then knows earlier what the final destination of passengers is and can anticipate on these requests. Another way of letting cabins move through the building, described in the variant, can optimise the functioning of the loop transport principle as well; shaft space is used more efficiently.
Within the model passenger misuse is not taken into account, but several possibilities exist for the loop transport principle to cope with stagnated cabins.

8 Case study

The model, developed in this master project in chapter 7, shows the positive and negative aspects of the loop transport principle. In this chapter the association of the model to a vertical transportation system for a building in practice is done with the help of a case study. Within this case study a vertical transportation system is designed for a fictive building of 60 stories (§8.1). and the influence of the height of the building onto the vertical transportation system is investigated (§8.2).

What building is investigated?
The building which is investigated is a fictitious building designed for the workshop high-rise 2007. During this workshop, organised by the faculty of architecture and civil engineering of Delft University of Technology, an office building of 250 meter had to be designed on a given plot in the centre of Rotterdam. Groups of five students had to work out five primary disciplines involved in high-rise design. Architecture, structural design, façade design, building services and building management had to be worked out. The tower designed by group 5, in this group Joost Colsen was present, is in this case study investigated on the aspect of vertical transportation. The tower, developed by group five, was called "The Ribbon", a picture of the tower is given in figure 58.

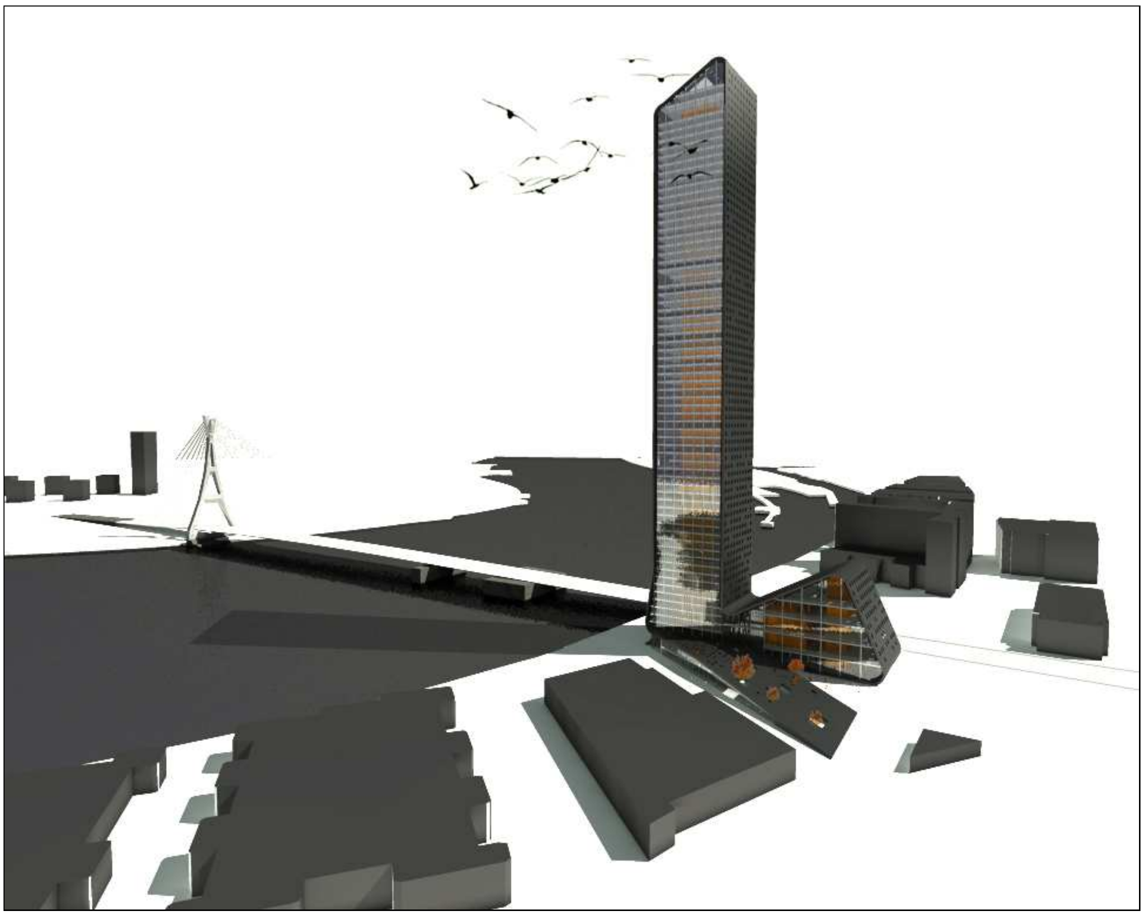

figure 58. Tower used for case study. Tower is called "the Ribbon" and designed in the workshop high-rise 2007.

Aim of the case:
Determine the lay-out of a vertical transportation system for a building. Give an indication how a vertical transportation system would look like and perform on basis of the developed model for a conventional lift and the loop transport principle in this master project. The performance of the loop

transport principle is compared to a conventional lift. The case may give an indication of the floor space consumed by the vertical transportation system in a building.

8.1 The case

The Ribbon exists of 60 floors which are used as offices. All the floors have the same outside dimensions and the number of individuals per floor is the same for all the floors.

In the workshop high-rise 2007 a vertical transportation system is designed for the Ribbon. The properties of the Ribbon used to design the vertical transport system can be found in table 21.

table 21. Properties used for the design of the vertical transport system of the Ribbon

Property		Unit
Number of floors	60	
Number of total individuals	5000	
Number of individuals per floor	83	
Handling capacity in 5 min	12,5	%
Percentage assumed attendant	100	%

The designed vertical transportation system in the workshop high-rise 2007 can be found in appendix k. The chosen vertical transportation system of the Ribbon exists of conventional lifts and double deck lifts. The number of lifts is at that time determined on the basis of simulations with the program Elevate®. The exact assumptions and used properties for the simulations in Elevate® could not be found anymore, therefore new simulations were done with the model developed in this master project. The starting points and the result of the simulations can be found in the following paragraph.

8.1.1 A conventional lift vs. the loop transport principle for the Ribbon

In the previous chapter, the models for a conventional lift and the loop transport principle were developed. These models were used as starting point for the determination of the number of shafts for the “Ribbon”. The properties of table 21 were used for the determination of the vertical transport system.

Assumptions for the determination of the vertical transport system for the Ribbon for both principles
- Storage of cabins is not taken into account.
- The space consumption of the lift installation and the lift technique are not taken into account.
- There are two sky lobbies at 1/3 and 2/3 of the height of the building.
- All the floors accommodate the same number of individuals.
- When individuals have to change lifts to reach their final destination, both lift journeys are assessed individually (Barney, 2003).
- Each journey with a lift is acceptable with a maximum waiting time of 30 seconds and a maximum travel time of 60 seconds (Barney, 2003).
- The determination of the number of shafts for both principles is based on an up peak traffic pattern.
- The vertical transport system has two conventional fire/freight lifts which serve all the floors. The capacity of these lifts is not needed for the vertical transportation of passengers during up peak.
- The capacity for fire/freight lifts for the Ribbon is in this case not determined. The capacity is taken over from the workshop high-rise.

In the following two paragraphs the vertical transportation is determined based on the model of the conventional lift and based on the model of the loop transport principle. The runs done in chapter 7 could not be taken over directly because the parameter values used to run the simulations differ too much for this case. Because of that new simulations were done. As done in the previous chapter, runs were done ten times per parameter series and the average waiting time and travel time is determined.

8.1.1.1 The Ribbon and a vertical transportation system based on conventional lifts

The parameters used for the simulations for the conventional lift can be found in table 22 and the resluts of the runs expressed in a maximum number of floors, based on a satisfactory waiting and travel time can be found in table 23. The results of the runs, expressed in average waiting time, average travel time and average journey time can be found in appendix I.

table 22. Parameter values used for case conventional lift.

Building data	unit	Passenger data	unit	Lift data	unit
Floor height	3,8 (m)	Passenger mass	75 (kg)	**Number of cabins[1]**	**2-4**
Number of floors	**5-20**	Passenger loading time	1,2 (s)	Door opening time	1,8 (s)
Number of persons per floor	83	Passenger unloading time	1,2 (s)	Door closing time	2,9 (s)
		Capacity factor	80 %	Acceleration	1,5 (m/s^2)
		Stair factor	0 %	Deceleration	1,5 (m/s^2)
				Max. speed of lift cabin	6 (m/s)
				Cabin capacity[2]	**600-1125** (kg)

Simulation data	unit
Duration of the simulation	300 (s)
Percentage of the building population assumed attendant	100 %
Percentage of the attendant people in the building which will be transported during the simulation	12,5 %
Traffic pattern	Up peak
Putting a hall call	Direction sel.
Time step for simulation	0,1 (s)

[1] The number of cabins for the conventional lift varies between two and four. More cabins take up more shafts
[2] Cabin capacity will vary for 6, 8, 10 or 12 passengers.

table 23. Maximum number of floors for conventional lift with a satisfactory travel time and waiting time based on parameters values of table 22.

Cabin capacity (passengers)	Maximum number of floors (2 shafts)	Maximum number of floors (3 shafts)	Maximum number of floors (4 shafts)
6	6	8	10
8	6	8	11
10	7	9	12
12	7	10	13

Result for vertical transportation system

The results of the runs are translated to a vertical transport system for the Ribbon, see figure 59 and table 24. There are three types of lifts: Local lifts, shuttle lifts and fire/freight lifts. The ribbon originally had two sky lobbies, these two sky lobbies are used to change lifts to the final destination of the passenger. From ground level and from both sky lobbies local lifts had to serve 1/3 of the building. The result of the runs shows that this is not possible with 4 local lifts, because the maximum number of floors which can be served is thirteen with four shafts. The local lifts are therefore split in two parts, the first four lifts serve the first eleven floors and the second four lifts serve the floors above the eleven floors and below the sky lobby or roof. The second four local lifts do not serve the same number of floors as the first four local lifts. The maximum number of floors for the second four local lifts is less because cabins need to make an express run to the first floor that is served by these lifts.

The shuttle lifts must transport 1/3 of the building population. Three shafts are used for the transportation of the passengers to the first sky lobby and four lifts are used for transportation of passengers to the second sky lobby. The transport capacity of the shuttle requires that 12.5% of 1/3 of the building population needs to be transported in 5 minutes. This was one of the starting requirements of the transport system. With these parameter values 208 passengers need to be transported in 5 minutes, this result in 42 passengers per minute. This can be done with the given number of lifts.

The fire/freight lift is present with two shafts; this was one of the assumptions.

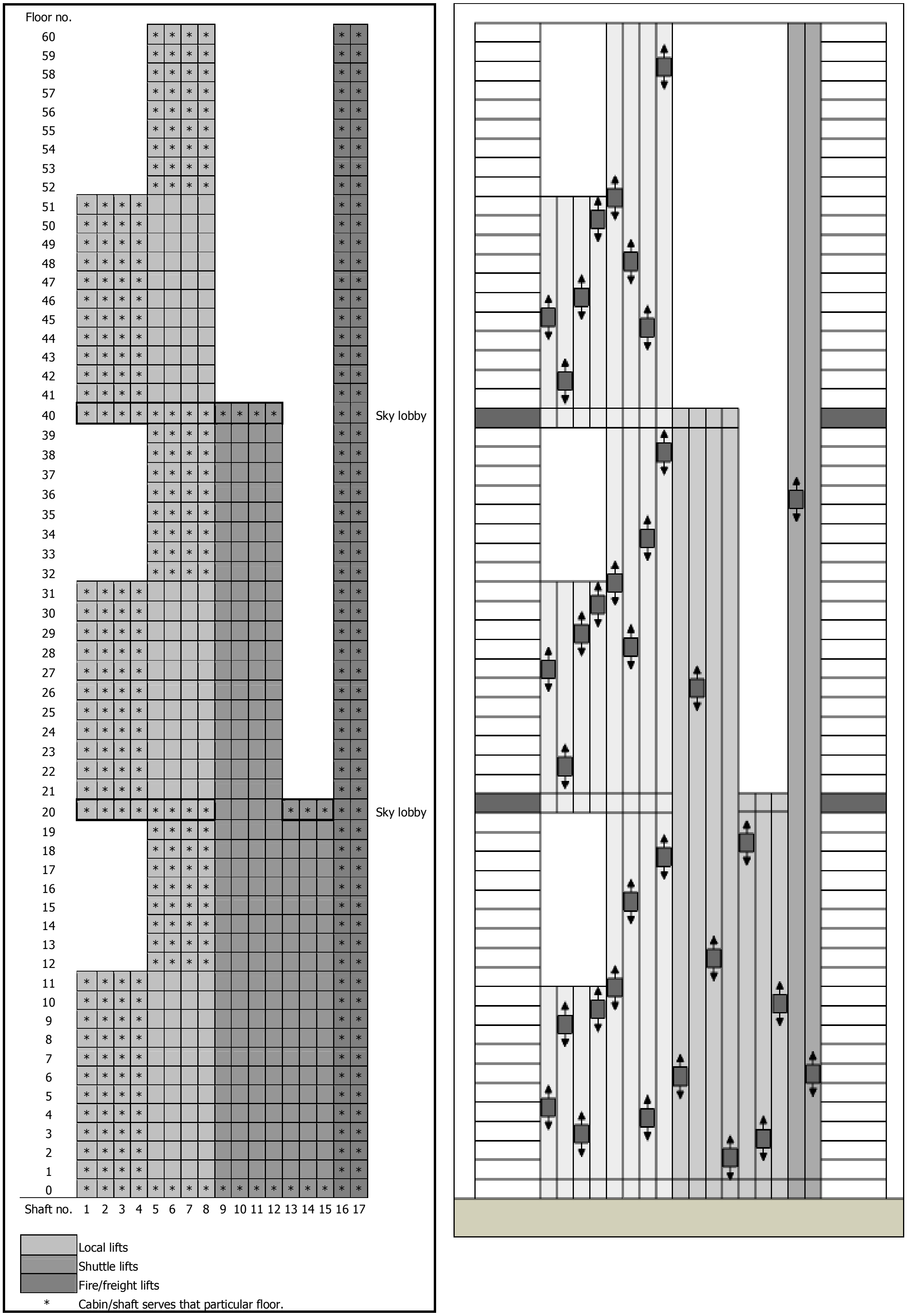

figure 59. Indication for vertical transport system for the Ribbon. Conventional lift.

table 24. Lift properties for conventional vertical transportation system, associated to figure 59.

Lift	amount	sort	cabin capacity (passengers)	cabin capacity (kg)	speed (m/s^2)	acceleration (m/s^3)
1 to 8	24	Local lifts	10	1000	6	1,5
9 to 15	12	Shuttle lifts	15	1400	6	1,5
16 to 17	2	Fire/ freight lifts	15	1400	6	1,5

8.1.1.2 The Ribbon and a vertical transportation system based on the loop transport principle

The parameters used for the simulations for the loop transport principle can be found in table 25 and the results of the runs expressed in a maximum number of floors, based on a satisfactory waiting and travel time can be found in table 26. The results of the runs, expressed in average waiting time, average travel time and average journey time can be found in appendix l.

table 25. Parameter values used for case loop transport principle.

Building data	unit	**Passenger data**	unit	**Lift data**	unit
Floor height	3,8 (m)	Passenger mass	75 (kg)	**Number of cabins[1]**	**2-8**
Number of floors	**5-20**	Passenger loading time	1,2 (s)	Time to change shafts	3 (s)
Number of persons per floor	83	Passenger unloading time	1,2 (s)	Door opening time	1,8 (s)
		Capacity factor	80 %	Door closing time	2,9 (s)
		Stair factor	0 %	Acceleration	1,5 (m/s^2)
				Deceleration	1,5 (m/s^2)
				Max. speed of lift cabin	6 (m/s)
				Cabin capacity[2]	**600-1125** (kg)

Simulation data	unit
Duration of the simulation	300 (s)
Percentage of the building population assumed attendant	100 %
Percentage of the attendant people in the building which will be transported during the simulation	12,5 %
Traffic pattern	Up peak
Putting a hall call	Direction sel.
Time step for simulation	0,1 (s)

[1]The number of cabins for the loop transport principle varies between two and eight, depends on the height of the building. More cabins do not take up more shafts.
[2] Cabin capacity will vary for 6, 8, 10 or 12 passengers.

table 26. Maximum number of floors for conventional lift with a satisfactory travel time and waiting time based on parameters values of table 25.

Cabin capacity (passengers)	Maximum number of floors (2 shafts)
6	5
8	8
10	11
12	12

Results for vertical transportation system

The vertical transportation system for the Ribbon based on the loop transport principle exists, just as the conventional system, of three types of lifts; local lifts, shuttle lifts and fire/freight lifts. For the lay-out of the loop transport principle for the Ribbon see figure 60. The sky lobbies are also used as places where passengers change lifts to reach their final destination. The number of shafts for the local lift are determined on the basis of the results of the simulations for the loop transport principle.

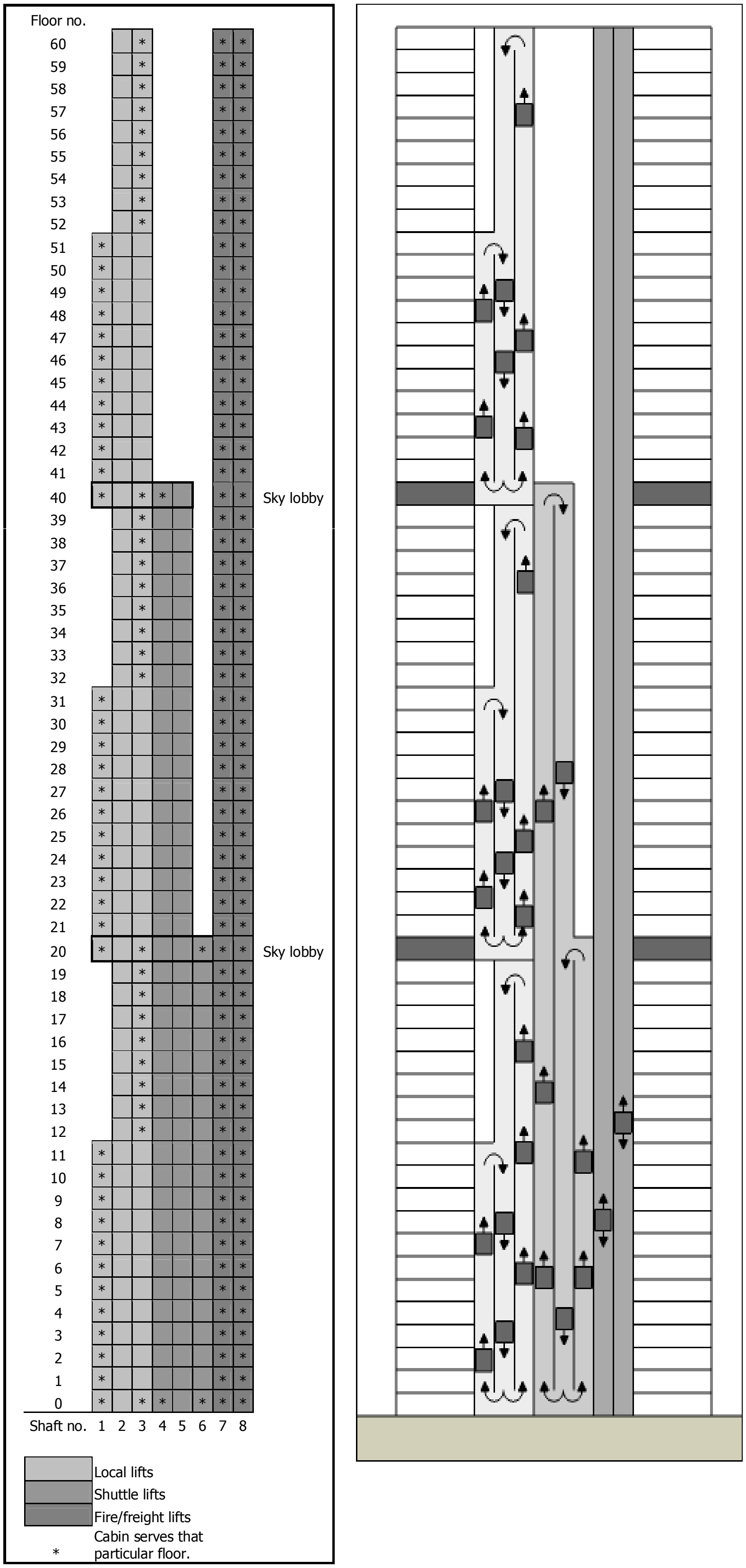

figure 60. Indication for vertical transport system for the Ribbon. Loop transport principle.

table 27. Lift properties for loop transport principle, associated to figure 60.

