A NEW ELEVATOR SYSTEM AND ITS IMPLEMENTATION

(*) Dipl. Ing. Thomas Dünser
(**) Dr. Romeo Deplazes
(***) Prof. Dr. Markus Meier

(*) Center of Product Development, ETH Zurich, Switzerland
thomas.duenser@imes.mavt.ethz.ch
(**) Schindler Elevators AG, Ebikon
romeo_deplazes@ch.schindler.com
(***) Center of Product Development, ETH Zurich, Switzerland
markus.meier@imes.mavt.ethz.ch

Economy of Space
Shaft layout components
Traffic performance

1 Abstract

To reduce the need of space of an elevator system in high-rise buildings and such with a high volume of traffic, a completely new elevator system must be developed. As a revolutionary idea, the new system lets move several cabins at the same time in one shaft, switching to another shaft if the route is blocked. Combined with the possibility to use smaller cabins by taxi rides, a major improvement of the main aspects of an elevator system can be expected. Herein, managing the additional degrees of freedom compared with today's system will be a key issue. This study's goal is to analyse the effect of the most important elements of an elevator shaft layout on the traffic volume regarding the technical implementation.

2 Introduction

2.1 Elevator environment and principal problems

Since the land price in downtown of major cities still is escalating, the trend of building skyscrapers will hold on, even if there recently appeared some disadvantages caused by terrorist attacks. The higher a building, the more people have to be transported and so the demands on the traffic performance increase. This normally leads to a higher need of space of the elevator system, that can be up to 30% of the total volume [1]. The cause can be found in the longer distance for a cabin to go, so that it takes much more cabins and, finally, additional shafts to handle the volume of traffic. If the elevator system occupies more space, there is less floor space left that can be let. The owners of such buildings are therefore highly interested in saving space. As additional aspect, the view of the passengers should not be neglected, either. Most important for them, the waiting time ought to be low. In addition to that, the time for a ride should not exceed a certain limit.

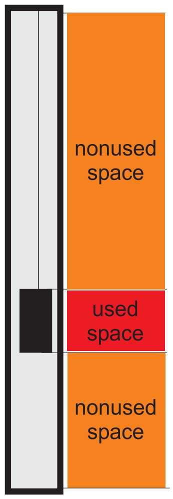

Figure 1: Proportion of used space and occupied volume in today's elevator

The reason of the cohesion of the traffic performance and the use of space can be found in the bad proportion of the used space and the occupied volume (see figure 1). With the increase of the height of the building, this proportion will even get worse. In the past, elevator companies started several approaches to improve it: Double- or even Trippledecker lifts (figure 2) increase the used space without increasing the occupied volume. As a further positive effect, the number of stops can be reduced about factor two respectively factor three. This solution, however, leads to a unsatisfying inflexibility for the passengers in choosing the target floors. In a second approach, the height of the shafts is split in two sections, so that the proportion of cabins to shaft volume could be reduced, too. Express elevators are transporting the passengers straight in the upper part of the building, where they have to change the cabin (see figure 3). This leads to a longer journey time and, besides, to passenger's inconvenience. Another solution's primary goal is to reduce the total time to target by grouping the passengers by their target floor. The shortened trip time (see figure 4) raises hope to be able to reduce the number of shafts needed in a building. This effect can only be stated at very large buildings, so that this variant is not an option for the reduction of space in normal sized buildings.

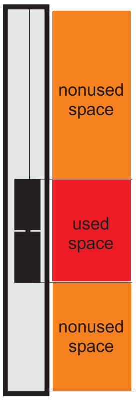

Figure 2: Double decker lift

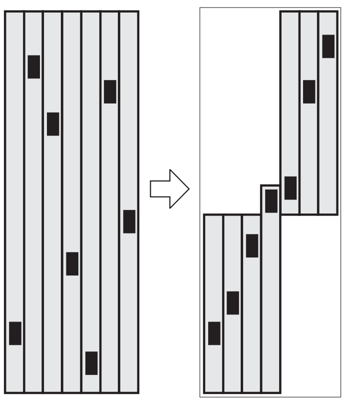

Figure 3: Express- and Dispension lift system

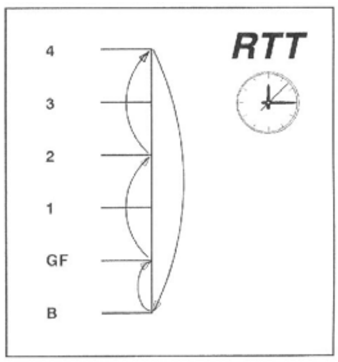

Figure 4: Reducing the Round Trip Time increases the efficiency of a shaft.

A revolutionary idea tackles this problem from two sides: By allowing many cabins to drive in the same shaft, the proportion of used volume and occupied space is increased (see figure 7). This should lead to a reduction of needed number of shafts. In addition to that, the area of the shafts can be reduced as well by using TAXI-Rides instead of today's BUS-Rides. Figure 5 illustrates the difference between the two principles in the view of a passenger who wants to go to the last floor. By using a Bus-system, he has to stop at several floors. With a taxi ride, no extra stop is done. With this measure certainly more cabins are needed to deliver the other passengers to their target floor. Because of the taxi rides, smaller cabins could replace the commonly used big sized cabins (figure 6). Although this concept seems very encouraging, it leads to some serious technical changes: First of all the cabins must be able to move horizontally and leave the shaft for that every cabin is able to reach all floors. For the needed flexibility for shaft changes and for movement in the same shaft, it is necessary to dispense with the rope. In today's elevators, the rope is used to transfer the traction force from the motor on top of the shaft to the cabin. On the other end, a counterweight is fixed to reduce the necessary force by equalizing the car's weight. So that there is no need to reduce the cabin's weight in today's elevator. If the rope is left away, no counterweight can be used anymore as well as the motor has to be directly on the cabin. As consequence, the weight of the cabin and the force density of the motor achieve greater relevance.

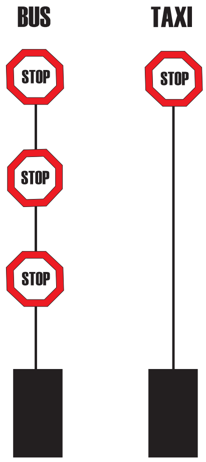

Figure 5: Taxi rides compared with bus rides

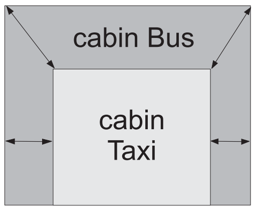

Figure 6: A 18 Passenger cabin for Bus rides compared with a 8 P-cabin for taxi rides

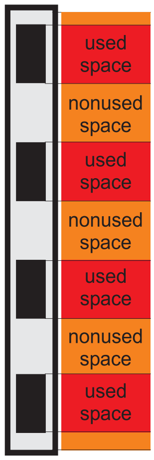

Figure 7: Many cabins in the same shaft increase the proportion of space.

2.2 Goal of the study

Although the potential of this concept seems to be evident, there are many questions and uncertainties to be studied. The way how the cabins are to be organized will be a key question for this first qualitative study. It will have effect on the final save of volume as well as on the necessary technical efforts. Therefore, different key elements and key questions of the traffic management will herein be discussed in the view of traffic coverage and their effect on the technical implementation.

2.3 Proceeding and Restrictions

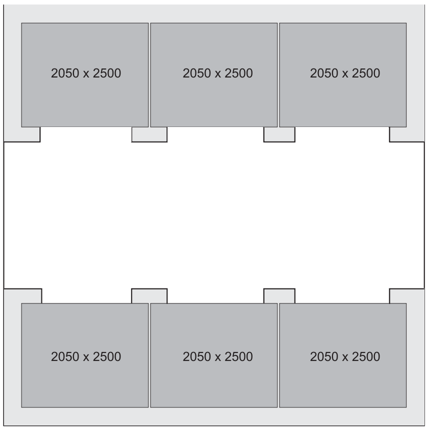

Figure 8: Shaft layout of the reference building

This first study has been limited to an existing building of 26 served floors (additional two floors are used for machine rooms, one floor in the basement is used for the compensation of the strain of the ropes) with known traffic stream. With a high volume of traffic, capacity problems are reported with today's elevator system.