Lift	amount	sort	cabin capacity (passengers)	cabin capacity (kg)	speed (m/s^2)	acceleration (m/s^3)
1 to 3	3	Local lifts	10	1000	6	1,5
4 to 6	1	Shuttle lifts	15	1400	6	1,5
7 to 8	2	Fire/ freight lifts	15	1400	6	1,5

The local lifts have to serve the floors from ground level or from both sky lobbies and then 1/3 of the building. This can not be done with one loop, because the maximum number of floors with one loop in case of the loop transport principle is twelve (based on simulations with the given parameter values). The minimum number of loops to serve 1/3 of the building is two. The second loop which serves the upper levels can not serve the same number of floors as the first loop. The number of floors served by the second loop is less because of the express run to the first floor which is served by this loop. These two loops can be positioned as figure 61 (left) describes. During up peak (all) cabins return empty to the main terminal or sky lobby. It is therefore not necessary to use two shafts for the cabins to travel downwards, the two shafts can be combined, see figure 61 (right). During down peak all the cabins move the other way around. A good synchronisation of the demand and the way in which the cabin travel is controlled is a very important aspect for the correct functioning of this lift system.

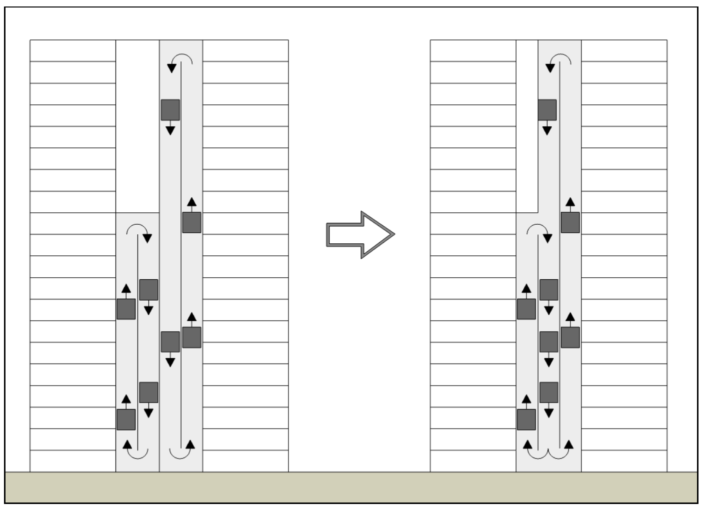

figure 61. Local lifts. Cabins travel empty down during up peak, therefore three shafts may be used instead of four.

The shuttle lifts have to serve the same number of passengers as the shuttle lifts of the conventional system do. This was 208 passengers per 5 minutes and 42 passengers per minute. The capacity of the shuttle lifts is 15 passengers, so every twenty seconds a cabin filed with 14 passengers has to arrive at the sky lobby.
The fire/freight lift is present with two shafts; this was one of the assumptions.

Remarks
Two loops are combined in three shafts, this is illustrated in figure 61. This is done for both local lifts and shuttle lifts. This can be done when the traffic for the vertical transportation system approaches an up peak traffic pattern or a down peak traffic pattern. How the system functions in case of an inter floor traffic pattern should be investigated and is not done is this master project. It must be said that the intensity of the inter floor traffic depends on the function of the building. When the building is used as a multi tenant building and every floor is used by another tenant, inter floor traffic would not occur frequently. When tenants use more floors, inter floor traffic is more logical, because colleagues need to visit colleagues. The function of the building was not described in the assumptions so the intensity of the inter floor traffic is hard to determine. When it appears that the inter floor traffic proposal is not sufficient, extra shafts are needed as figure 61 (left) describes.

8.2 *The height of the building related to the used floor space for vertical transportation*

A building with more floors, and the same number of individuals per floor, requires relatively more floor space for vertical transportation. The Ribbon was used to get more insight in the relation of the height of the building compared to the used floor space for vertical transportation. A difference was made between a conventional lift system and the loop transport principle.

The lift configurations of paragraph 8.1 are used as a starting point for the determination of the number of shafts for a satisfactory vertical transportation system with fewer floors than the original Ribbon. The fire and freight lifts are not taken into account, in this paragraph the minimum floor space used for transportation of individuals is figured out. As a starting point for the determination of the used floor space, the number of passengers per cabin is determining for the floor space taken by the cabin. It is assumed that one passenger takes up 0,27m^2 (Strakosch, 1998). In front of every lift a streaming area is present which is at least as big as the cabin (Strakosch, 1998). Therefore, it is assumed that a lift takes up 0.54 m^2 (2*0.27m^2) per passenger. So for example a lift wit a capacity (the capacity factor of 80% included) of 10 passengers will take up 5.4 m^2 per floor where the lift comes along. The configuration of the total vertical transportation system depends on the height of the building, more floors require more transportation capacity because more passengers have to be transported and more floors require longer distances which have to be passed. The configuration of the transportation system is done for the theoretical case that the Ribbon exists of fewer floors. The configuration for a conventional lift can be found in figure 62, the configuration for the loop transport principle can be found in figure 64 (the meaning of the colours of figure 62 and figure 64 is the same as the meaning of the colours of figure 59 and figure 60.)

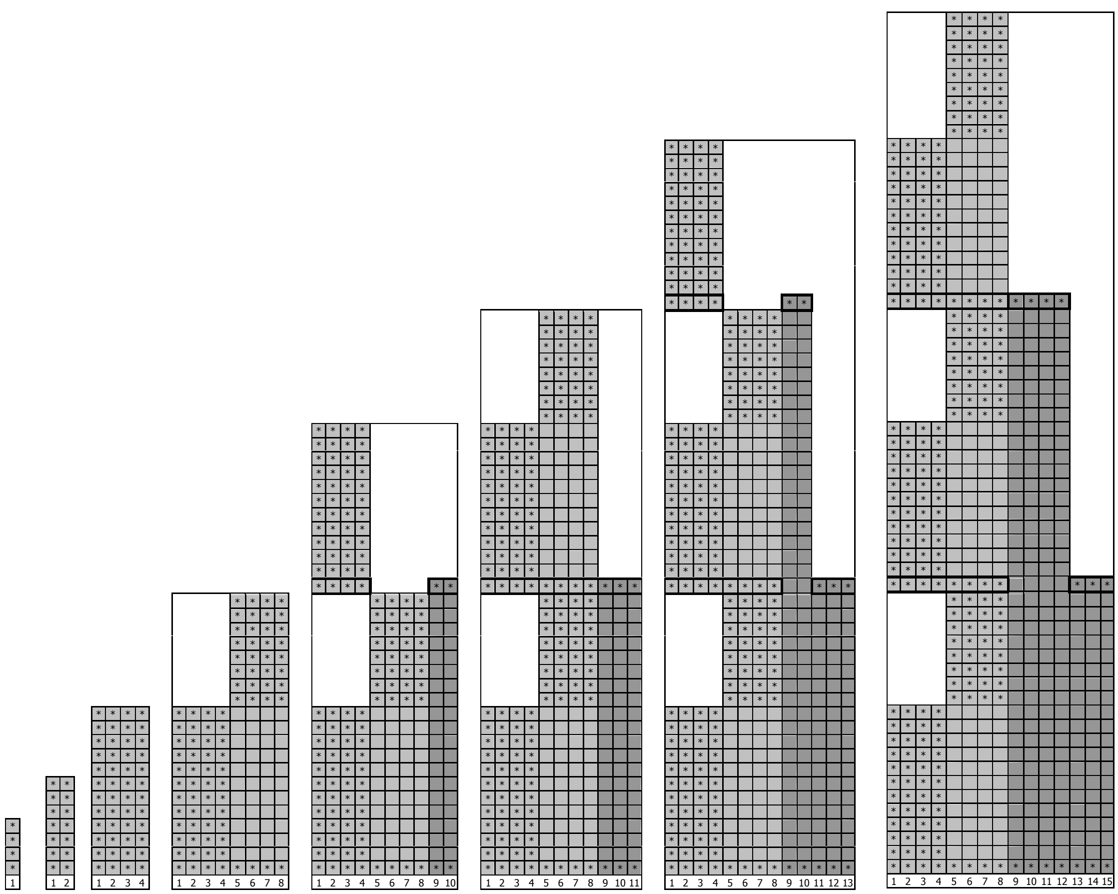

figure 62. Indication of configuration for vertical transport system for different heights of the Ribbon. Conventional lift.

The configuration of figure 62 is used to determine the total floor space taken by the vertical transportation. The floor space taken up by the vertical transportation system is set down in a graph which can be found in figure 63.

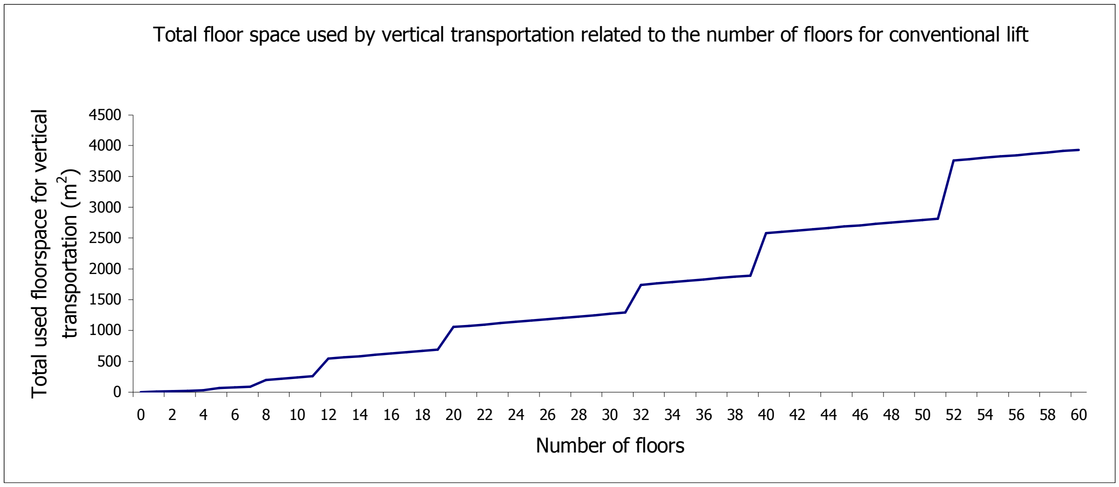

figure 63. Floor space used for vertical transportation for conventional lift, based on configuration of figure 62.

Loop transport principle

The loop transport principle is worked out with the same assumptions as for the conventional lift. The indication of the configuration for vertical transport system for different heights of the Ribbon for the loop transport principle can be found in figure 64.

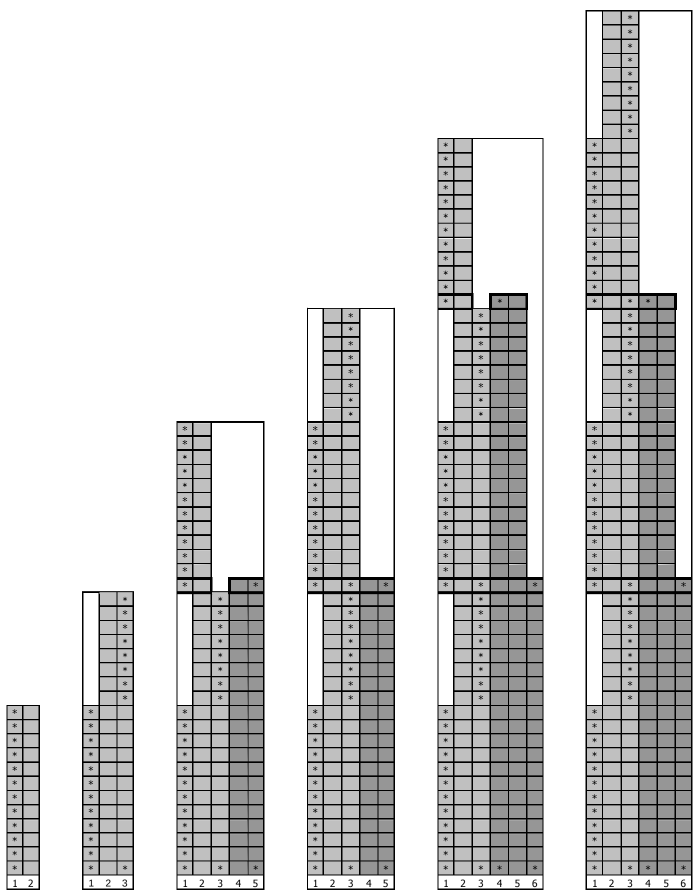

figure 64. Indication of configuration for vertical transport system for different heights of the Ribbon. Loop transport principle.

The associated used floor space for vertical transportation for the loop transport principle can be found in figure 65.

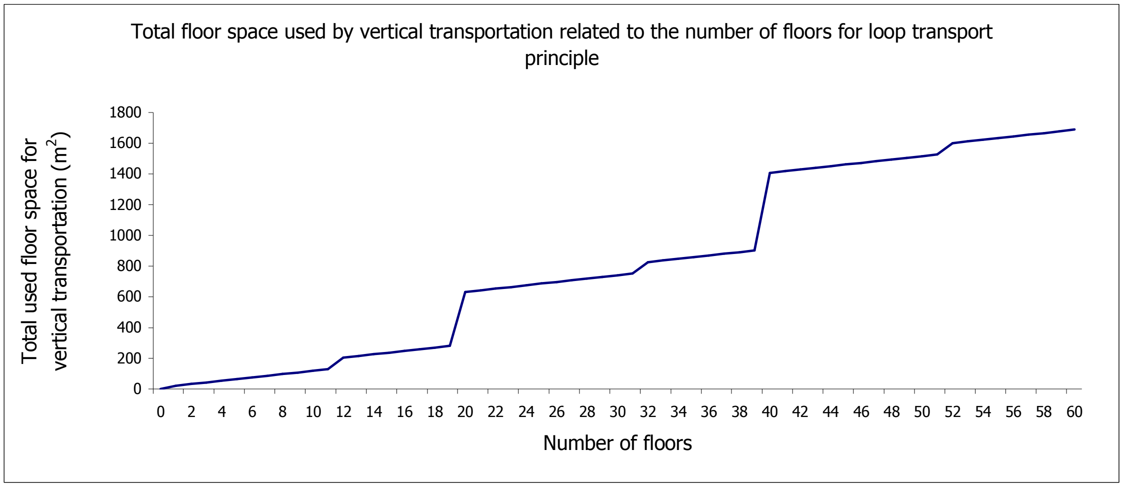

figure 65. Floor space used for vertical transportation for conventional lift, based on configuration of figure 64.

Differences in used floor space for vertical transportation systems
Combining figure 63 and figure 65 visualise the difference in used floor space for vertical transportation, this can be seen in figure 66. The data of figure 66 can be found in appendix m.

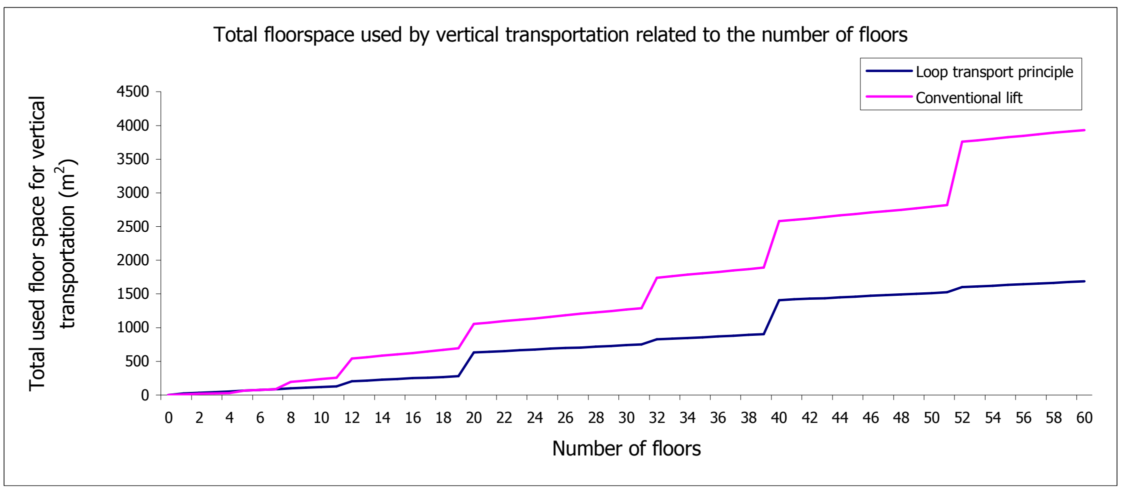

figure 66. Total floor space used for vertical transportation, same data as used for figure 63 and figure 65.

The conventional lift uses more floor space, from 8 floors about twice as much. The loop transport principle is less capricious compared to the used floor space for the conventional lift. The absolute difference in used floor space is bigger when the number of floors increases, so with more floors more absolute floor space can be gained with the loop transport principle.

8.3 Conclusion

The loop transport principle results for the Ribbon in a vertical transportation system which takes up less floor space compared to a conventional lift. The determination of the number of shafts is based on the model for a conventional lift and loop transport lift, developed in this master project. The number of shafts for a conventional vertical transport system is 17 including fire/freight lifts, the number of shafts for a loop transport principle is 8, including two conventional fire/freight lifts.
Higher buildings take up absolutely but also relatively more floor space for vertical transportation, this is illustrated with the theoretical case that the Ribbon exists of less floors.

9 Concluding remarks and recommendations

This chapter contains the concluding remarks and the recommendations for this master project.

9.1 Concluding remarks

- The loop transport principle consists of two parts, the way in which the cabins are controlled and the way in which they travel. Because the control algorithm is decisive for the movements, these parts are interdependent.

- Systems for a physical movement of the cabins as described in the loop transport principle are, as far as could be found, currently not available. Techniques which can be used for the physical movement of cabins for the loop transport principle are described in several patents. These techniques can be used as a starting point for the further development of the loop transport principle which is potentially very promising.

- The control of the cabins is a very important aspect for an optimal functioning of the loop transport principle. Within this master project a simulation model for the loop transport principle has been developed. The control of this model is based on a static allocation assigning a passenger to a cabin. The direction selection principle is used for putting a hall call. With the model of the loop transport principle and the model of the conventional lift a parameter study is performed for an up peak traffic pattern. Within this parameter study the used floor space for vertical transportation is assumed fixed, two shafts are used. The maximum height for a building with a satisfactory vertical transportation system is reviewed for both systems. The number of assumed individuals per floor is 50, for the remaining parameters see table 16. The maximum number of floors is shown in table 28.

table 28. Max. number of floors for a satisfactory vertical transportation system with two shafts, (used parameters see table 16)

Cabin capacity (passengers)	Maximum number of floors for conventional lift	Maximum number of floors for loop transport principle
6	8	19
8	9	17
10	9	17
12	9	17

- A journey consists of waiting and travelling. Within a conventional lift the average waiting time becomes leading when the passenger traffic supply becomes too large, travel time still satisfies. Within the loop transport principle the average travel time becomes leading when the passenger traffic supply becomes too large and waiting time still satisfies.

- A well functioning loop transport principle results in a system which acts more as a taxi whereas a conventional lift acts as a bus. Conventional lifts fill and after that they will stop several times to deliver passengers. The loop transport principle has a more individual functioning so smaller cabins can be used to achieve the same or better transport capacity.

- Storage of cabins is necessary for periods with less traffic demand. This storage is necessary to avoid unnecessary cabin movements with empty cabins. Empty cabins can block the shaft and have to move to make room for cabins which convey passengers. This may have a negative effect on the transport capacity and energy consumption.

- The loop transport principle is less sensitive to changes in demand. With a larger demand than the system can handle for satisfactory travel and journey times, the waiting time and travel time for the loop transport principle will increase less rapidly compared to the conventional lift.

- Within the model of the loop transport principle developed in this master project, passenger misuse is not taken into account. There are several possibilities for the loop transport principle to cope with stagnated cabins due to passenger misuse. Stagnated cabins within a conventional lift immediately block an entire shaft. This does not have to be the case in the loop transport principle. When it is physically possible and controllable for a cabin to pass the stagnated cabin, such a cabin does not have to cause a totally blocked and useless shaft.