The chosen building's shaft layout is represented in figure 8. The cabin size was measured for 18 Passengers or 1350 kg, meaning that the inner dimensions of the shaft become 205 x 250 [cm^2] (total of $51*10^3$[cm^2]).

In this study, several shaft layouts were analysed to find the best solution for this special building, regarding the traffic performance und technical aspects. The analysis led to the general results presented in chapter 3.3. The two best traffic layouts are presented in chapter 3.4.

3 The effects on the traffic coverage and the technical implementation

3.1 Introduction

Two factors lead to economy of space: The cars driving in the same shaft and the smaller cabin area due to taxi rides. As the latter certainly is not depending on the height of the building, the potential of this measure is discussed in the first sub-chapter. The effect of the traffic management system – especially of the shaft layout – based on the idea of allowing many cars in the same shaft. In the second sub-chapter, the key questions about the traffic management system are formulated. They will be discussed in Chapter 3.4. To show how a complete shaft layout will look, two different systems are presented in 3.5.

3.2 Principal considerations on the economy of space

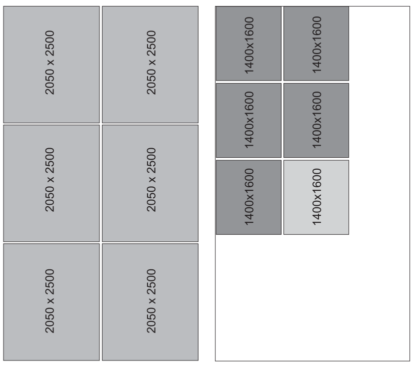

Figure 9: Reduction of occupied space by using smaller cabins

The smallest cabin for wheelchairs is dimensioned for 8 Persons or 630 kg. The shaft dimensions of this kind of cabin are 140 x 160 [cm^2] (i.e. a total of $22*10^3$ [cm^2]), meaning that the shaft area in this special building amounts to only 44% of the former size (figure 9). In addition to that, neither a machine room nor the buffering space will be needed. This means that all floors can be served and the economy of space will be even better. Further reduction of the need of space are to be expected by a suited traffic management system, especially by the arrangement of the shafts and other elements.

3.3 Overview on the investigated questions

A traffic management system can be divided in two major parts: As the basic part, the shaft layout, a composition of different elements, provides the basic framework for the cabins and defines the possible degrees of freedom. For example, the actual elevator system is composed of one lane without any switches to move horizontally, so the possible degrees of freedom are very restricted. The second part of a traffic management system defines the overall strategy (e.g. the aims of the passenger delivery like minimization of the waiting time; e.g. the strategy of grouping the passengers) and the individual strategy of the cabins (e.g. collision prevention) by controlling principles. Although some sub-parts like the basic collision prevention can be applied to various shaft layouts and overall strategies, the detailed implementation depends on the degrees of freedom defined by the shaft layout. So a study like this has to focus on the shaft layout with its possible components. Based on this information, different strategies of controlling can be defined and optimised.

The main discussion points of a shaft layout are:

Lateral Movement with Passengers:

Should the filled cabin be allowed to move horizontally or not? The passenger will hardly accept any unexpected movement, so that they have to hold at a grip in the cabin.

Time aspects of the changing of the shaft

Two different kinds of the changing of the shaft can be determined: One without and one with time loss. The time loss can be caused by separated movement in vertical and horizontal direction (figure 10), meaning that the cabin has to stop, to change eventually the guideshoes and then, to move horizontally. Horizontal movement that happens simultaneously to the vertical motion is a preposition to not loosing time changing the shaft (see figure 11).

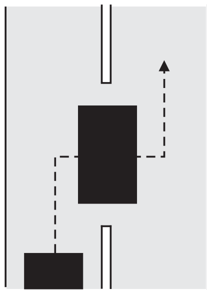

Figure 10: Shift with time loss

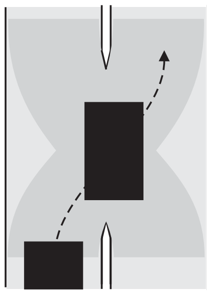

Figure 11: Shift without time loss

Position of Stops

Similar to bus stops, it could be possible to let the passengers exit outside of the driving lane, so that other cabins could pass at the same time.

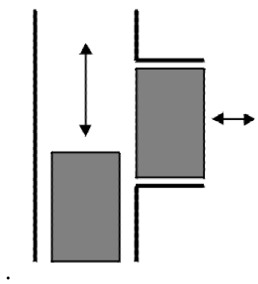

Figure 12: External Stop

Storage of cabins

There are two basic possibilities to use cabin storage:

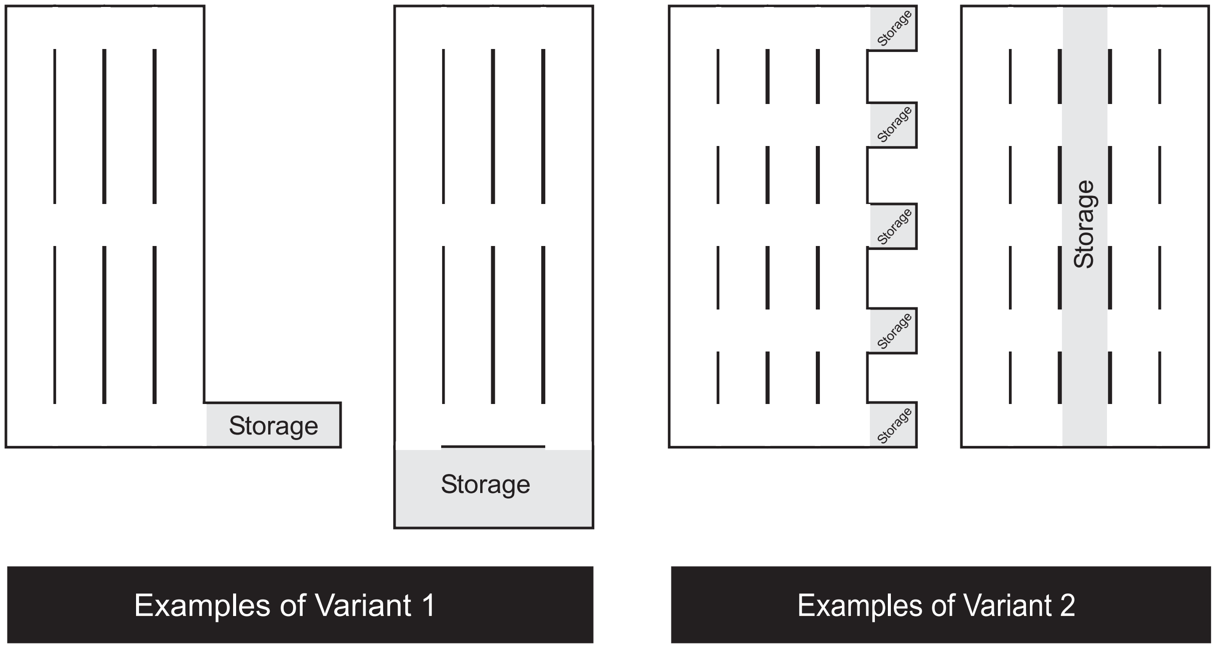

Figure 13: Storage types

1. Over a longer period of time it is estimated how many cabins are necessary to manage the traffic volume without major interferences. Typically, only one big storage is needed.
2. There are many small storage rooms placed over the shaft's height. The cabins go back in the next storage after serving a call except there is no another suitable call available. Vice-versa, the cabins in the storages are always close to the next call, so that the waiting times constantly ought to be low.

Passing lanes

Long distance rides could be quicker if the danger of a tailback can be minimized by passing lanes. Passing lanes don't have entrance doors.

Number of switches of shafts

The more possibilities to change the shaft, the more flexible the system should be. On the other side, the costs of the total system increase with every additional switch. It's therefore essential to find out the optimal number of switches for sufficient flexibility.

Number of doors per floor

The number of shafts will not only be specified of their traffic capacity but from the number of necessary entrance and exit doors in the main floors.