- A case study was done for a fictitious office building of 60 floors which accommodates 5,000 individuals. A conventional lift would result in a vertical transport system of 17 shafts whereas the loop transport principle results in a vertical transport system with 8 shafts. In this particular case a conventional lift system would need about twice as much space as the loop transport principle.

9.2 Recommendations

- A system that makes it physically possible for lift cabins to move through a building according to the loop transport principle is not available as yet and has to be developed. Patented techniques to let cabins move above each other and in succession are available. Further research should be carried out on how the suggested techniques or other techniques may be used for the loop transport principle.

- Optimisation of the control of the loop transport principle. This master project describes the results of simulations for the basic loop transport principle for an up peak traffic pattern. Static allocation to link a passenger to a cabin is used and direction selection is used for putting a hall call. Dynamic allocation and destination selection would influence the functioning of the loop transport principle in a positive way or at least with similar results. Journey time might be considerably shorter. Further research should quantify the effects.

- Determine control algorithms for the variants of the loop transport principle and different traffic patterns.

- Quantify the influence of passenger misuse for the loop transport principle and its variants.

- Quantify the benefits for the saved floor space within a building so that it can be determined what a loop transport principle may cost.

- Within the loop transport principle it is possible for cabins, also occupied ones, to accelerate, decelerate or even stop completely. In that case they have to wait for another cabin which is serving a call. It has to be investigated how passengers will react to these movements when they are in a closed cabin.

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http://www.wikipedia.org
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http://www.ctbuh.org
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Software:
- Elevate, version 7.18TK
- Matlab, version 7.5.0.342 (R2007b)
- Microsoft Office Excel 2003
- Microsoft Office Visio 2003
- Microsoft Office Word 2003
- XNView, version 1.94

Appendix

a. Traffic patterns

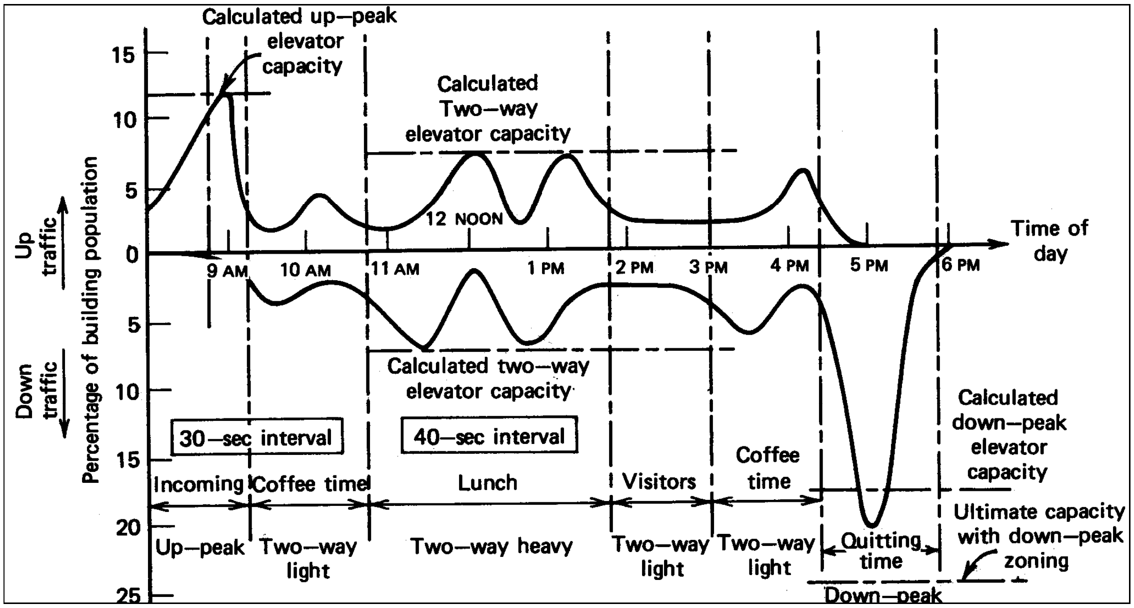

figure 67. Typical traffic flow- diversified office building observed on and off lifts at the main lobby (Strakosch 1998)

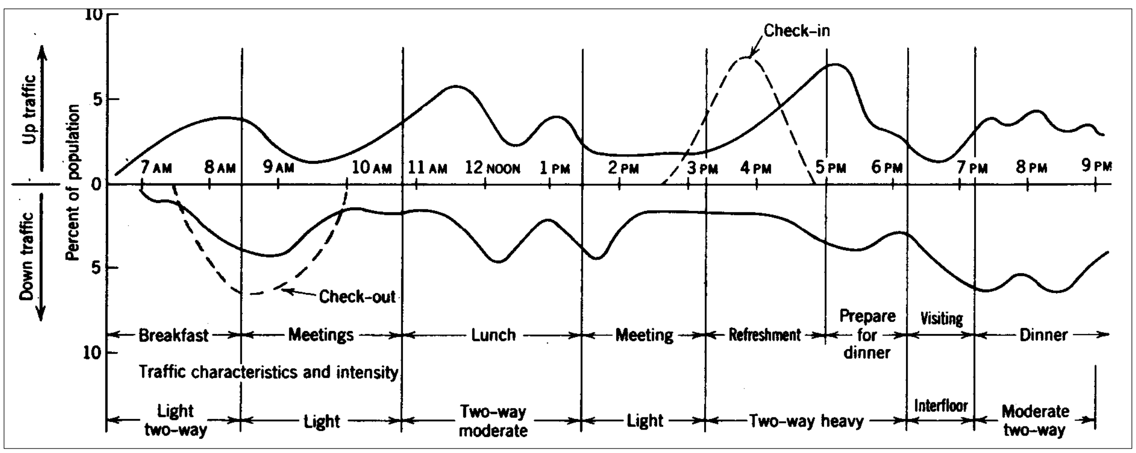

figure 68. Traffic flowcharts-traffic in and out of elevators at a main lobby Motel-hotel convention type (Strakosch 1998)

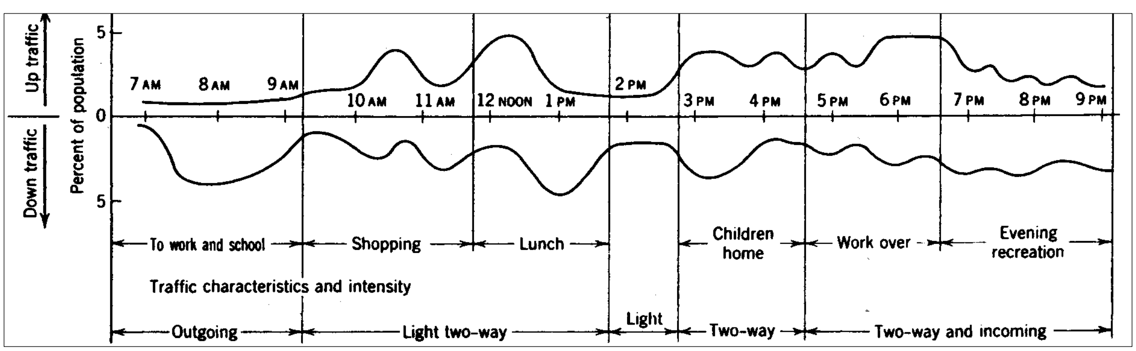

figure 69. Traffic flowcharts-traffic in and out of elevators at a main lobby for an apartment building (Strakosch 1998)

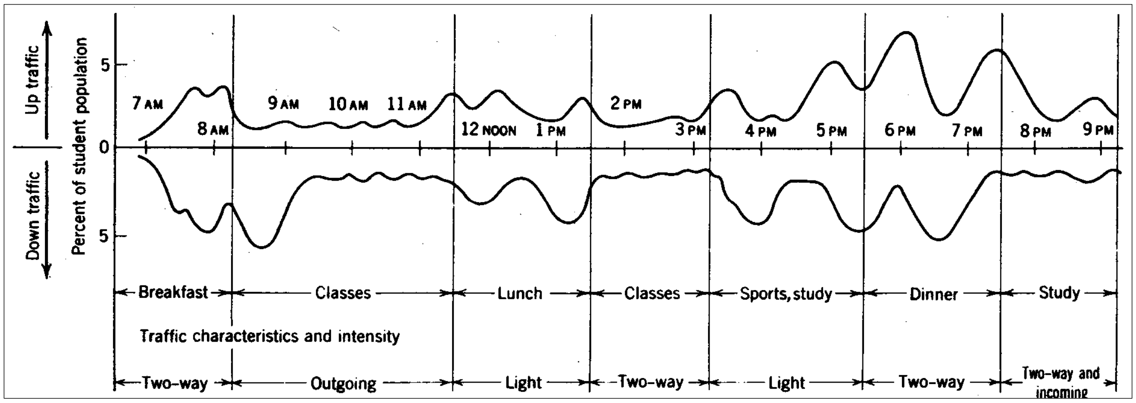

figure 70. Traffic flowcharts-traffic in and out of elevators at a main lobby dormitory(Strakosch 1998)

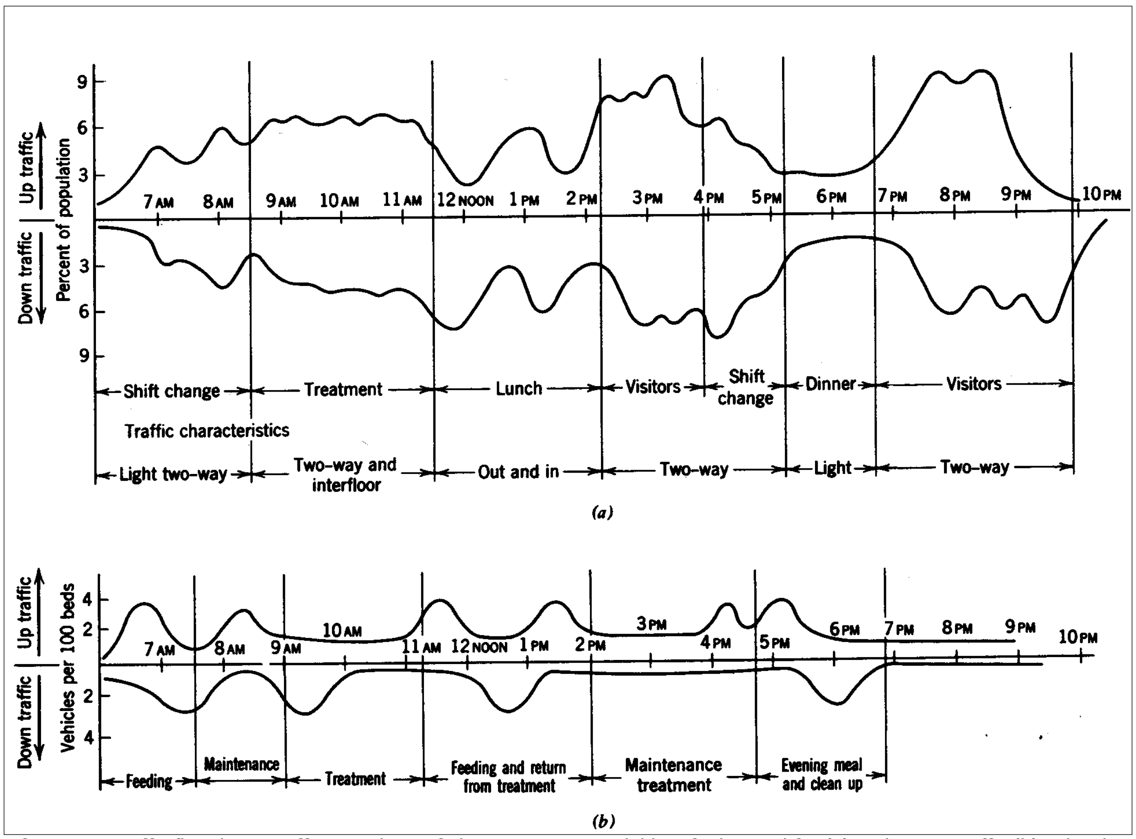

figure 71. Traffic flowcharts-traffic in and out of elevators at a main lobby of a hospital for (a) pedestrian traffic (b) vehicular traffic (Strakosch 1998)

b. Spatial Movements

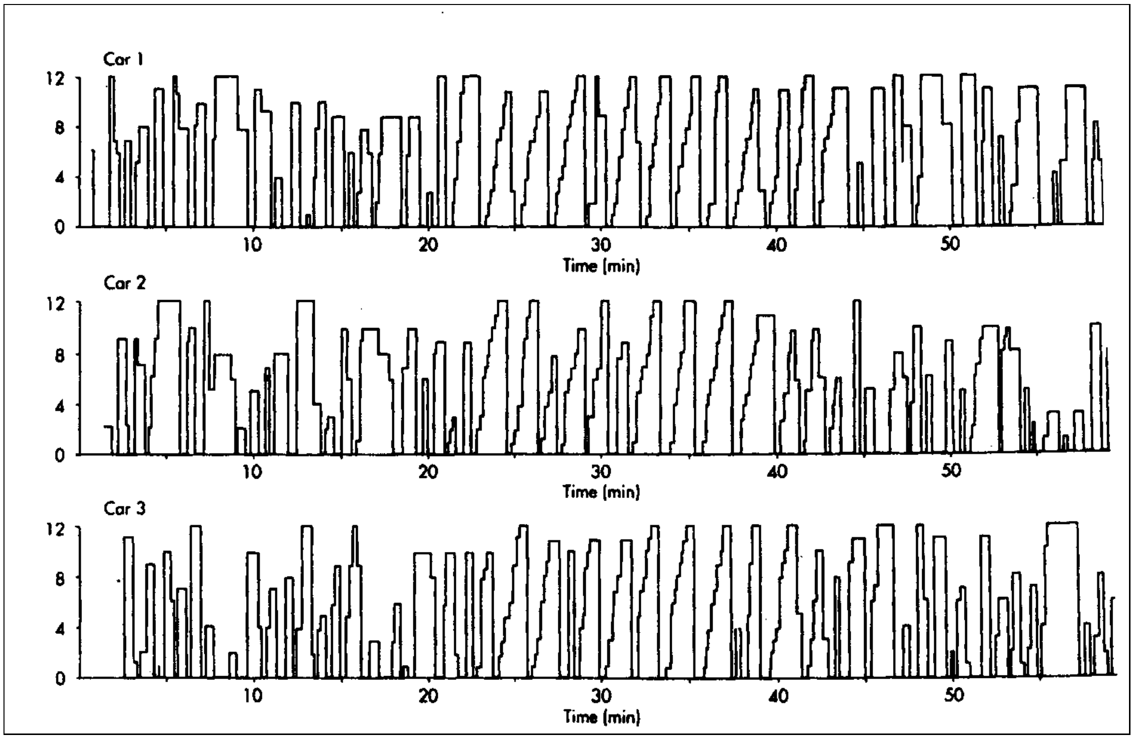

figure 72. Screen shot of the spatial movements of lift cars during up peak traffic (Barney 2003).

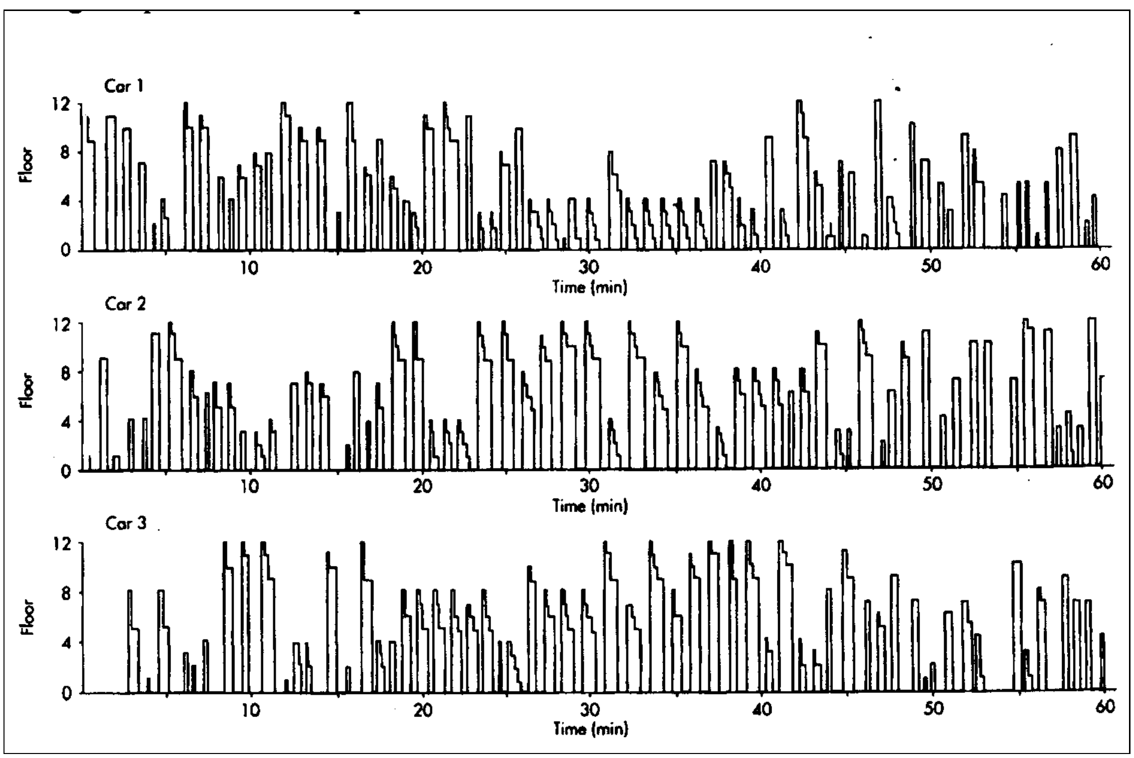

figure 73. Screen shot of lift cars during down peak traffic (Barney 2003).