Restrictions of the driving direction

The system is more flexible with no limitation of the driving direction. On the other hand, the capacity could be higher with restricted one-way traffic.

3.4 Results

3.4.1 Lateral movement with Passengers

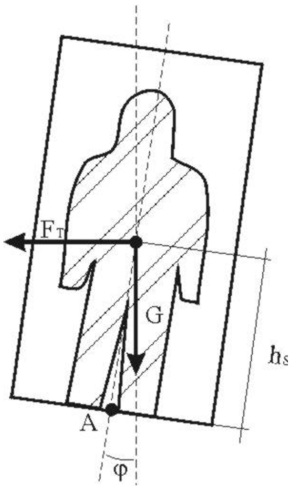

Figure 14: Compensation of lateral forces by toppling the cabin

Traffic management aspects

If a loaded cabin is not allowed to change the shaft, the cabin has to look for a non-reserved shaft to load the passenger, so that it can go to the target floor without interfering with other cabins. The systems gets very inflexible due to the long term reservation of a shaft once a cabin has loaded passengers. On the other hand, the driving time gets longer if each switching of the shaft is linked with a time loss (see 3.3.3).

General and technical aspects

Lateral movement of a cabin with people standing will reduce the comfort of the passengers due to the acceleration forces. Passengers will only accept the new system, if they don't feel that the cabin is moving laterally. It is possible to compensate the lateral forces by toppling the cabin to the side, like illustrated in figure 14. The technical effort will anyhow be huge, especially if the lateral movement is performed like in figure 11. It is difficult to estimate the robustness and the liability of such solutions. As a principal predication, the big amount of additional parts leads certainly to additional problem zones compared with the same cabin who is not allowed to move horizontally with passengers. Similar solutions in trains show another problem that cannot be determined in advance: Some people get seasick because of the toppling of the wagon. Such problems can only be determined by a physical prototype. If it won't be possible to solve this insecurity, the future of the whole system is vague. Therefore the simpler variant should be preferred, in case that there is a solution to satisfy the traffic demands.

3.4.2 Number of switches of shafts

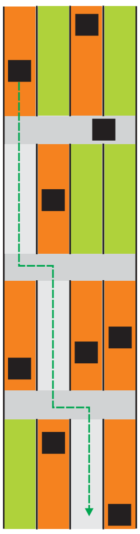

Figure 15: Sections between Switches (grey)

Traffic management aspects

The number of switches and their position defines the length of a shaft that can be blocked with one cabin stopping. If two cabins are in the same section, there is no possibility for the second cabin to pass by if the first stops. Therefore the number of switches correlates with the maximum number of cabins that can be at once in the same shaft. Since the proportion of used volume und occupied space depends highly on the number of cabins in the shaft, this question is elementary for such a system. It turned out that one switch per five floors is enough to maintain a sufficient flexibility. Most important is the ratio between number of sections and the number of vehicles in the whole system. There should always be enough unused sections available for that the loaded cabins can find a way to their target. If the ratio comes close to 1 or even lower, there will occur capacity problems. In figure 15, the blocking of the sections between two switches is illustrated: If a cabin blocks a section, it is coloured orange. As a negative aspect of the limited number of switches, the system has to handle detours if one cabin wants to pass the preceding vehicle and therefore the journey time takes longer.

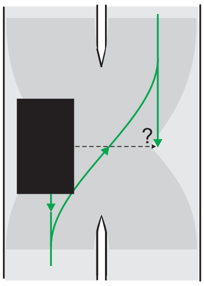

Figure 16: Detour because of a switch type

General and technical aspects

There are various technical possibilities of implementing switches, mostly depending on the shaft layout: A system with only two switches on the top and bottom of the building is implemented differently than a system with more degrees of freedom. Similarly, the arrangement and the number of shafts cause different technical solutions. Most important is the kind of motor to be chosen: It should be possible to use the motor for the horizontal movement as well or – at least – to be detached from the vertical guidance during the changing of the shaft. Looking at the cost aspects, it is possible to make some general statements: The number of switches and the complexity will certainly influence the initial costs.