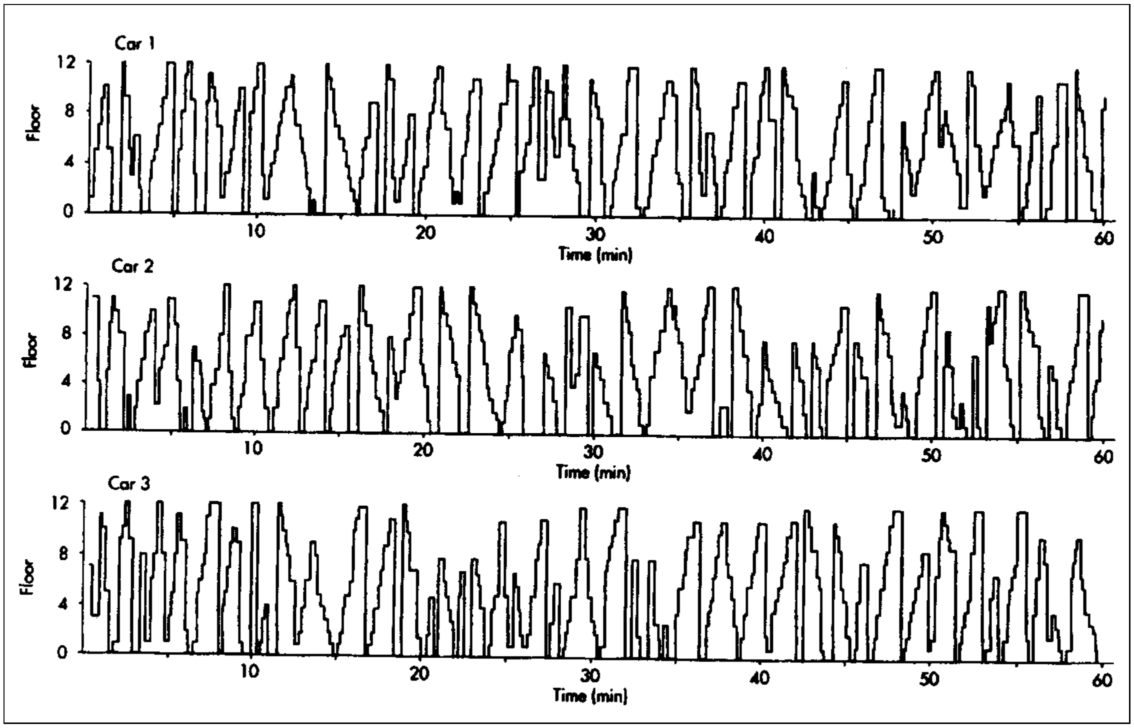

figure 74. Screen shot of lift cars during balanced interfloor traffic (Barney 2003).

c. Patents of Lift systems with linear drive system

1.
United States Patent Application
Pub. No.: 2007/0199770A1
Pub. Date: August.30, 2007
Title: *Elevator installation with a linear drive system and linear drive system for such an elevator installation*

2.
Weltorganisation für geistiges Eigentum
Internationale veroffentlichung snummer: WO 02/02451 A1
Internationales veroffentlichungsdatum: 10 Januar 2002
Title: *Elevator comprising a linear motor drives*

3.
Canadian Intellectual Property Office
Int.Cl.: B66B 011/04,H02K 041/03
06-02-1998
Title: *Linear motor for driving an elevator car*

4.
United States patent
Patent number: 5,234,079
Date of patent: Aug.10,1993
Title: *Rope less linear motor elevator system*

The full version of the patents can be found on: http://looptransportprinciple.googlepages.com

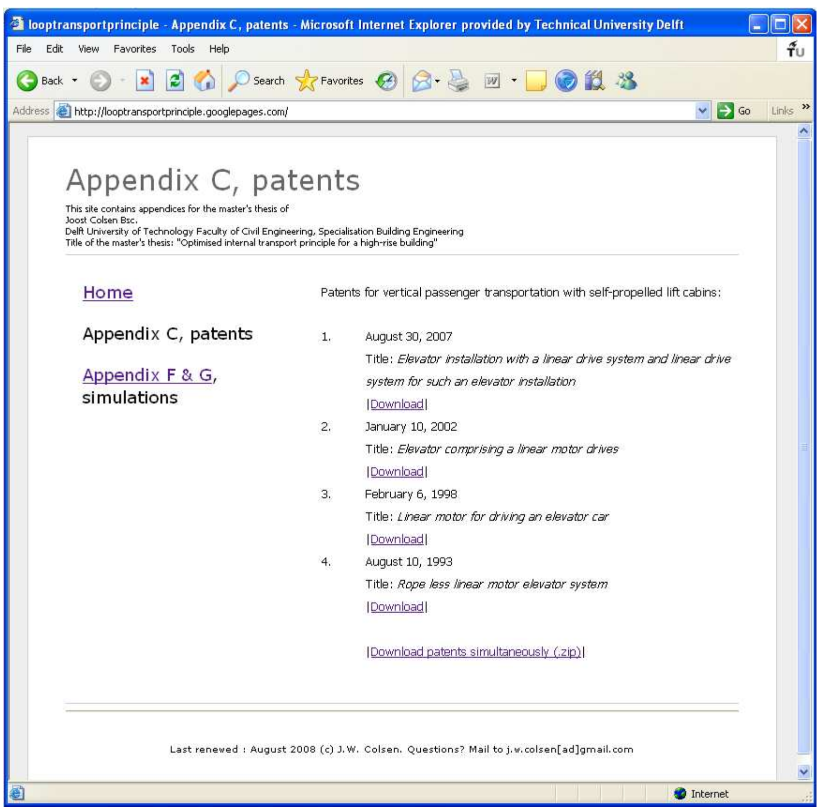

figure 75. Screenshot patents @ http://looptransportprinciple.googlepages.com

d. *Technical description Maastoren Rotterdam*

Technische omschrijving Maastoren Rotterdam
Versie OVG Projecten XX/fla/1.0 d.d. 14 augustus 2007 blad 15

5.11. Transport
Liftinstallaties
Het gebouw wordt voor het personenvervoer van de begane grond naar de kantoorverdiepingen voorzien van zeven elektrisch aangedreven personenliftinstallaties (vier low-rise en drie high-rise). Voor het personenvervoer van de parkeerverdiepingen naar de begane grond worden drie shuttleliften voorzien.

Voor het selecteren van de kantoorliften worden de volgende streefwaarden gehanteerd:
- personenbezetting: ter berekenen op basis van 1 persoon op 19,7m2 BVO op de kantoorverdiepingen.
- gelijktijdigheid tijdens de piek: 85%
- berekening met computersimulatie bij :
- 12,5% aanbod in 5 minuten tijdens piekperiode in de ochtend
- gemiddelde reistijd maximaal 110 seconden
- bestemmingsbesturing

Het liftsysteem wordt separaat geprogrammeerd voor piek- en daltijden. Op de kantoorverdiepingen is toegang tot alle liften voorzien. Tijdens de daluren kunnen alle liften stoppen op alle kantoorverdiepingen. De liftinstallatie dient te voldoen aan de eisen van "handboek toegankelijkheid", 3e druk.

De afwerking van de kozijnen en de cabine- en schachtdeuren zijn van geborsteld roestvrijstaal,
Het kooi-interieur als volgt af te werken:
- wanden uitvoeren met harde kunststof op een houten ondergrond
- plafond uitvoeren met aluminium panelen of full-reflex rooster metdaarboven TL-verlichting
- alle wanden te voorzien van leuningen.
- achterwand bekleden met blanke spiegel vanaf leuning tot plafond
- vloerafwerking identiek centrale hal, indien vloerbedekking dan gemakkelijkverwisselbaar aanbrengen
- spreek-luisterverbinding
- 1 lift per groep geschikt voor vervoer van scheidingswanden (2700 x1200 mm)

Het gebouw wordt voor het personenvervoer van de parkeerlagen naar de begane grond voorzien van drie elektrisch aangedreven personenliftinstallaties (Shuttle liften): twee naar bovengrondse parkeergarage en één naar de ondergrondse parkeergarage.

Voor het selecteren van de shuttle-liften worden de volgende streefwaarden gehanteerd:
- Personenbezetting: 1 persoon per parkeerplaats
- gelijktijdigheid tijdens de piek: 85%
- 12,5% aanbod in 5 minuten tijdens piekperiode in de ochtend
- Gemiddelde wachttijd: maximaal 35 seconden

e. Determination of review criteria for a conventional lift

Interesting values, anticipating on the eventual research and to get feeling how a lift cabin will move through a lift shaft of a building are the average number of passenger in a cabin (P), the expected number of stops (s) and the average highest floor (H) for a lift cabin.

e.1 Average number of passengers (P)

The number of passengers transported by a lift cabin almost never reaches the maximum car capacity (CC), even when queues exist. Passengers have personal space around them and they feel uncomfortable if people stand in their personal space and come too close. This personal space is different for individuals. Persons who know each other can stand closer to each other than strangers. Another point of interest is the circulation difficulties, passengers at the back of the car do want to get out at the first stop. So taken all these factors into account it is reasonable to consider and it is well accepted to calculate the average number of passengers in a lift capacity calculation as:

$$P = 0{,}8 * CC$$

A cabin will (almost) never be filled for 100%, in lift capacity calculations the maximum is set at 80%.

e.2 Expected number of stops (S)

The number of stops on a round trip time of a lift cabin is an important parameter for a capacity calculation of a lift system. Stops will consume time, not only the stops itself but also the deceleration, door opening time, loading time, door closing time and the deceleration took time. Time that is not used for a direct transportation, but just to wait. It is therefore good to get an insight in the number of stops and it is interesting to calculate the expected number of stops. This can be done by the method of Basset Jones, he published in 1923 the method to calculate the expected number of stops for a building with N floors above the main terminal. Assume that each floor is equally likely as a destination for passengers and all floors have an equal population. There are for example office buildings where this estimation is very well possible.

The probability that one passenger will leave the lift at any particular floor is 1/N. The probability that one passenger will not leave the lift at any particular floor is:

$$1 - \frac{1}{N} = \frac{N-1}{N}$$

Assume that all passengers act independent, the probability that no passengers from a lift with P passengers will leave the lift at any particular floor is:

$$\left(\frac{N-1}{N}\right) * \left(\frac{N-1}{N}\right) \ldots\ldots \left(\frac{N-1}{N}\right) = \left(\frac{N-1}{N}\right)^P$$

The probability that a stop will be made at any particular floor is:

$$1 - \left(\frac{N-1}{N}\right)^P$$

The expected number or average number of stops (S) for N floors is:

$$S = N\left(1 - \left(\frac{N-1}{N}\right)^P\right)$$

e.3 Average highest floor (H)

The parameter H is the average highest floor for the lift cabin. This is also a key aspect in calculating the round trip time and so the performance of a lift system. To calculate H (Basset Jones, 1923), the same assumptions are made compared to the calculation of the previous parameter S (each floor is equally likely as a destination for passengers and all floors have a equal population.)

The probability that one passenger will not leave the car at a given floor is:

$$1-\frac{1}{N}$$

The probability that none of the passengers will leave the car at a given floor is:

$$\left(1-\frac{1}{N}\right)^{P}$$

The probability of the car travelling no higher than the i th floor is equal to the probability that no one leaves the lift at the Nth, (N-1)th, (N-2)th, … and (i +1)th floor is:

$$\left(1-\frac{1}{N}\right)^{P}\left(1-\frac{1}{N-1}\right)^{P}\left(1-\frac{1}{N-2}\right)^{P}\left(1-\frac{1}{N-3}\right)^{P}\ldots\left(1-\frac{1}{i+1}\right)^{P}=\left(\frac{i}{N}\right)^{P}$$

So the {probability that i is the highest floor attained}={probability that a lift travels no higher than the ith floor} minus {probability that the lift travels no higher than the (i – 1)th floor} is:

$$\left(\frac{i}{N}\right)^{P}-\left(\frac{i-1}{N}\right)^{P}$$

The average (or mean) highest floor H is:

$$H=\sum_{i=1}^{N-1} i\left[\left(\frac{i}{N}\right)^{P}-\left(\frac{i-1}{N}\right)^{P}\right]$$

Expanding and simplifying:

$$H=N-\sum_{i=1}^{N-1}\left(\frac{i}{N}\right)^{P}$$

Table (app 1) gives an idea about the qualities of H and S by a changing car capacity and a changing building height (floors(N)).

table 29. Values of H (average highest floor) and S (Excepted number of stops) for a Car capacity (0,8 * CC). Each floor is equally likely as a destination for passengers and all floors have a equal population.

Car capacity	6 (4,8)		8 (6,4)		10 (8,0)		13 (10,4)		16 (12,8)		21 (16,8)		26 (20,8)		33 (26,4)	
Floors N	H	S	H	S	H	S	H	S	H	S	H	S	H	S	H	S
5	4,6	3,3	4,7	3,8	4,8	4,2	4,9	4,5	4,9	4,7	5,0	4,9	5,0	5,0	5,0	5,0
6	5,4	3,5	5,6	4,1	5,7	4,6	5,8	5,1	5,9	5,4	6,0	5,7	6,0	5,9	6,0	6,0
7	6,2	3,7	6,5	4,4	6,6	5,0	6,8	5,6	6,8	6,0	6,9	6,5	7,0	6,7	7,0	6,9
8	7,1	3,8	7,4	4,6	7,5	5,3	7,7	6,0	7,8	6,6	7,9	7,2	7,9	7,5	8,0	7,8
9	7,9	3,9	8,2	4,8	8,4	5,5	8,6	6,4	8,7	7,0	8,8	7,8	8,9	8,2	9,0	8,6
10	8,7	4,0	9,1	4,9	9,3	5,7	9,5	6,7	9,7	7,4	9,8	8,3	9,9	8,9	9,9	9,4
11	9,6	4,0	10,0	5,0	10,2	5,9	10,5	6,9	10,6	7,8	10,8	8,8	10,8	9,5	10,9	10,1
12	10,4	4,1	11,7	5,2	12,0	6,1	12,3	7,3	12,5	8,3	12,7	9,6	12,8	10,5	12,9	11,4
13	11,2	4,1	11,7	5,2	12,0	6,1	12,3	7,3	12,5	8,3	12,7	9,6	12,8	10,5	12,9	11,4
14	12,1	4,2	12,6	5,3	12,9	6,3	13,2	7,5	13,4	8,6	13,6	10,0	13,7	11,0	13,8	12,0
15	12,9	4,2	13,4	5,4	13,8	6,4	14,1	7,7	14,3	8,8	14,6	10,3	14,7	11,4	14,8	12,6
16	13,7	4,3	14,3	5,4	14,7	6,5	15,0	7,8	15,3	9,0	15,5	10,6	15,7	11,8	15,8	13,1
17	14,5	4,3	15,3	5,5	15,6	6,5	16,0	8,0	16,2	9,2	16,5	10,9	16,6	12,2	16,8	13,6
18	15,4	4,3	16,0	5,5	16,6	6,6	16,9	8,1	17,1	9,3	17,4	11,1	17,6	12,5	17,7	14,0
19	16,2	4,3	16,9	5,6	17,4	6,7	17,8	8,2	18,1	9,5	18,4	11,3	18,5	12,8	18,7	14,4
20	17,0	4,4	17,8	5,6	18,2	6,7	18,7	8,3	19,0	9,6	19,3	11,6	19,5	13,1	19,7	14,8
21	17,9	4,4	18,6	5,6	19,1	6,8	19,6	8,4	19,9	9,8	20,3	11,7	20,5	13,4	20,6	15,2
22	18,7	4,4	19,5	5,7	20,0	6,8	20,5	8,4	20,9	9,9	21,2	11,9	21,4	13,6	21,6	15,6
23	19,5	4,4	20,4	5,7	20,9	6,9	21,4	8,5	21,8	10,0	22,1	12,1	22,4	13,9	22,6	15,9
24	20,3	4,4	21,2	5,7	21,8	6,9	22,4	8,6	22,7	10,1	23,1	12,3	23,3	14,1	23,5	16,2

e.4 Traffic profile is not ideal (Number of stops and Average Highest floor).

The traffic demand in a building can change over the building, this depend on the purpose of the building. If there is a multipurpose building some floors can have more activities compared to others. If there is for example an office combined with a residential part, demands on floors can change significantly.

Unequal demand, Number of stops (S).

Consider a building with:

- N floors above the main terminal
- P the average number of passengers present in a lift as it leaves the main terminal
- U the total building population above the main terminal
- U_i the population of floor i.

U and U_i have been represented as the population: it could equally represent the demand per floor.

The approach will be similar with the approach of the equal demand, the probability that one passenger will leave the lift at any particular floor i is:

$$\frac{U_i}{U}$$

Assuming that the passengers are independent of each other, the probability that one passenger will not leave the lift at the first floor is:

$$1-\frac{U_1}{U}$$

The probability that none of the P passengers in the lift will leave the lift at the first floor is:

$$\left(1-\frac{U_1}{U}\right)^P$$

Thus the probability that no passengers will leave the lift for the first i floors is:

$$\left(1-\frac{U_1}{U}\right)^P+\left(1-\frac{U_2}{U}\right)^P+....+\left(1-\frac{U_i}{U}\right)^P$$

This is synonymous to the lift not stopping at the first i floors.
Then the probability that stops will be made at the first i floors is:

$$1-\left(1-\frac{U_1}{U}\right)^P+\left(1-\frac{U_2}{U}\right)^P+...+\left(1-\frac{U_i}{U}\right)^P$$
$$=1-\sum_{i=1}^{i}\left(1-\frac{U_i}{U}\right)^P$$

The expected number of stops (S) for N floors can be shown as (after some algebraic manipulation):

$$S=N\left(1-\frac{1}{N}\sum_{i=1}^{N}\left(1-\frac{U_i}{U}\right)^P\right)$$

Unequal demand, Average highest floor (H)
Consider a building with:

N floors above the main terminal
P the average number of passengers present in a lift as it leaves the main terminal
U the total building population above the main terminal
U_i the population of floor i.

U and U_i has been represented as the population: it could equally represent the demand per floor.

The approach will be similar with the approach of the equal demand, the probability that one passenger will leave the lift at any particular floor i is

$$\frac{U_i}{U}$$

Which becomes the probability of the lift travelling no higher than the ith floor obtained by extension and subsequent algebraic simplification:

$$\left(\sum_{i=1}^{i}\left(\frac{U_i}{U}\right)^P\right)$$

Using the same procedure as done by an equal demand and the determination of H:

$$H = \sum_{i=1}^{N} i\left(\left(\sum_{i=1}^{i}\frac{U_i}{U}\right)^{p} - \left(\sum_{i=1}^{i}\frac{U_{i-1}}{U}\right)^{p}\right)$$
$$= N - \sum_{i=1}^{N-1}\left(\sum_{i=1}^{i}\frac{U_i}{U}\right)^{p}$$

Example

Consider three buildings all with 10 floors above the main terminal with a different demand for each floor. The average highest floor (H) and the expected number of stops (S) will be calculated.

Building A

Floor	1	2	3	4	5	6	7	8	9	10
Population	60	60	60	60	60	60	60	60	60	60

The expected number of stops (S) for building A:

$$S = N\left(1-\left(\frac{N-1}{N}\right)^{p}\right)$$
$$= 10\left(1-\left(\frac{10-1}{10}\right)^{8}\right)$$
$$= 10\,(1-0,43) = 5,7$$

The average highest floor (H) for building A:

$$H = N - \sum_{i=1}^{N-1}\left(\frac{i}{N}\right)^{p}$$
$$= 10 - \left(\frac{1}{10}\right)^{8} + \left(\frac{2}{10}\right)^{8} + \left(\frac{3}{10}\right)^{8} + \left(\frac{4}{10}\right)^{8} + \left(\frac{5}{10}\right)^{8} + \left(\frac{6}{10}\right)^{8} + \left(\frac{7}{10}\right)^{8} + \left(\frac{8}{10}\right)^{8} + \left(\frac{9}{10}\right)^{8}$$
$$= 10 - (0,67731333) = 9,3$$

Building B

Floor	1	2	3	4	5	6	7	8	9	10
Population	5	10	25	25	50	50	100	100	100	100

The expected number of stops (S) for building B:

$$S = N - \sum_{i-1}^{N}\left(1-\frac{U_i}{U}\right)^{p}$$
$$= 10 - \left(\left(1-\frac{5}{565}\right)^{8} + \left(1-\frac{10}{565}\right)^{8} + 2\left(1-\frac{25}{565}\right)^{8} + 2\left(1-\frac{50}{565}\right)^{8} + 4\left(1-\frac{100}{565}\right)^{8}\right)$$
$$= 10 - \frac{1}{565^{8}}\left[560^{8} + 555^{8} + 2*540^{8} + 2*515^{8} + 4*454^{8}\right]$$
$$= 10 - 4,986 = 5,014$$

The average highest floor (H) for building B:

$$
\begin{aligned}
H &= N - \sum_{i=1}^{N-1} \left(\sum_{i=1}^{i} \frac{U_i}{U} \right)^P \\
&= 10 - \frac{1}{565^8} \left[5^8 + 15^8 + 40^8 + 65^8 + 115^8 + 165^8 + 265^8 + 365^8 + 465^8 \right] \\
&= 10 - 0,245 = 9,755
\end{aligned}
$$

Building C

Floor	1	2	3	4	5	6	7	8	9	10
Population	100	100	100	100	50	50	25	25	10	5

The expected number of stops (S) for building C:

$$
\begin{aligned}
S &= N - \sum_{i-1}^{N} \left(1 - \frac{U_i}{U} \right)^P \\
&= 10 - \left(4\left(1 - \frac{100}{565}\right)^8 + 2\left(1 - \frac{50}{565}\right)^8 + 2\left(1 - \frac{25}{565}\right)^8 + \left(1 - \frac{10}{565}\right)^8 + \left(1 - \frac{5}{565}\right)^8 \right) \\
&= 10 - \frac{1}{565^8} \left[4 * 454^8 + 2 * 515^8 + 2 * 540^8 + 555^8 + 560^8 \right] \\
&= 10 - 4,986 = 5,014
\end{aligned}
$$

The average highest floor (H) for building B

$$
\begin{aligned}
H &= N - \sum_{i=1}^{N-1} \left(\sum_{i=1}^{i} \frac{U_i}{U} \right)^P \\
&= 10 - \frac{1}{565^8} \left[100^8 + 200^8 + 300^8 + 400^8 + 450^8 + 500^8 + 525^8 + 550^8 + 560^8 \right] \\
&= 10 - 2,99 = 7,01
\end{aligned}
$$

f. General explanation of flowchart

General explanation of flowchart
A flowchart is a schematic representation of an algorithm or a process and is used in this master project to describe the processes and algorithms. The items within a flowchart represent a particular function. There are Input/Output, Data, Process and Decision boxes with distinctive shapes, the arrows describe the direction of the flow of the algorithm/process, see **Error! Reference source not found.**. The interpretation of the flowchart has to start from the top of the figure.

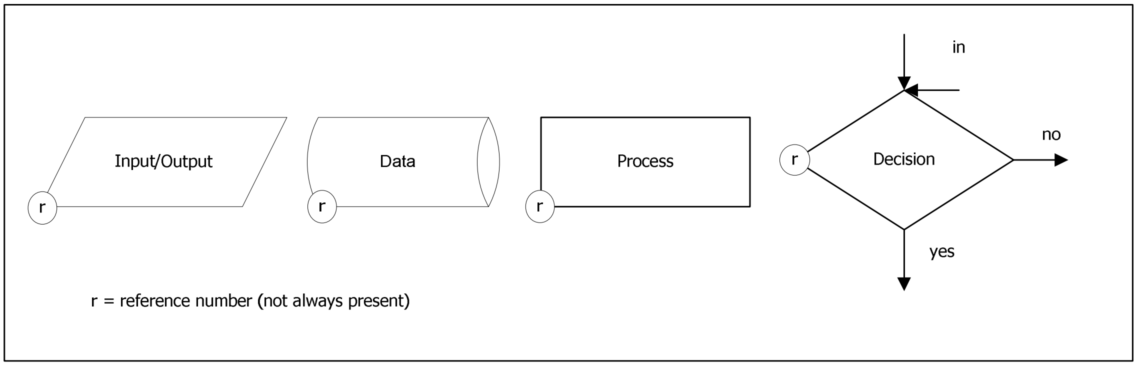

Figure 76. Explanation of symbols in flowchart

g. Simulations conventional lift

The simulations of the conventional lift can be found on:
http://looptransportprinciple.googlepages.com

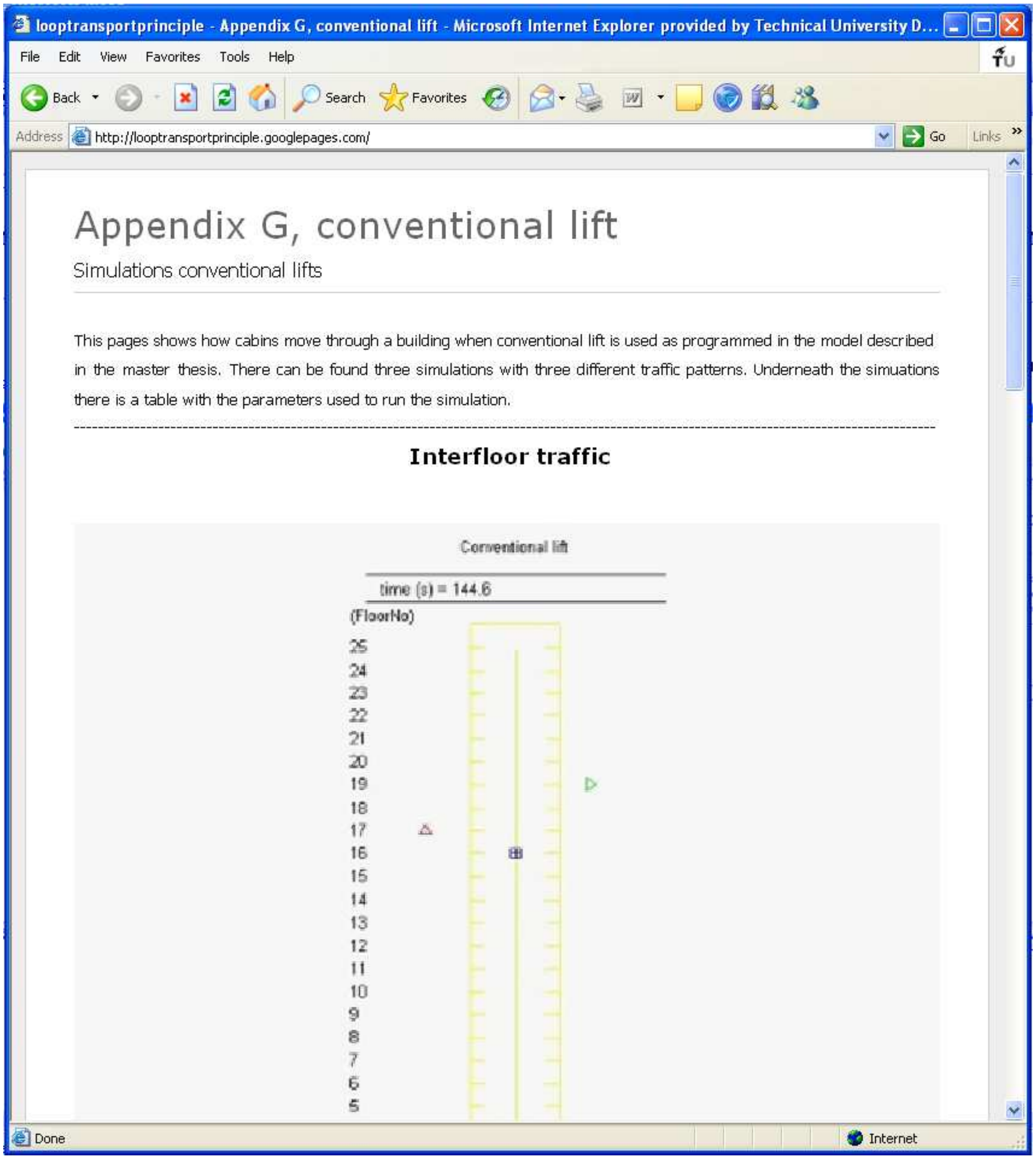

figure 77. Screenshot conventional lift @ http://looptransportprinciple.googlepages.com

h. Simulations loop transport principle

The simulations of the loop transport principle can be found on:
http://looptransportprinciple.googlepages.com

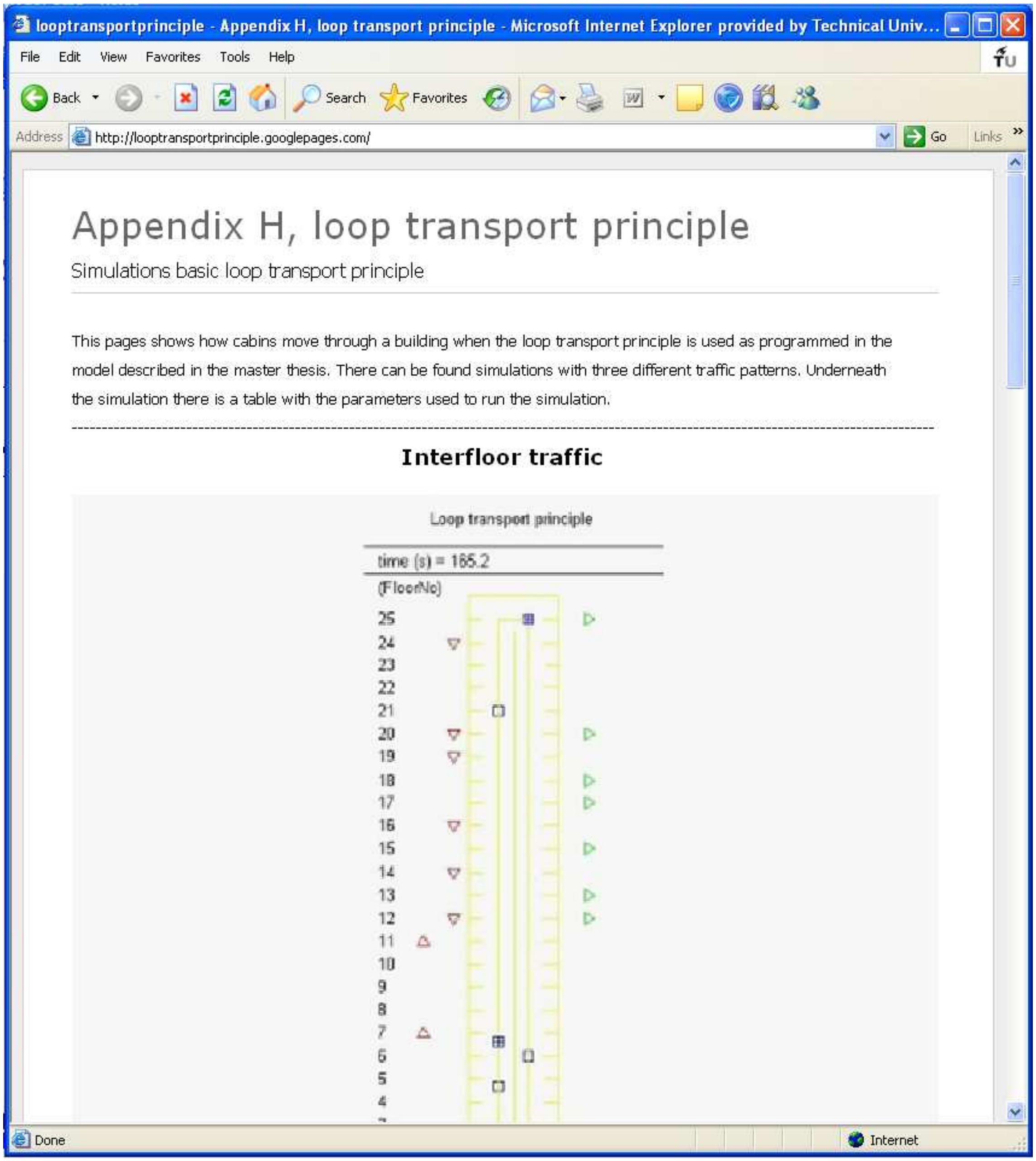

figure 78. Screenshot: http://looptransportprinciple.googlepages.com

i. Overview features Elevate®

Below the features of the lift simulation program Elevate are given. The text underneath quoted the first part of the chapter introduction of the manual Elevate "Getting started with Elevate".

An overview
Elevate is software used by designers worldwide to select the number, size and speed of elevators for all types of buildings both new or old. Elevate can also be used to demonstrate that modernizing an existing elevator installation can improve service for passengers.

Elevate's main features.
Analysis of elevator performance in
Offices
Hotels
Hospitals
Shopping centres
Residential buildings
Car parks
Mixed use buildings
Airports
Public buildings
Sports and leisure complexes schools
Colleges

This is achieved by techniques ranging from up peak round trip time calculations through to full dynamic simulation.

Dynamic simulation incorporating a graphical display of elevators responding to passenger calls. For your clients, this provides a convincing visual demonstration of your proposals.

An easy to use Windows interface. Enter basic information for a quick analysis or comprehensive data for a detailed model.

Kinematics calculations are applied to generate accurate elevator speed profiles.

Fully comprehensive help system and online user support.

A facility to demonstrate your own dispatcher control system using Elevate Developer Interface.

This facility is useful to test and develop dispatcher algorithms. A more comprehensive list of features of the features included in Elevate are shown overleaf.

Warning! Elevate is an extremely powerful traffic analysis tool. However, it will not make the user an elevator traffic analysis expert. For details of training courses and recommended books, please select Elevate on the web from the Help menu, while connected to the internet.

j. Results parameter study

Results parameter study conventional lift:

table 30. Conventional lift, waiting time(s) values linked to figure 40

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	15,55	16,12	16,15	15,46
6	18,51	17,37	18,75	17,82
7	23,79	21,87	20,76	21,71
8	26,23	23,88	23,07	23,60
9	40,94	27,95	26,68	26,95
10	58,86	46,13	32,13	32,85
11	84,26	58,49	42,18	38,99
12	103,85	71,75	49,78	42,37
13	127,45	97,37	78,03	59,27
14	157,70	108,50	92,35	74,03
15	182,24	142,28	112,32	94,24
16	212,88	169,53	131,69	111,67
17	239,14	190,18	157,68	128,94
18	266,40	210,81	184,89	147,97
19	308,43	242,20	202,30	174,66
20	332,63	266,60	229,45	196,61
21	371,21	306,18	253,15	222,51
22	401,85	341,63	283,20	241,73
23	441,07	366,15	298,86	264,55
24	471,67	392,99	337,13	293,14
25	509,04	423,90	367,32	316,48
26	556,58	461,84	391,70	345,50
27	591,00	492,30	420,54	374,73
28	620,88	520,57	454,71	389,60
29	668,15	551,99	479,71	432,18
30	706,62	591,91	518,61	454,95

table 31. Conventional lift, travel time (s) values linked to figure 41

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	19,95	20,23	20,73	20,76
6	22,95	23,39	23,16	23,31
7	27,44	27,23	26,42	28,13
8	28,53	31,73	32,44	30,55
9	33,15	33,89	35,65	35,25
10	34,13	38,44	40,89	39,66
11	36,32	40,53	44,18	44,96
12	36,62	41,89	45,14	48,29
13	37,63	42,52	47,58	50,53
14	38,90	43,57	49,59	53,32
15	40,93	45,33	50,80	54,79
16	40,03	46,79	52,07	56,03
17	40,91	47,38	53,25	59,09
18	41,32	48,83	54,83	59,00
19	42,92	49,21	55,81	61,54
20	42,46	50,13	58,06	62,84
21	44,23	52,59	57,54	64,62
22	44,34	52,58	59,07	64,19
23	45,32	52,35	60,52	65,34
24	45,77	53,72	61,40	66,70
25	45,26	54,46	61,26	68,32
26	46,88	55,32	62,37	69,34
27	47,36	55,88	62,51	71,38
28	47,35	56,05	64,66	70,23
29	47,69	56,47	64,77	72,79
30	48,59	57,32	64,95	73,19

table 32. Conventional lift, journey time (s) values linked to figure 42.

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	35,51	36,35	36,88	36,22
6	41,46	40,75	41,91	41,13
7	51,24	49,10	47,18	49,84
8	54,76	55,60	55,50	54,15
9	74,09	61,84	62,33	62,20
10	92,99	84,57	73,01	72,51
11	120,57	99,02	86,36	83,96
12	140,47	113,64	94,92	90,66
13	165,08	139,90	125,61	109,80
14	196,60	152,08	141,93	127,35
15	223,17	187,60	163,12	149,03
16	252,91	216,32	183,75	167,70
17	280,06	237,56	210,93	188,02
18	307,72	259,64	239,71	206,98
19	351,35	291,41	258,11	236,20
20	375,09	316,73	287,51	259,44
21	415,44	358,76	310,69	287,13
22	446,19	394,21	342,28	305,92
23	486,39	418,49	359,38	329,88
24	517,44	446,71	398,52	359,84
25	554,30	478,36	428,58	384,79
26	603,46	517,15	454,07	414,84
27	638,36	548,17	483,05	446,12
28	668,24	576,62	519,37	459,83
29	715,84	608,45	544,49	504,96
30	755,22	649,23	583,56	528,14

Results parameter study loop transport principle lift:

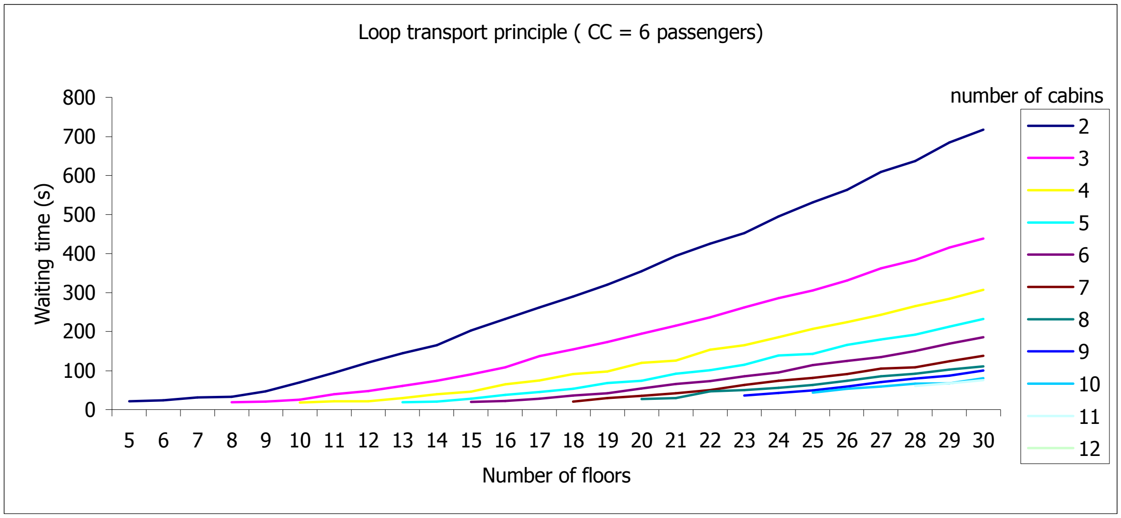

figure 79. Loop transport principle, average waiting time with a cabin capacity (cc) of 6 passengers for a different number of cabins

table 33. Loop transport principle, values average waiting time (s) with a cabin capacity (cc) of 6 passengers

	Number of cabins										
	2	3	4	5	6	7	8	9	10	11	12
Number of floors											
5	21,47										
6	23,62										
7	30,71										
8	33,17	18,46									
9	47,17	20,71									
10	69,41	25,64	17,71								
11	94,31	39,11	21,57								
12	120,34	47,97	21,57								
13	144,34	60,87	29,26	18,80							
14	165,59	74,15	39,65	20,87							
15	203,14	90,41	45,59	27,74	19,64						
16	232,80	108,03	64,74	37,85	22,09						
17	261,98	136,74	74,65	44,57	27,97						
18	289,25	154,48	91,20	53,42	36,14	20,92					
19	319,81	173,18	97,43	68,20	41,70	29,61					
20	354,67	194,60	120,07	74,44	53,85	35,85	26,83				
21	393,88	214,70	126,14	91,95	65,79	41,34	29,02				
22	425,32	236,04	153,29	100,95	73,62	49,93	46,87				
23	452,53	261,86	165,64	114,77	85,92	63,64	50,03	36,48			
24	494,95	286,06	185,60	139,36	94,76	74,42	55,32	42,59			
25	531,66	305,21	207,24	142,85	113,92	80,87	63,28	49,34	43,36		
26	562,64	330,24	224,00	166,39	125,24	90,96	74,19	58,76	53,46		
27	609,02	362,34	243,21	179,59	134,60	105,39	85,38	70,41	59,31		
28	636,83	383,19	265,06	192,07	150,04	108,45	91,85	79,80	66,44	61,02	
29	683,90	415,71	284,55	212,59	169,04	123,79	102,52	87,50	66,94	67,38	
30	717,46	438,45	307,40	232,67	185,01	138,16	111,52	100,38	80,55	75,33	65,75

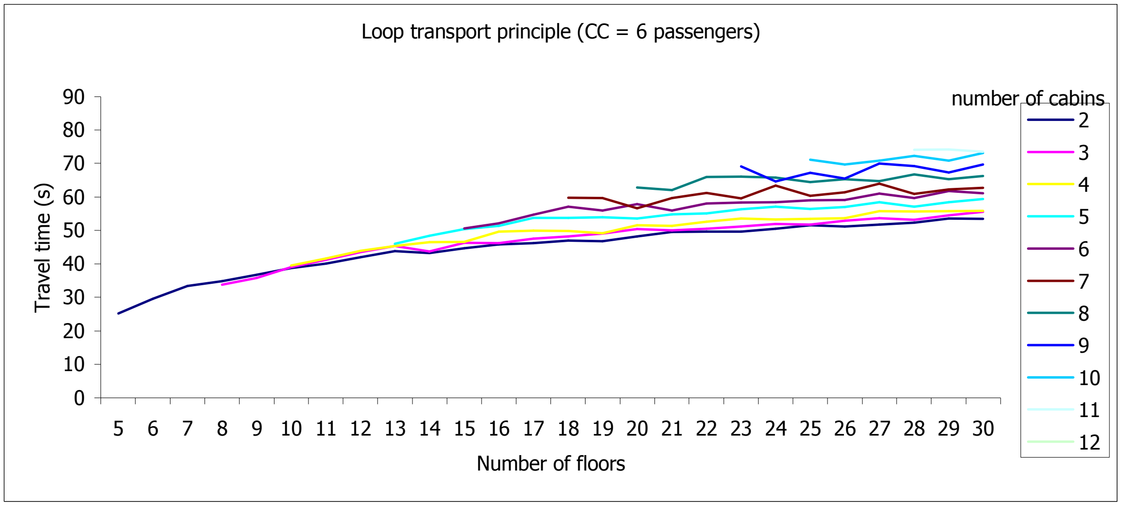

figure 80. Loop transport principle, average travel time with a cabin capacity (cc) of 6 passengers for a different number of cabins

table 34. Loop transport principle, values average travel time (s) with a cabin capacity (cc) of 6 passengers