3.4.3 Time aspects of the changing of the shaft

Traffic management aspects

As mentioned above, the number of switches is elementary for the flexibility of the system. The efficiency of the changing of the shafts is therefore a basic question that influences the reasonable number of switches. If a cabin needs more time to change the shaft than by waiting until the preceding vehicle goes on, the number of switches ought to be reduced to an minimum. If the cabin looses no time by changing, it is very useful to increase the number of switches (see discussion in 3.3.2). The worst possibility for a switch from the perspective of time eases the cabin to stop before it can move horizontally (see figure 10). This means, that the shaft is blocked for the time of the switching, so that this reduces the capacity of the system. From the view of the cabin, this would lead to a time loss that increases the time to the target from the passenger (in case if the lateral movement with passengers is allowed). A switch with no time loss must prevail the cabin to stop, so that it should look like illustrated in figure 11. But this kind also causes some problems in traffic management: To change the shaft if positioned on a switch, it is necessary to do a detour like illustrated in figure 16.

General and technical aspects

From the view of the traffic management, the switch without time loss should be preferred. On the technical side, this variant causes much more difficulties than the other proposal: The motor has to go round curves, so that the justification would be quite more complex. The guidance of the cabin will be much more complicated as well, especially if it’s necessary to do the changing of shaft with passengers (see 3.3.1). The guidance of the cabin and of the motor as well can be implemented much simpler, since the driving directions (vertical and horizontal) are separated. Nevertheless, the guidance has to handle two directions instead of one with today’s elevators, so that it will be more difficult to reach the goal of keeping the high level of passenger’s comfort even if they will only be moved vertically.

3.4.4 Position of Stops

Traffic management aspects

The principal advantage of letting the passengers exit off the driving lane is to increase the capacity of the shaft. But there are many reasons that reduce this positive effect: Depending on the height of one floor, it usually should not be possible to get out of the lane without time loss (illustrated in figure 11), because a cabin stopping at the next floor would prevent the cabin to go to its target floor, even if it is not occupied. This would lower the flexibility of the system. So, by choosing a switch like illustrated in figure 10, every stop looses time by getting out of the driving lane. In fact, this happens twice per ride, so that the time to target of each passenger would be lengthened. Nevertheless, the lane is blocked anyhow for the time to change the shaft. The advantage mentioned in the beginning is not relevant anymore.

General and technical aspects

The need of an entry/exit station on every floor means that many additional switches have to be installed, so that the cost of the system will increase. In addition to that, the need of space is as high as with a second shaft, whereby the latter offers more advantages (will be discussed in 3.3.6). Only the costs of the vertical tracks can be saved by using external stops.

3.4.5 Storage of cabins

Traffic management aspects

Basically, the need of a adaption of the number of active cabins is very desirable. Different traffic situations lead to different ideal numbers of cars. If there is no possibility to store the unneeded vehicles, seeking the right way for a loaded cabin turned out to be more difficult (compare with section 3.3.2).
To variant 1: One big sized storage with one entry increased the deadheads due to the distance to the storage. Raising the traffic volume lowers the capacity available for the passenger transport. Since the adaption of the number of active cabins still works inflexible, the short-time-empty vehicles interfered with the loaded cabins. Anyhow, the traffic flow is better than without any storage, especially in long term changes of traffic volume. But the traffic peaks have not been managed better.
To variant 2: The buffering of non-used cabins in short time intervals turned out to be a very good solution, since the whole traffic capacity of the shafts could be used only for passenger rides. Combining this principle with a further shaft that is used as vertical depot with many entries (illustrated in figure 13, type d), the deadheads could be minimized. A further important aspect is the possibility to reduce the waiting time on a constant low level, since the waiting time is mostly depending on the time for a cabin to get out of the depot shaft and go to the start floor. So the number of exits defines the longest distance from the exit to the start floor. It turned out that only one exit per 6 floors is enough to lower the mean waiting time to 10 Seconds during a high traffic volume. Apparently important as well is the time for the changing of the shaft, like discussed in 3.3.3.