	Number of cabins										
	2	3	4	5	6	7	8	9	10	11	12
Number of floors											
5	25,15										
6	29,62										
7	33,46										
8	34,78	33,83									
9	36,82	35,79									
10	38,76	38,99	39,51								
11	40,11	41,24	41,59								
12	42,01	43,51	43,85								
13	43,83	45,35	45,33	46,04							
14	43,23	43,69	46,47	48,34							
15	44,68	46,34	46,55	50,48	50,65						
16	45,85	46,24	49,59	51,31	52,14						
17	46,21	47,53	49,89	53,76	54,69						
18	46,92	48,23	49,80	53,78	57,10	59,81					
19	46,74	49,09	49,15	53,98	55,90	59,66					
20	48,18	50,46	51,52	53,61	57,84	56,67	62,87				
21	49,56	49,99	51,32	54,79	55,95	59,67	62,03				
22	49,64	50,56	52,61	55,13	58,07	61,20	66,01				
23	49,66	51,19	53,56	56,28	58,36	59,64	66,06	69,14			
24	50,51	51,94	53,25	57,10	58,46	63,42	65,77	64,63			
25	51,51	51,77	53,48	56,49	58,99	60,34	64,50	67,22	71,16		
26	51,16	52,91	53,67	56,97	59,05	61,45	65,23	65,44	69,66		
27	51,82	53,64	55,77	58,44	61,03	63,98	64,74	69,93	70,87		
28	52,33	53,15	55,64	57,10	59,72	60,98	66,73	69,19	72,27	74,12	
29	53,55	54,47	55,73	58,46	61,75	62,25	65,28	67,35	70,85	74,22	
30	53,54	55,59	55,79	59,38	61,12	62,74	66,29	69,69	73,14	73,56	76,44

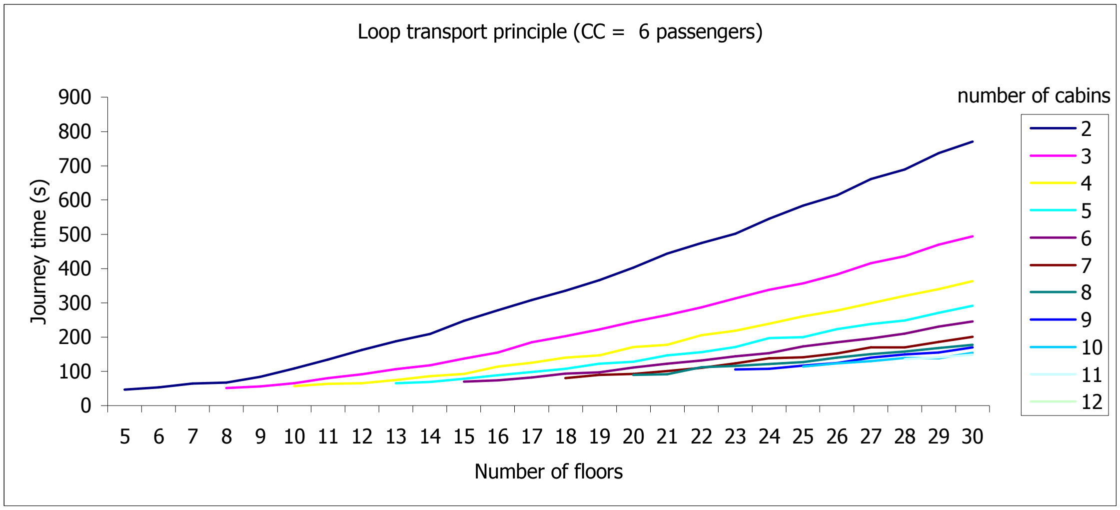

figure 81. Loop transport principle, average journey time with a cabin capacity (cc) of 6 passengers for a different number of cabins

table 35. Loop transport principle, values average journey time (s) with a cabin capacity (cc) of 6 passengers

	Number of cabins										
	2	3	4	5	6	7	8	9	10	11	12
Number of floors											
5	46,62										
6	53,24										
7	64,17										
8	67,95	52,29									
9	83,99	56,51									
10	108,17	64,63	57,21								
11	134,43	80,35	63,16								
12	162,35	91,48	65,42								
13	188,17	106,22	74,59	64,84							
14	208,82	117,84	86,12	69,21							
15	247,82	136,75	92,14	78,22	70,29						
16	278,64	154,27	114,33	89,15	74,22						
17	308,19	184,27	124,54	98,33	82,66						
18	336,17	202,71	141,00	107,20	93,24	80,73					
19	366,56	222,27	146,58	122,18	97,60	89,27					
20	402,85	245,06	171,60	128,04	111,69	92,52	89,71				
21	443,44	264,69	177,46	146,74	121,74	101,02	91,05				
22	474,96	286,61	205,90	156,07	131,69	111,14	112,88				
23	502,19	313,05	219,19	171,05	144,27	123,27	116,09	105,62			
24	545,45	338,00	238,85	196,46	153,22	137,84	121,09	107,22			
25	583,17	356,98	260,72	199,34	172,91	141,21	127,79	116,55	114,52		
26	613,80	383,15	277,66	223,36	184,29	152,42	139,43	124,20	123,12		
27	660,84	415,98	298,99	238,03	195,63	169,37	150,12	140,34	130,17		
28	689,16	436,34	320,70	249,16	209,75	169,43	158,58	148,99	138,71	135,15	
29	737,46	470,18	340,27	271,05	230,79	186,04	167,80	154,85	137,79	141,60	
30	771,00	494,04	363,19	292,04	246,13	200,90	177,81	170,07	153,69	148,89	142,18

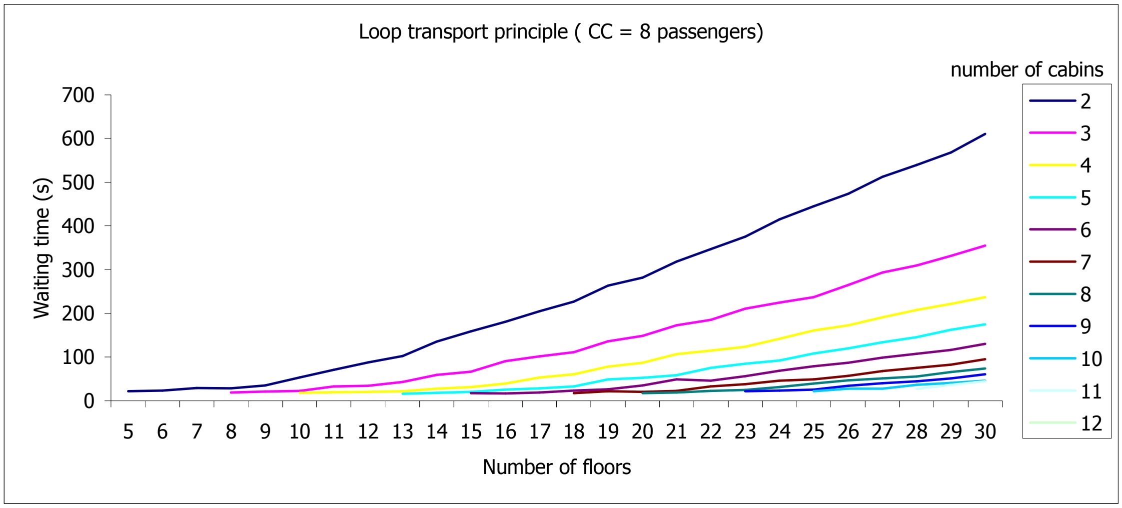

figure 82. Loop transport principle, average waiting time with a cabin capacity (cc) of 8 passengers for a different number of cabins

table 36. Loop transport principle, values average waiting time (s) with a cabin capacity (cc) of 8 passengers

	Number of cabins										
	2	3	4	5	6	7	8	9	10	11	12
Number of floors											
5	21,91										
6	23,64										
7	28,85										
8	28,15	18,49									
9	35,05	20,38									
10	52,85	22,53	18,18								
11	70,67	32,60	19,56								
12	87,40	34,24	20,20								
13	101,67	42,88	21,92	15,99							
14	135,23	59,26	27,30	17,92							
15	158,73	65,97	30,89	20,02	17,08						
16	180,63	90,37	39,13	25,60	16,70						
17	204,66	101,53	52,83	28,45	18,59						
18	226,55	110,68	60,80	32,12	23,55	17,52					
19	263,37	135,52	77,70	48,97	25,99	21,71					
20	281,91	148,10	86,79	52,08	35,42	20,15	17,22				
21	318,23	173,25	106,99	58,33	48,98	22,42	18,83				
22	346,72	185,38	115,20	75,01	46,43	32,29	22,78				
23	375,43	211,03	122,99	84,89	56,40	38,08	24,71	21,97			
24	414,79	224,89	141,74	92,14	68,66	46,47	31,22	23,39			
25	445,13	236,93	160,29	108,30	78,61	49,12	38,98	25,66	22,25		
26	473,09	264,43	172,07	119,69	86,48	57,18	46,82	34,29	27,28		
27	512,32	293,78	191,19	133,89	98,79	68,53	51,22	39,76	27,82		
28	539,33	309,26	207,76	145,10	107,58	75,41	54,87	44,24	36,25	26,83	
29	567,50	331,11	221,81	162,71	116,41	82,83	65,78	51,16	40,90	36,73	
30	610,09	354,54	236,89	175,19	130,05	94,79	73,82	60,38	45,86	44,95	34,24

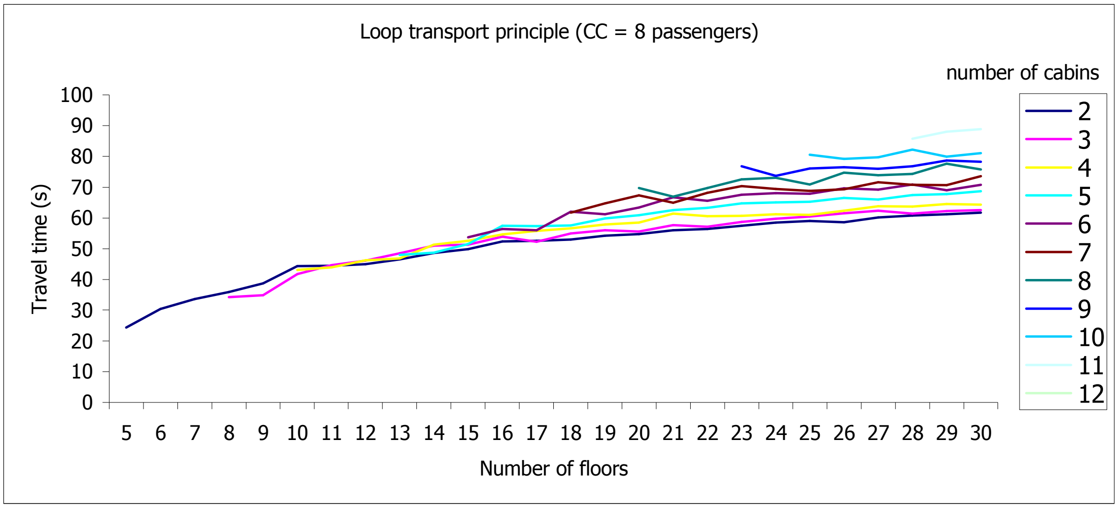

figure 83. Loop transport principle, average travel time with a cabin capacity (cc) of 8 passengers for a different number of cabins

table 37. Loop transport principle, values average travel time (s) with a cabin capacity (cc) of 8 passengers

	Number of cabins										
	2	3	4	5	6	7	8	9	10	11	12
Number of floors											
5	24,32										
6	30,40										
7	33,62										
8	35,86	34,28									
9	38,79	34,79									
10	44,34	41,82	43,07								
11	44,46	44,59	43,92								
12	45,00	46,12	46,14								
13	46,46	48,49	46,90	47,94							
14	48,65	50,94	51,24	48,70							
15	49,90	51,25	52,55	51,58	53,71						
16	52,37	53,95	54,64	57,44	56,39						
17	52,50	52,26	55,75	57,36	55,96						
18	52,97	55,00	56,62	57,51	62,02	61,72					
19	54,20	55,96	57,84	59,88	61,14	64,72					
20	54,69	55,53	58,48	60,90	63,42	67,33	69,75				
21	55,93	57,63	61,37	62,52	66,77	65,01	66,97				
22	56,40	57,13	60,57	63,34	65,59	68,16	69,73				
23	57,39	58,68	60,62	64,72	67,47	70,35	72,49	76,77			
24	58,56	59,72	61,17	65,11	68,13	69,36	73,07	73,70			
25	59,05	60,49	60,91	65,31	67,86	68,76	70,86	76,05	80,50		
26	58,60	61,58	62,35	66,52	69,59	69,29	74,72	76,53	79,13		
27	60,18	62,28	63,80	65,91	69,20	71,64	73,85	75,90	79,69		
28	60,81	61,36	63,72	67,42	70,84	70,73	74,24	76,79	82,15	85,72	
29	61,14	62,24	64,46	67,74	69,01	70,63	77,64	78,66	79,94	88,04	
30	61,73	62,48	64,26	68,73	70,72	73,54	75,74	78,30	80,99	88,84	87,38

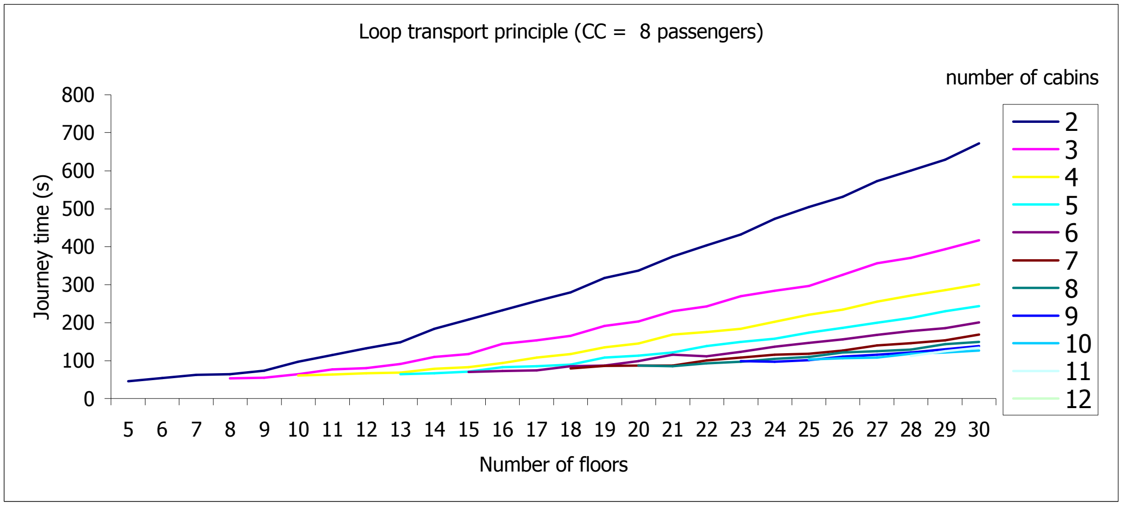

figure 84. Loop transport principle, average journey time with a cabin capacity (cc) of 8 passengers for a different number of cabins

table 38. Loop transport principle, values average journey time (s) with a cabin capacity (cc) of 8 passengers

	Number of cabins										
	2	3	4	5	6	7	8	9	10	11	12
Number of floors											
5	46,23										
6	54,04										
7	62,47										
8	64,02	52,77									
9	73,83	55,17									
10	97,19	64,36	61,25								
11	115,13	77,19	63,48								
12	132,40	80,36	66,34								
13	148,13	91,37	68,83	63,93							
14	183,87	110,20	78,54	66,62							
15	208,63	117,22	83,44	71,61	70,79						
16	233,00	144,32	93,77	83,04	73,09						
17	257,16	153,79	108,58	85,81	74,55						
18	279,52	165,68	117,42	89,63	85,57	79,23					
19	317,57	191,49	135,53	108,85	87,13	86,43					
20	336,60	203,63	145,28	112,98	98,84	87,48	86,97				
21	374,17	230,88	168,36	120,85	115,75	87,43	85,80				
22	403,12	242,52	175,76	138,36	112,02	100,45	92,51				
23	432,82	269,71	183,61	149,61	123,87	108,43	97,20	98,74			
24	473,34	284,60	202,91	157,25	136,79	115,83	104,28	97,09			
25	504,18	297,42	221,20	173,61	146,47	117,89	109,85	101,71	102,75		
26	531,70	326,01	234,41	186,21	156,06	126,47	121,54	110,82	106,41		
27	572,51	356,07	254,99	199,80	168,00	140,18	125,07	115,66	107,50		
28	600,14	370,62	271,48	212,52	178,42	146,14	129,11	121,04	118,40	112,55	
29	628,63	393,35	286,27	230,45	185,42	153,47	143,42	129,81	120,84	124,77	
30	671,83	417,02	301,15	243,93	200,77	168,32	149,56	138,68	126,85	133,79	121,62

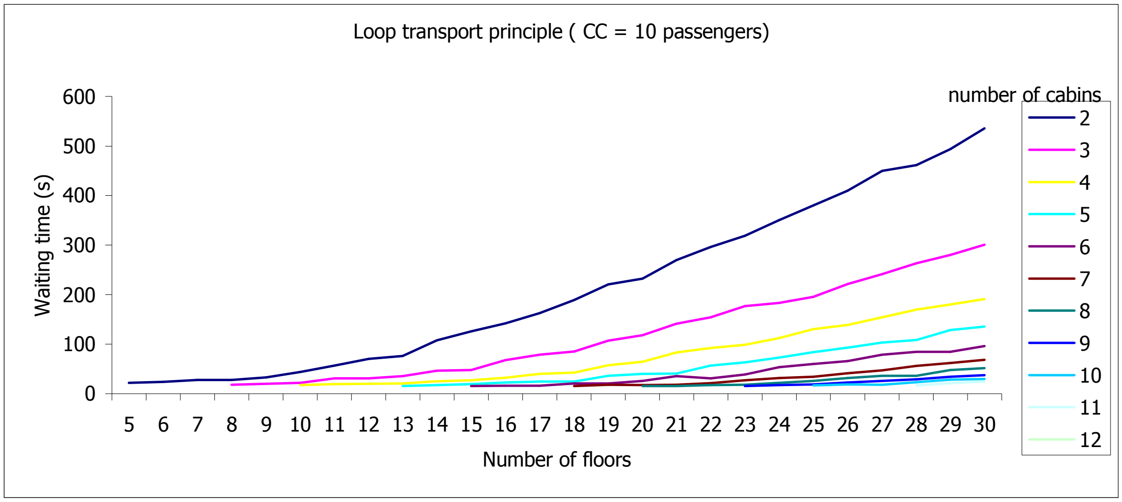

figure 85. Loop transport principle, average waiting time with cabin capacity (cc) of 10 passengers for a different number of cabins

table 39. Loop transport principle, values average waiting time (s) with cabin capacity (cc) of10 passengers

	Number of cabins										
	2	3	4	5	6	7	8	9	10	11	12
Number of floors											
5	21,91										
6	23,52										
7	28,16										
8	28,13	18,33									
9	33,04	20,16									
10	44,02	22,07	17,77								
11	56,47	31,09	19,65								
12	70,20	31,26	19,80								
13	75,81	35,51	20,55	15,98							
14	107,58	46,37	24,77	17,40							
15	125,93	47,80	27,19	19,56	16,00						
16	142,07	68,24	31,91	22,24	16,59						
17	162,60	79,01	39,91	24,41	16,47						
18	189,16	85,20	42,48	24,24	20,53	15,86					
19	220,78	107,13	57,95	36,30	20,35	18,31					
20	232,44	117,90	64,55	40,22	25,43	17,32	15,21				
21	269,34	141,47	83,34	40,91	34,99	18,42	15,43				
22	296,45	154,23	92,03	56,38	30,95	21,42	17,75				
23	318,67	176,59	98,79	62,94	38,63	27,04	18,07	15,53			
24	350,53	183,46	112,33	72,97	53,27	31,28	21,81	17,75			
25	380,28	195,31	130,27	83,77	60,08	34,10	25,54	18,81	17,29		
26	409,94	221,45	138,82	92,62	65,42	41,10	31,61	22,39	18,79		
27	449,77	241,40	154,03	103,39	78,94	47,24	35,61	25,33	18,25		
28	461,65	263,39	170,22	108,67	84,19	56,10	36,48	29,44	23,36	17,17	
29	493,79	279,73	180,27	128,56	84,68	61,67	47,76	33,89	28,77	21,29	
30	535,42	300,70	191,06	135,44	96,00	68,67	51,49	37,69	30,05	24,36	18,18