General and technical aspects

Generally: If the empty cabins have to watch not to interfere with the loaded vehicles, they will be eased to do deadheads anyway. Deadheads mean a unnecessary need of energy. So the use of a storage, that will surely be linked with a higher traffic volume by cabins go in there, does not lead to deadheads only by its own, although their number will increase.
1. This variant locally needs much space, so that it is difficult to integrate in the building. The needed area can on the other hand be reduced to the maximum number of vehicles, but then it will hardly be possible to enhance the storage.
2. Although the occupied room is increasing by using this kind of storage, it is evenly spread over the whole height of the building so it can more easily be integrated in a building.

3.4.6 Passing lanes

Traffic management aspects

The key function is the same like already mentioned in 3.3.4. about the external stops: The stopping cabins don't block the cabins that want to pass by. Using two shafts instead of one shaft allows the short distance rides to stay on the first lane and not to slow down the long distance cabins by accelerating on the fast track, leading to a better overall performance. The kind of switch must be the one without time loss for that the acceleration phase can least partly be done on the first track. The number of necessary switches can be limited to one per five floors without mentionable losses in traffic capacity.

General and technical aspects

Compared with the variant with external stops, the number of switches can be reduced in addition to a better performance in the matter of capacity. This leads to smaller costs, even more, if the need of space is equal.

3.4.7 Number of doors per floor

Traffic management aspects

The number of entry doors in the first floor are highly influencing the capacity during the early morning when all people want to get up to their bureau. In the tested building, at least three doors have to be used to maintain the traffic flow. But this was very tight, so that mostly four doors have been used. The bottleneck in the first floor is not only depending on the number of doors: The number of cabins and how they could get to the entry stations appeared as just as important.

General and technical aspects

The number of necessary doors defines the minimum numbers of shafts with entries. This means that there is no possibility to save one shaft by managing the traffic if the number of shafts happens to be just as much as the minimal number of doors. So using passing lanes (3.3.6) is only possible in very large buildings, since the passing lane has no doors.

3.4.8 Restrictions of the driving direction

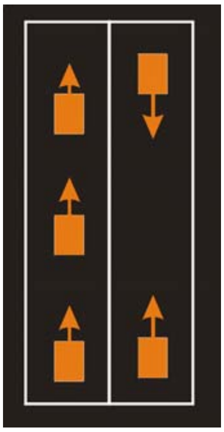

Figure 17: One-way traffic leads to shorter security distances

Traffic management aspects

In a highly flexible system, the cabins can move in each shaft in the direction they want to. So only stopping vehicles provoke detours. It happens, that cabins move towards each other in the same shaft, so the security or breaking distance must be doubled compared with the breaking distance in an one-way shaft (see figure 17). One way shafts have therefore a higher capacity. But they also induce additional detours by restricting the shafts to choose.

3.5 Example layouts

3.5.1 Introduction

Following the preceding discussions about the different aspects of shaft layouts, two examples will be presented in order to show different possibilities for combination. They are the best variants for the chosen building from the view of the traffic capacity, measured by waiting and journey time per call.

3.5.2 Variant A

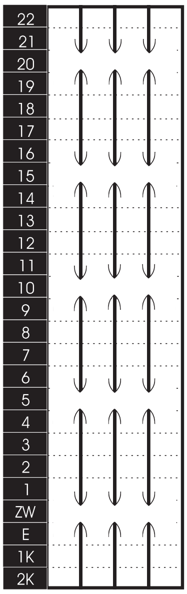

Figure 18: Schematic shaft layout with switches

Description:

Lateral Movement with Passengers:	**Allowed**
Time aspects of the changing of the shaft:	**No time loss**
Position of Stops:	**In the shaft**
Storage of cabins:	**None**
Passing lanes:	**None**
Number of switches of shafts:	**1 per 5 floors**
Number of doors per floor:	**4**
Restrictions of the driving direction:	**None**

Figure 18 illustrates the front view of the shaft-system with the position and the number of switches. By the kind of switches and the lack of any limitations, this variant is very flexible. Even with only one switch per five floors, it is possible to manage the traffic volume with four shafts, which means a reduction of 2 shafts in addition of the economy of space by the small cabins.