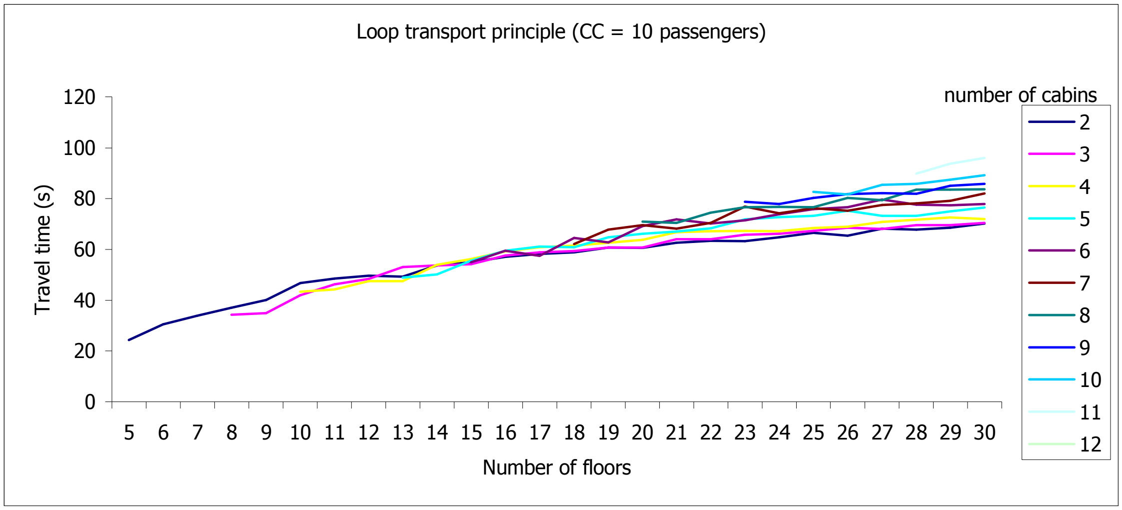

figure 86. Loop transport principle, average travel time with a cabin capacity (cc) of 10 passengers for a different number of cabins

table 40. Loop transport principle, values average travel time (s) with a cabin capacity (cc) of 10 passengers

	Number of cabins										
	2	3	4	5	6	7	8	9	10	11	12
Number of floors											
5	24,32										
6	30,43										
7	33,97										
8	37,00	34,25									
9	40,11	34,81									
10	46,70	41,96	43,24								
11	48,50	46,28	44,26								
12	49,57	48,38	47,47								
13	49,16	53,03	47,40	48,80							
14	53,73	53,70	53,96	50,14							
15	54,87	54,19	56,19	55,48	54,95						
16	57,03	57,54	59,16	59,39	59,45						
17	58,18	58,79	60,83	61,05	57,45						
18	58,81	59,29	61,46	60,77	64,56	62,08					
19	60,73	60,72	62,66	64,78	62,77	67,88					
20	60,63	60,76	63,81	66,22	69,11	69,51	70,92				
21	62,56	64,05	66,79	66,95	71,71	68,13	70,41				
22	63,33	64,09	67,08	68,33	70,23	70,44	74,47				
23	63,16	65,75	67,19	71,81	71,39	76,88	76,64	78,76			
24	64,80	66,14	67,07	72,66	73,76	74,25	76,77	77,90			
25	66,49	67,18	68,41	73,12	75,86	76,25	76,60	80,32	82,60		
26	65,31	68,49	68,89	75,12	76,58	75,24	80,22	81,68	81,53		
27	68,23	68,08	70,76	73,21	79,59	77,49	79,35	82,17	85,39		
28	67,87	69,53	71,63	73,18	77,50	78,12	83,53	81,82	85,77	89,72	
29	68,51	69,45	72,61	74,94	77,30	79,04	83,44	85,05	87,39	93,69	
30	70,19	70,46	71,95	76,43	77,85	82,06	83,62	85,79	89,21	96,11	96,03

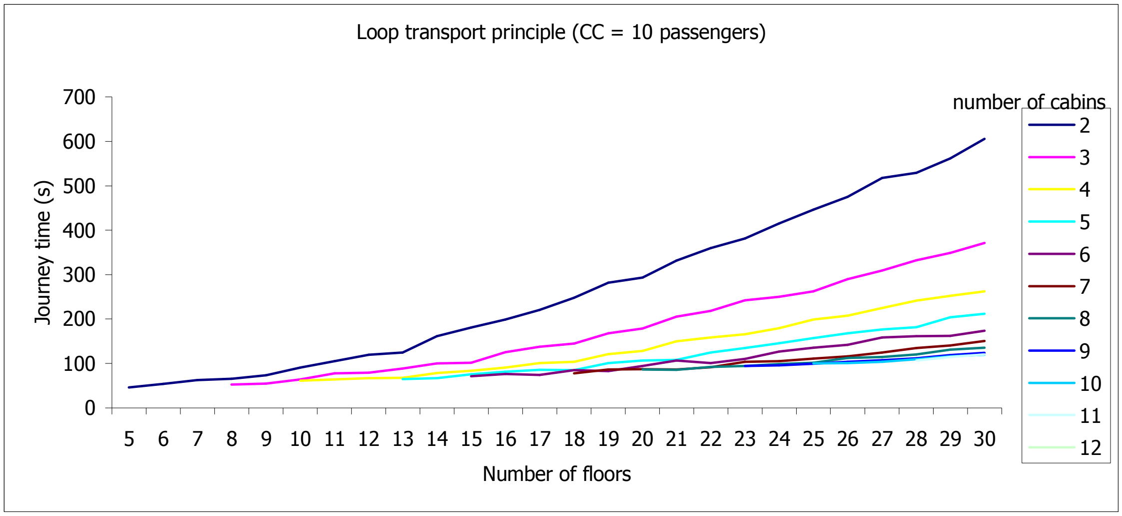

figure 87. Loop transport principle, average journey time with a cabin capacity (cc) of 10 passengers for a different number of cabins

table 41. Loop transport principle, values average journey time (s) with a cabin capacity (cc) of 10 passengers

	Number of cabins										
	2	3	4	5	6	7	8	9	10	11	12
Number of floors											
5	46,23										
6	53,94										
7	62,13										
8	65,13	52,58									
9	73,15	54,97									
10	90,72	64,03	61,02								
11	104,97	77,37	63,91								
12	119,77	79,64	67,27								
13	124,97	88,53	67,94	64,78							
14	161,31	100,06	78,73	67,54							
15	180,80	101,98	83,38	75,04	70,95						
16	199,11	125,77	91,07	81,62	76,04						
17	220,78	137,80	100,74	85,46	73,92						
18	247,97	144,49	103,94	85,01	85,10	77,94					
19	281,50	167,85	120,61	101,08	83,12	86,19					
20	293,07	178,66	128,37	106,44	94,55	86,83	86,12				
21	331,90	205,52	150,13	107,86	106,70	86,55	85,84				
22	359,78	218,32	159,10	124,71	101,18	91,86	92,22				
23	381,83	242,34	165,98	134,75	110,03	103,91	94,71	94,29			
24	415,33	249,60	179,39	145,62	127,03	105,53	98,59	95,66			
25	446,77	262,49	198,69	156,89	135,94	110,35	102,14	99,13	99,89		
26	475,25	289,94	207,72	167,74	142,00	116,34	111,83	104,07	100,32		
27	518,00	309,48	224,79	176,60	158,53	124,72	114,96	107,49	103,64		
28	529,52	332,93	241,85	181,86	161,69	134,22	120,01	111,25	109,12	106,88	
29	562,31	349,19	252,88	203,49	161,98	140,70	131,20	118,94	116,16	114,97	
30	605,61	371,17	263,01	211,86	173,86	150,74	135,11	123,48	119,26	120,46	114,21

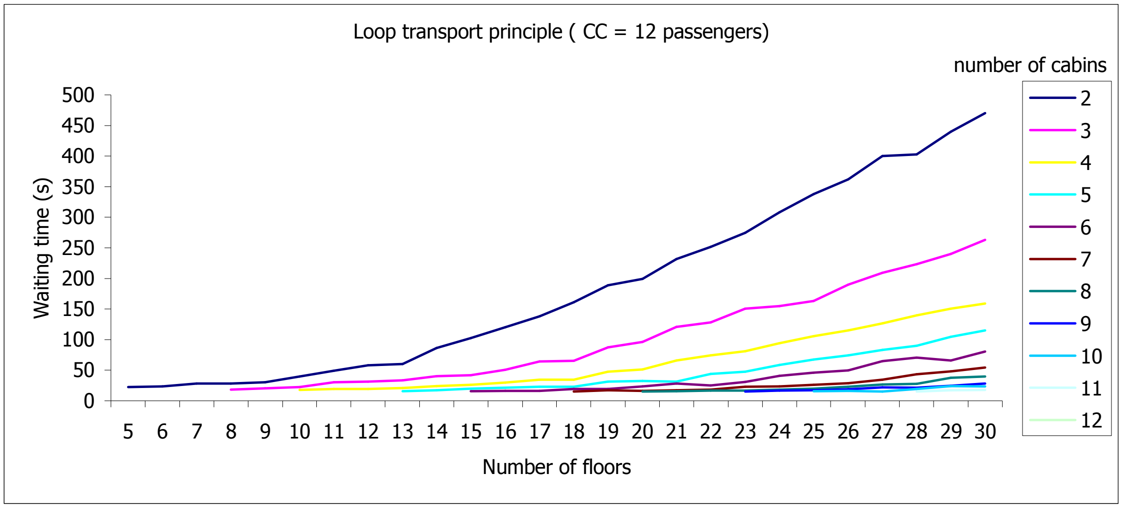

figure 88. Loop transport principle, average waiting time with a cabin capacity (cc) of 12 passengers for a different number of cabins

table 42. Loop transport principle, values average waiting time (s) with a cabin capacity (cc) of 12 passengers

	Number of cabins										
	2	3	4	5	6	7	8	9	10	11	12
Number of floors											
5	21,91										
6	23,52										
7	27,97										
8	27,96	18,39									
9	29,96	20,11									
10	39,18	22,02	17,63								
11	49,09	29,81	19,44								
12	58,25	31,05	19,33								
13	60,16	33,52	20,50	15,62							
14	85,94	39,82	24,16	17,39							
15	102,31	41,76	26,22	19,55	15,56						
16	119,85	50,66	29,29	21,28	16,18						
17	137,90	63,78	34,49	22,82	16,32						
18	160,72	65,69	34,31	22,82	18,95	15,20					
19	188,51	87,11	47,08	30,93	19,22	17,40					
20	199,41	95,92	51,07	32,37	22,91	16,43	14,87				
21	231,65	120,39	65,78	30,86	28,20	17,09	15,52				
22	251,38	127,75	74,55	43,82	25,21	18,08	16,70				
23	274,72	150,66	80,53	47,12	30,35	22,73	16,77	14,59			
24	308,03	154,75	93,84	58,74	40,78	23,57	18,27	16,50			
25	337,72	163,07	105,41	67,25	45,95	26,24	19,79	17,44	15,72		
26	361,52	189,24	114,47	74,17	49,64	28,52	22,83	18,49	16,28		
27	400,06	209,15	126,42	83,40	64,59	34,39	26,65	21,45	15,47		
28	402,45	222,75	139,29	89,89	70,55	43,24	27,70	21,01	19,00	14,95	
29	439,93	240,37	150,53	104,50	65,78	47,65	37,60	24,52	24,20	17,17	
30	470,01	262,61	158,83	115,15	80,01	54,30	39,29	28,13	23,27	17,56	15,19

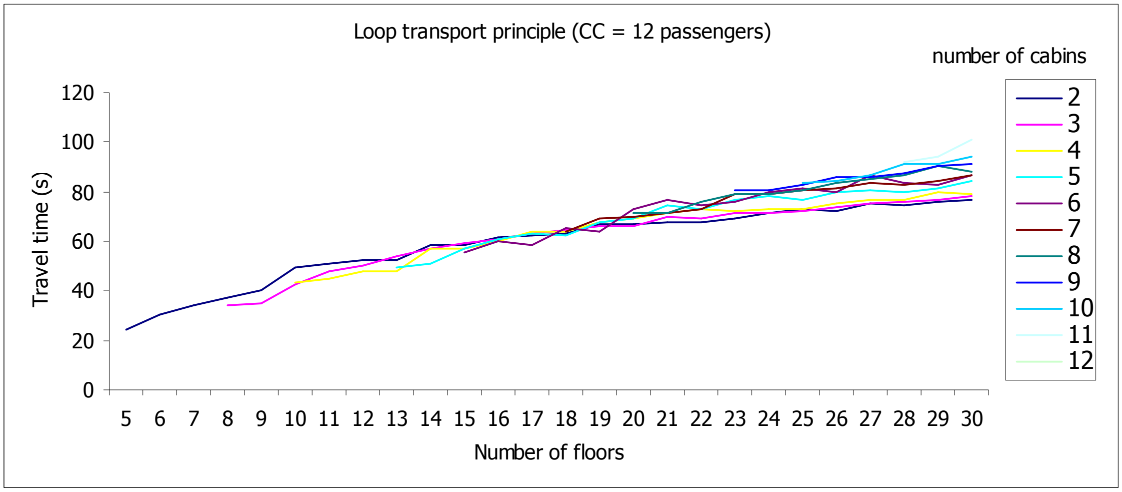

figure 89. Loop transport principle, average travel time with a cabin capacity (cc) of 12 passengers for a different number of cabins

table 43. Loop transport principle, values average travel time (s) with a cabin capacity (cc) of 12 passengers

	Number of cabins										
	2	3	4	5	6	7	8	9	10	11	12
Number of floors											
5	24,32										
6	30,43										
7	33,87										
8	37,42	34,41									
9	39,93	34,78									
10	49,11	42,52	43,22								
11	51,17	47,49	44,66								
12	52,62	49,96	47,55								
13	52,55	54,25	48,10	49,02							
14	58,38	57,02	56,84	50,59							
15	58,34	58,93	57,27	56,87	55,75						
16	61,61	60,90	60,21	61,09	60,15						
17	62,19	62,93	63,92	62,96	58,79						
18	63,39	64,20	64,04	62,21	65,34	63,79					
19	67,06	65,96	67,35	67,60	64,04	68,94					
20	66,67	66,17	69,07	69,39	72,89	70,00	71,18				
21	67,93	70,21	71,72	74,39	76,34	71,03	71,55				
22	67,54	68,98	72,87	72,84	74,65	73,25	75,71				
23	68,96	71,18	72,33	76,82	75,57	78,82	78,96	80,60			
24	71,16	71,54	72,90	78,17	79,49	78,77	78,69	80,46			
25	72,93	72,02	73,26	77,03	81,64	80,40	80,67	82,74	83,58		
26	72,18	73,97	75,54	79,40	80,08	81,59	83,49	85,58	84,17		
27	74,98	75,02	76,60	80,79	86,47	83,89	85,13	85,75	86,41		
28	74,44	76,00	76,82	79,37	83,35	82,76	86,45	87,13	91,26	91,94	
29	76,10	76,95	79,43	81,41	82,91	84,03	90,10	90,63	91,25	94,44	
30	76,35	77,89	78,82	84,41	86,70	86,82	87,79	91,24	93,95	100,88	99,22

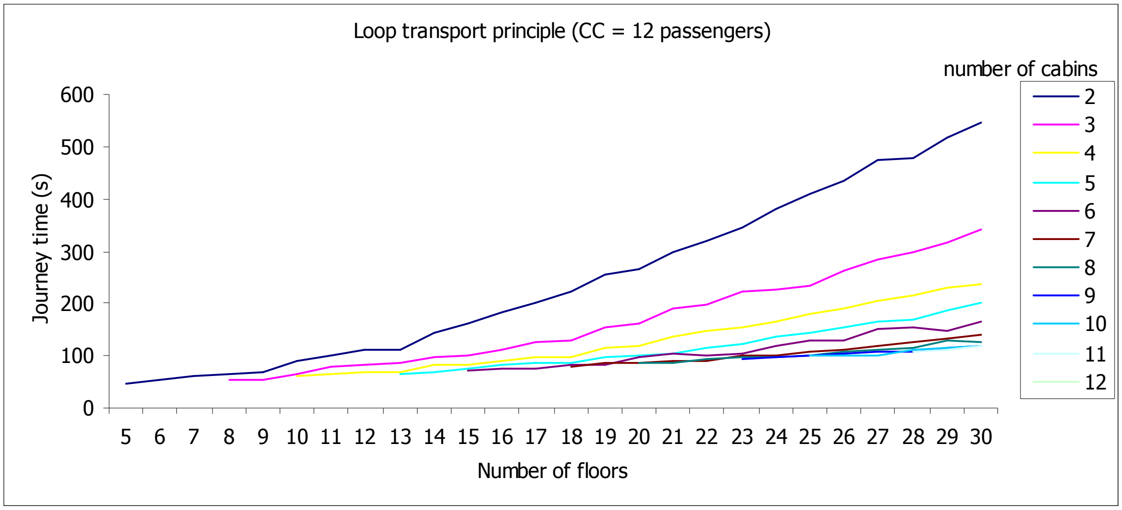

figure 90. Loop transport principle, average journey time with a cabin capacity (cc) of 12 passengers for a different number of cabins

table 44. Loop transport principle, values average journey time (s) with a cabin capacity (cc) of 12 passengers

	Number of cabins										
	2	3	4	5	6	7	8	9	10	11	12
Number of floors											
5	46,23										
6	53,94										
7	61,83										
8	65,38	52,81									
9	69,89	54,89									
10	88,29	64,54	60,85								
11	100,26	77,30	64,09								
12	110,87	81,01	66,88								
13	112,71	87,76	68,59	64,64							
14	144,32	96,84	80,99	67,98							
15	160,64	100,69	83,49	76,42	71,30						
16	181,46	111,57	89,50	82,36	76,33						
17	200,09	126,71	98,41	85,77	75,11						
18	224,11	129,89	98,35	85,03	84,29	78,99					
19	255,57	153,07	114,43	98,53	83,26	86,34					
20	266,08	162,08	120,14	101,76	95,80	86,43	86,05				
21	299,58	190,60	137,50	105,25	104,54	88,12	87,07				
22	318,93	196,72	147,41	116,66	99,86	91,32	92,41				
23	343,68	221,84	152,86	123,94	105,92	101,55	95,73	95,19			
24	379,20	226,28	166,75	136,91	120,27	102,34	96,96	96,96			
25	410,65	235,09	178,67	144,29	127,59	106,64	100,46	100,18	99,30		
26	433,70	263,21	190,00	153,57	129,73	110,10	106,33	104,07	100,45		
27	475,04	284,17	203,01	164,18	151,06	118,28	111,77	107,20	101,88		
28	476,90	298,75	216,12	169,26	153,89	125,99	114,15	108,14	110,25	106,89	
29	516,03	317,32	229,96	185,91	148,70	131,67	127,70	115,15	115,44	111,61	
30	546,36	340,50	237,65	199,56	166,70	141,12	127,08	119,38	117,22	118,43	114,42

table 45. Loop transport principle, minimum average waiting time (s). Values linked to figure 49.

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	21,47	21,91	21,91	21,91
6	23,62	23,64	23,52	23,52
7	30,71	28,85	28,16	27,97
8	18,46	18,49	18,33	18,39
9	20,71	20,38	20,16	20,11
10	17,71	18,18	17,77	17,63
11	21,57	19,56	19,65	19,44
12	21,57	20,20	19,80	19,33
13	18,80	15,99	15,98	15,62
14	20,87	17,92	17,40	17,39
15	19,64	17,08	16,00	15,56
16	22,09	16,70	16,59	16,18
17	27,97	18,59	16,47	16,32
18	20,92	17,52	15,86	15,20
19	29,61	21,71	18,31	17,40
20	26,83	17,22	15,21	14,87
21	29,02	18,83	15,43	15,52
22	46,87	22,78	17,75	16,70
23	36,48	21,97	15,53	14,59
24	42,59	23,39	17,75	16,50
25	43,36	22,25	17,29	15,72
26	53,46	27,28	18,79	16,28
27	59,31	27,82	18,25	15,47
28	61,02	26,83	17,17	14,95
29	67,38	36,73	21,29	17,17
30	65,75	34,24	18,18	15,19

table 46. Loop transport principle, minimum average travel time (s). Values linked to figure 50

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	25,15	24,32	24,32	24,32
6	29,62	30,40	30,43	30,43
7	33,46	33,62	33,97	33,87
8	33,83	34,28	34,25	34,41
9	35,79	34,79	34,81	34,78
10	39,51	43,07	43,24	43,22
11	41,59	43,92	44,26	44,66
12	43,85	46,14	47,47	47,55
13	46,04	47,94	48,80	49,02
14	48,34	48,70	50,14	50,59
15	50,65	53,71	54,95	55,75
16	52,14	56,39	59,45	60,15
17	54,69	55,96	57,45	58,79
18	59,81	61,72	62,08	63,79
19	59,66	64,72	67,88	68,94
20	62,87	69,75	70,92	71,18
21	62,03	66,97	70,41	71,55
22	66,01	69,73	74,47	75,71
23	69,14	76,77	78,76	80,60
24	64,63	73,70	77,90	80,46
25	71,16	80,50	82,60	83,58
26	69,66	79,13	81,53	84,17
27	70,87	79,69	85,39	86,41
28	74,12	85,72	89,72	91,94
29	74,22	88,04	93,69	94,44
30	76,44	87,38	96,03	99,22

table 47. Loop transport principle, minimum average journey time (s). Values linked to figure 51

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	46,62	46,23	46,23	46,23
6	53,24	54,04	53,94	53,94
7	64,17	62,47	62,13	61,83
8	52,29	52,77	52,58	52,81
9	56,51	55,17	54,97	54,89
10	57,21	61,25	61,02	60,85
11	63,16	63,48	63,91	64,09
12	65,42	66,34	67,27	66,88
13	64,84	63,93	64,78	64,64
14	69,21	66,62	67,54	67,98
15	70,29	70,79	70,95	71,30
16	74,22	73,09	76,04	76,33
17	82,66	74,55	73,92	75,11
18	80,73	79,23	77,94	78,99
19	89,27	86,43	86,19	86,34
20	89,71	86,97	86,12	86,05
21	91,05	85,80	85,84	87,07
22	112,88	92,51	92,22	92,41
23	105,62	98,74	94,29	95,19
24	107,22	97,09	95,66	96,96
25	114,52	102,75	99,89	99,30
26	123,12	106,41	100,32	100,45
27	130,17	107,50	103,64	101,88
28	135,15	112,55	106,88	106,89
29	141,60	124,77	114,97	111,61
30	142,18	121,62	114,21	114,42

k. Case: Vertical transportation system for Workshop high-rise 2007 "The Ribbon"

In figure 91 the configuration of the conventional vertical transportation system is given which is developed in the workshop high-rise 2007. The vertical transportation system is part of the design of the Ribbon. The associated lifts characteristics can be found in table 48.

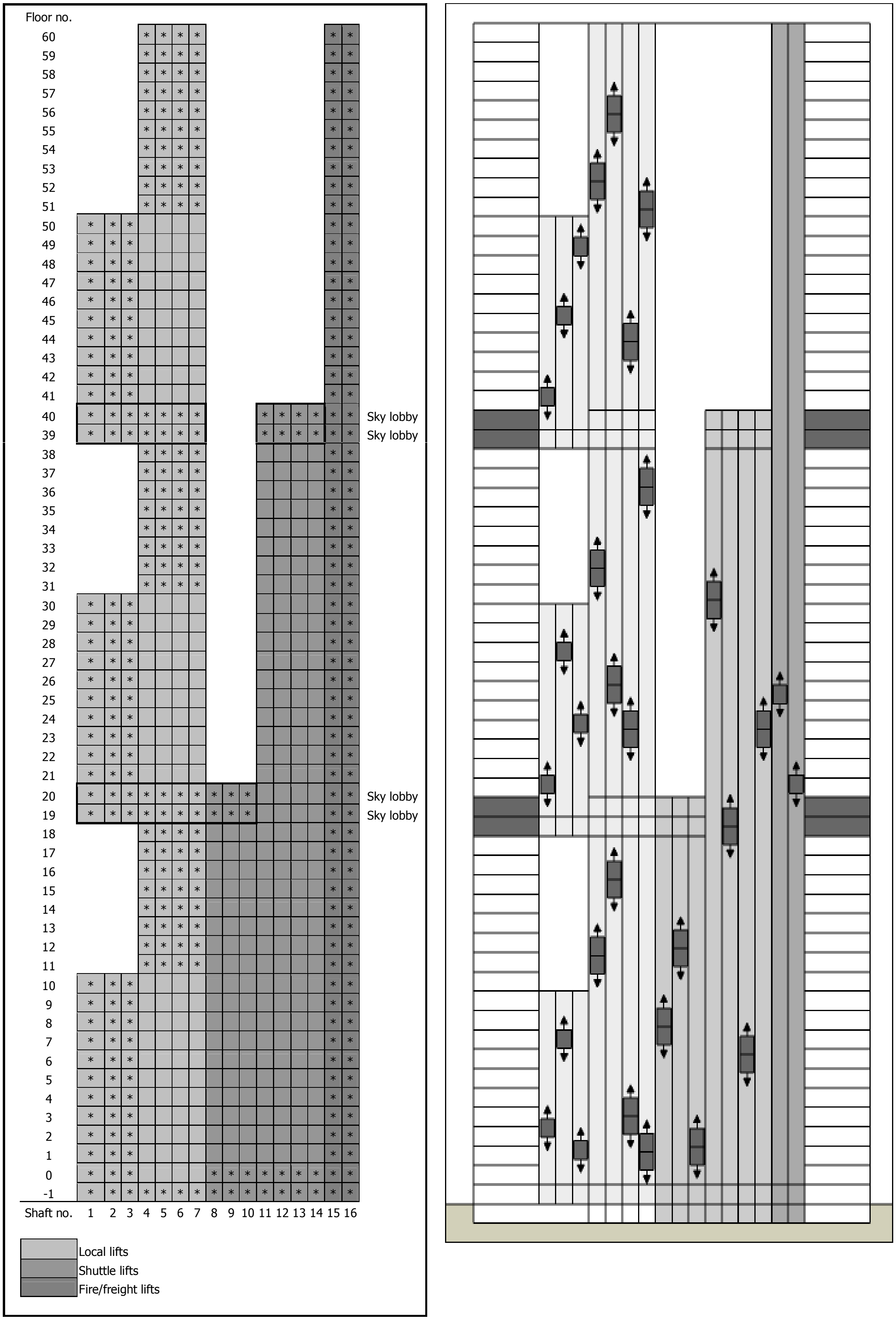

figure 91. Vertical transport system developed in workshop high-rise 2007. The Ribbon.

table 48. Lifts used for vertical transportation system developed in the Workshop high-rise 2007.

Lift	amount	sort	Capacity (kg)	speed (m/s^2)	acceleration (m/s^3)
1 to 3	9	single	800	2,5	0,8
4 to 7	12	double decks	800	5,0	0,8
8 to 10	3	double decks	1200	5,0	0,8
11 to 14	4	double decks	1400	5,0	0,8
15 to 16	2	fire freight	1400	5,0	0,8

I. *Case: Results of runs for conventional and loop transport principle model for case study*

Results conventional lift
Based on parameter series table 22.

2 cabins

table 49. Conventional lift, case study. Average waiting time (s) for two shafts.

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	21,41	20,20	19,73	19,09
6	29,36	27,66	23,89	23,13
7	65,13	40,70	29,00	29,68
8	89,48	63,96	46,99	37,00
9	128,21	89,57	70,34	50,56
10	181,15	137,96	100,44	75,65
11	218,44	165,79	130,41	104,82
12	261,19	206,67	167,04	144,27
13	309,01	238,94	202,81	164,81
14	354,65	282,46	237,89	194,34
15	407,23	332,32	280,83	230,51
16	460,49	378,60	315,48	274,60
17	512,85	421,18	358,68	309,09
18	570,92	468,99	399,42	353,30
19	613,35	512,81	444,26	388,91
20	668,57	565,62	491,85	431,38

table 50. Conventional lift, case study. Average travel time (s) for two shafts.

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	25,18	25,20	25,64	24,31
6	27,68	29,88	29,30	29,71
7	30,82	33,12	33,76	34,53
8	32,27	35,91	38,35	39,72
9	33,67	38,14	40,68	43,82
10	36,25	40,75	44,02	45,04
11	36,20	41,77	45,85	48,82
12	37,98	43,70	47,60	52,38
13	38,58	43,61	50,21	54,28
14	39,32	46,10	51,43	54,72
15	39,96	46,10	51,76	56,27
16	41,33	48,49	53,78	57,61
17	42,17	48,72	55,14	59,12
18	42,52	50,00	56,22	61,68
19	42,54	49,80	57,58	63,43
20	43,26	51,61	57,77	64,43

table 51. Conventional lift, case study. Average journey time (s) for two shafts.

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	46,60	45,40	45,37	43,41
6	57,04	57,54	53,20	52,83
7	95,95	73,82	62,75	64,21
8	121,75	99,87	85,34	76,72
9	161,88	127,71	111,01	94,38
10	217,40	178,71	144,47	120,68
11	254,63	207,56	176,27	153,64
12	299,18	250,37	214,64	196,65
13	347,59	282,55	253,01	219,09
14	393,97	328,56	289,33	249,06
15	447,19	378,42	332,60	286,78
16	501,82	427,09	369,26	332,21
17	555,01	469,91	413,82	368,21
18	613,44	518,98	455,64	414,98
19	655,89	562,61	501,84	452,33
20	711,83	617,23	549,62	495,81

3 cabins

table 52. Conventional lift, case study. Average waiting time (s) for three shafts.

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	14,86	14,97	14,94	15,20
6	16,19	16,11	16,34	16,37
7	20,14	18,96	17,76	18,74
8	29,12	21,76	20,44	21,51
9	49,86	31,98	23,19	23,62
10	77,78	44,57	34,87	29,46
11	98,79	69,90	49,91	39,70
12	130,76	96,34	66,74	54,78
13	153,20	120,00	91,04	68,80
14	182,37	141,93	112,76	86,45
15	222,81	170,63	134,80	106,29
16	253,87	199,89	157,41	131,69
17	293,09	227,27	190,02	161,09
18	314,37	261,71	210,84	174,34
19	354,83	294,59	242,00	211,88
20	395,64	323,47	272,39	237,11

table 53. Conventional lift, case study. Average travel time (s) for three shafts.

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	21,09	21,54	20,64	20,71
6	25,41	24,86	24,45	23,98
7	27,85	29,01	30,04	28,28
8	31,30	33,09	32,38	33,64
9	33,51	37,32	36,45	38,89
10	35,34	39,14	41,82	43,45
11	36,10	40,74	45,05	47,08
12	37,12	43,28	45,70	50,46
13	37,55	44,05	48,22	51,68
14	39,46	45,01	50,38	52,63
15	39,38	46,37	51,05	56,79
16	41,72	47,05	53,20	57,81
17	41,93	48,28	54,18	59,94
18	41,73	48,81	54,23	61,17
19	42,74	50,17	56,55	62,30
20	43,26	51,09	57,41	62,98

table 54. Conventional lift, case study. Average journey time (s) for three shafts.

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	35,95	36,51	35,57	35,91
6	41,60	40,97	40,79	40,35
7	47,99	47,97	47,80	47,03
8	60,42	54,85	52,82	55,15
9	83,38	69,30	59,64	62,51
10	113,11	83,71	76,69	72,90
11	134,90	110,63	94,95	86,78
12	167,88	139,62	112,44	105,24
13	190,76	164,04	139,25	120,48
14	221,84	186,94	163,14	139,09
15	262,19	217,00	185,85	163,08
16	295,60	246,94	210,61	189,50
17	335,02	275,55	244,20	221,03
18	356,10	310,52	265,07	235,50
19	397,57	344,76	298,55	274,17
20	438,90	374,56	329,79	300,09

4 cabins

table 55. Conventional lift, case study. Average waiting time (s) for four shafts.

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	13,90	13,75	13,71	13,75
6	14,39	14,33	14,45	14,89
7	15,59	15,61	15,01	14,94
8	17,36	16,76	16,10	15,76
9	22,22	17,85	17,53	17,82
10	29,21	21,16	19,06	19,02
11	47,15	26,29	24,32	22,83
12	64,31	36,88	29,57	23,61
13	85,95	55,55	33,31	29,23
14	104,51	74,16	53,47	39,31
15	130,27	90,28	69,55	53,64
16	149,05	113,08	86,59	62,51
17	185,35	133,42	105,16	82,86
18	202,74	157,53	126,93	96,96
19	225,63	178,86	139,71	119,48
20	253,74	199,04	160,09	134,13

table 56. Conventional lift, case study. Average travel time (s) for four shafts.

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	19,84	20,58	20,23	20,02
6	21,60	22,54	23,26	22,33
7	25,92	25,30	25,25	24,74
8	28,11	28,56	28,61	29,01
9	30,91	31,87	31,72	32,35
10	33,12	36,64	36,18	35,53
11	34,69	38,95	41,31	40,96
12	37,10	41,34	44,53	45,90
13	37,90	43,51	45,72	48,98
14	39,09	44,42	48,15	52,85
15	39,65	44,64	51,16	55,06
16	40,34	47,23	52,63	56,87
17	41,54	47,67	53,07	58,49
18	42,08	49,56	54,92	59,48
19	42,12	49,05	55,68	61,14
20	42,72	50,47	56,68	63,21

table 57. Conventional lift, case study. Average journey time (s) for four shafts.

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	33,74	34,33	33,94	33,77
6	35,99	36,87	37,71	37,22
7	41,51	40,91	40,26	39,68
8	45,47	45,32	44,72	44,78
9	53,13	49,71	49,25	50,16
10	62,33	57,80	55,25	54,55
11	81,83	65,24	65,63	63,79
12	101,41	78,22	74,10	69,51
13	123,85	99,06	79,04	78,22
14	143,60	118,57	101,62	92,15
15	169,92	134,93	120,71	108,70
16	189,39	160,31	139,22	119,38
17	226,89	181,09	158,23	141,36
18	244,82	207,08	181,85	156,43
19	267,75	227,91	195,39	180,62
20	296,45	249,51	216,77	197,33

Results loop transport principle
Based on parameter series table 25.

table 58. Loop transport principle, case study. Average waiting time (s) for two shafts.

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	28,44	26,61	25,78	25,29
6	43,51	30,50	28,78	28,41
7	74,96	49,31	35,59	33,27
8	44,34	29,61	26,99	25,57
9	62,43	41,50	32,51	29,12
10	49,55	32,81	25,91	24,47
11	59,73	40,23	29,40	25,23
12	87,88	60,86	43,68	32,67
13	69,81	44,36	31,02	24,58
14	85,61	54,91	39,03	29,66
15	79,10	48,65	31,38	23,36
16	101,28	68,46	48,02	33,89
17	118,74	80,32	54,32	43,17
18	114,40	73,84	50,25	35,45
19	124,74	81,36	56,97	39,59
20	129,62	82,09	56,18	38,75

table 59. Loop transport principle, case study. Average travel time (s) for two shafts.

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	28,76	29,13	28,79	29,09
6	32,15	33,86	34,59	35,20
7	34,77	37,25	38,49	38,59
8	38,63	42,29	43,80	44,31
9	39,33	43,70	45,53	46,86
10	44,31	48,93	50,25	50,51
11	45,21	49,78	52,88	53,43
12	45,88	51,83	55,95	58,21
13	51,71	56,25	60,02	62,14
14	51,03	55,48	60,64	63,30
15	56,21	61,60	64,35	68,75
16	56,40	64,31	69,13	72,79
17	56,54	64,60	69,90	73,83
18	60,57	68,76	74,27	79,38
19	61,27	68,20	75,85	79,92
20	65,52	72,64	79,85	83,22

table 60. Loop transport principle, case study. Average journey time (s) for two shafts.

	Cabin capacity (passengers)			
Number of floors	6	8	10	12
5	57,20	55,74	54,57	54,38
6	75,66	64,36	63,37	63,60
7	109,73	86,56	74,08	71,86
8	82,97	72,80	70,79	69,88
9	101,76	85,20	78,04	75,98
10	93,87	81,74	76,16	74,97
11	104,94	90,01	82,28	78,66
12	133,76	112,69	99,63	90,88
13	121,52	100,62	91,04	86,72
14	136,63	110,39	99,67	92,96
15	135,31	110,25	95,73	92,11
16	157,69	132,76	117,15	106,68
17	175,29	144,91	124,21	117,00
18	174,97	142,60	124,52	114,84
19	186,01	149,56	132,82	119,51
20	195,14	154,73	136,03	121,97

m. Case: Floor space vertical transport system used for different heights of a building

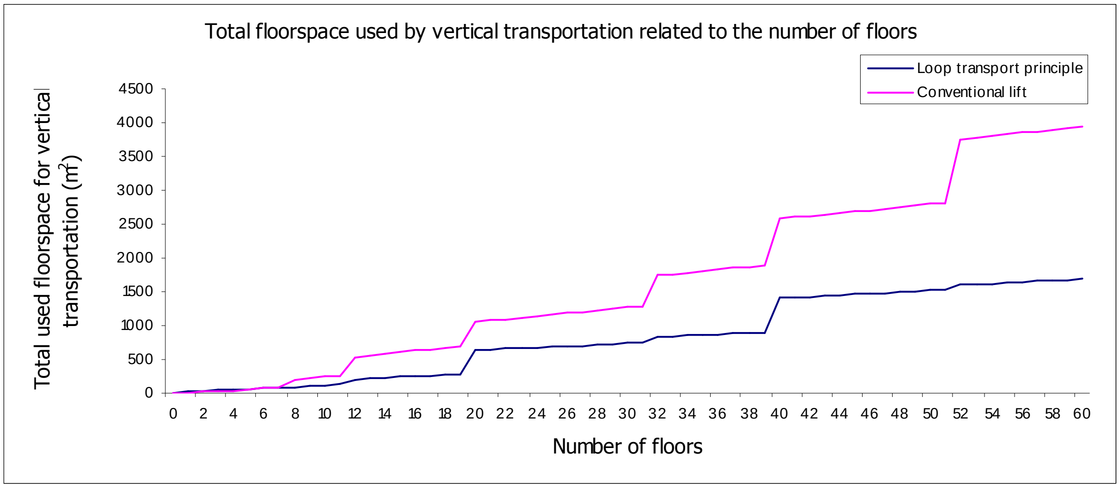

figure 66. Total floor space used for vertical transportation (Same as figure 66 in report).

table 61. Data associated to figure 66.

	Total used floor space over all the floors [m^2]	
Floor no.	Conventional lift	Loop transport principle
60	3933,9	1687,5
59	3912,3	1676,7
58	3890,7	1665,9
57	3869,1	1655,1
56	3847,5	1644,3
55	3825,9	1633,5
54	3804,3	1622,7
53	3782,7	1611,9
52	3761,1	1601,1
51	2816,1	1525,5
50	2794,5	1514,7
49	2772,9	1503,9
48	2751,3	1493,1
47	2729,7	1482,3
46	2708,1	1471,5
45	2686,5	1460,7
44	2664,9	1449,9
43	2643,3	1439,1
42	2621,7	1428,3
41	2600,1	1417,5
40	2578,5	1406,7
39	1892,7	901,8
38	1871,1	891
37	1849,5	880,2
36	1827,9	869,4
35	1806,3	858,6
34	1784,7	847,8
33	1763,1	837
32	1741,5	826,2
31	1290,6	750,6
30	1269	739,8
29	1247,4	729
28	1225,8	718,2
27	1204,2	707,4
26	1182,6	696,6
25	1161	685,8
24	1139,4	675
23	1117,8	664,2
22	1096,2	653,4
21	1074,6	642,6
20	1053	631,8
19	691,2	280,8
18	669,6	270
17	648	259,2
16	626,4	248,4
15	604,8	237,6
14	583,2	226,8
13	561,6	216
12	540	205,2
11	259,2	129,6
10	237,6	118,8
9	216	108
8	194,4	97,2
7	86,4	86,4
6	75,6	75,6
5	64,8	64,8
4	27	54
3	21,6	43,2
2	16,2	32,4
1	10,8	21,6
0	0	0

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o. *List of tables*