3.5.3 Variant B

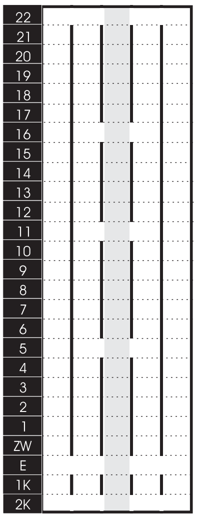

Figure 19: Schematic shaft layout of Variant B

Description:

Lateral Movement with Passengers:	**Not Allowed**
Time aspects of the changing of the shaft:	**With time loss**
Position of Stops:	**In the shaft**
Storage of cabins:	**Yes, vertical**
Passing lanes:	**None**
Number of switches of shafts:	**1 per 6 floors resp. 2 per shaft**
Number of doors per floor:	**4**
Restrictions of the driving direction:	**Yes**

In figure 19, a front view of the shaft layout is shown. The vertical storage (coloured grey) is arranged in the middle with switches to the next shafts on every 5th respectively 6th floor. These two shafts are used for short distance journeys, so that the cabins can go back into the storage without major time loss. The last two shafts all to the right and left are mostly used for long distance rides, so that only three switches per shaft are necessary. With this shaft layout, 5 shafts are sufficient for the necessary traffic performance. With the use of the vertical storage as short time buffer, it is possible to achieve high capacity, although from the view of technology, only components with the lowest effort for development are used.

3.5.4 Comparison

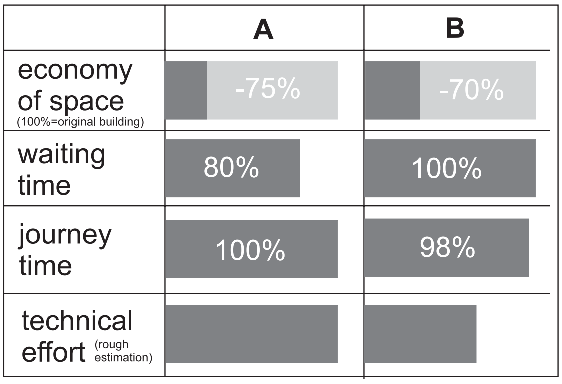

Figure 20: Comparison of Variant A and B

In figure 20, several aspects of the two presented variants are compared. The percentage in “economy of space” is based on the occupied volume of the actual elevator system inclusive machine room, etc. The number of cabins is the most important factor. With both variants, it is possible to use less shafts than the actual system. System A achieves lower waiting times, but regarding the journey times, both systems achieve the same performances. The technical effort for the further development is estimated to be much lower for variant B (see discussion in 3.3)
As the essential result of this comparison, both variants achieve almost the same traffic performance, although the technical implementation will be simpler with variant B.

4 Discussion and Conclusion

4.1 Discussion of the results

The main goal of this study was to show the potential of this new idea – especially the potential of a more complex shaft layout - on a typical building with a statement about the effect to the saving of space, to the traffic performance and to the technical implementation. It is possible to state that the economy of space amounts up to 75% of the original elevator system (meaning that the new system only needs 25% of the former shaft area). The traffic performance could be increased, even though the taxi rides could be realized. Additionally, the passengers will highly appreciate the constantly low waiting times. Surprisingly, Variant B as one of the technically simplest layouts (only regarding complex shaft layouts), reached one of the best traffic performances.
This results are basing on one specific traffic situation in a specific building. This means that the quantitative results must be handled carefully, if one wants to generalize the numeric results. On the other side, the qualitative statements are surely usable for shaft layouts in general, so that further discussions about the right shaft layout for different buildings can base on this study.
In this early state of development, the technical obstacles are hard to be recognized. But yet this principle discussions about technical aspects showed that there are major differences between shaft layouts, even if the traffic handling capacities are equal. So the system with one of the best traffic performances is not linked with the highest effort in the technical implementation. This raises hope to further steps in this development, although, the necessary effort still is huge. No existing component can be used in such a system, some even need a new technology to be implemented (e.g. a linear motor).
After all, the customers’ demand will decide upon the success of such a development. From this point of view, the new elevator system will be accepted the best if the passengers won’t notice any changes to the former system. This means, a solution without lateral acceleration with passengers like Variant B must be preferred for implementing in the first product, so that the passenger slowly can adapt to further changes.

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