Econometrics in the elevator

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This contribution describes how eleven business-econometrics students together with their supervisor tackled the long waiting times for the elevators in the 17-floor high H-building of the Erasmus University. Data were collected both by web questionnaire and by counting people in the elevators themselves. With own built simulation programs the elevator configuration was studied and changes were suggested. The most important one is to remove the floor partitioning, i.e. all floors should be served by all elevators.

Introduction

Elevators are essential elements in buildings as they allow the transport of people over various floors. Yet waiting for an elevator can be one of the main annoyances in one's experience with high buildings. This was and is definitely the case for the staff and students of the Woudestijn H-building. Many complaints were made to the faculty desk about the functioning of the elevators. Many stated that the waiting time for the elevators was too high and that sometimes the elevators were not even working at all. As some parts of the elevator system were in need of an overhaul the faculty-director Sander de Iongh wondered whether some more clever way of operation could reduce the complaints. The elevator system had been studied some ten years ago by an econometrician and he wondered whether that discipline could do something on it today. So in September 2000 he send an email to Professor Dekker. This one approached his students with the question to make it the subject for a working class. So it was decided and the students started half October and this paper reports on their adventures.

The H-building has a terrain floor (T), a ground floor (G) and 17 other floors for staff rooms and student classes. Two elevator systems are in place, the so-called **small elevators** (two elevators at the back of the building, serving all the floors T, B, 1 – 17) and the **large elevators**. The latter are divided into the so called *high-rise elevators* (three elevators serving T, B, 6 – 17) and the *low-rise elevators* (three elevators serving T, B, 1 – 6). This split up was made to separate the student stream (going to classrooms on floors 3,4,5 and 6) from the staff stream (to the remaining floors).

Approach

Most working classes start with a more or less idealized problem formulation. In this case it turned out to be essential to specify the real problem, nail it down to a researchable question and make a project plan, as all the work needed to be finished before Christmas. Moreover, a contingency plan was needed, in case some research phases took too much time. After a meeting with the faculty-director, the goal of the project was defined as follows: "Find out what division of the elevators leads to optimal use of the current capacity". Six research steps were defined to meet this objective. First, a questionnaire for all of the students and staff in the School of Economics should be made to investigate more details about the shortcomings of the elevator system and to get more insight into the travel patterns. Second, a group of students studied the literature to find out if these problems had been studied before and what solutions were recommended. Third, we had to schedule an appointment with the elevator supplier OTIS. Of course, we needed detailed data, like velocity, acceleration and closing time of the elevator doors, and so on.

Furthermore, they confirmed that most of the traffic was at the arrival of staff (in the morning), during lunch time (from 12:00h – 14:00h) and at the departure of the staff (in the afternoon). If the system can handle the traffic at these time points, then the remaining parts of the day would pose no problems. Fourth, we needed data on the traffic load of the elevators in order to quantify their performance. Fifth, alternatives should be proposed. The current settings (low- and high-rise with sixth floor as change-floor) needed to be compared with other alternatives, in order to decide which setting of the elevators was best. Also, we needed to know what settings are changeable, like velocity for instance. And finally, a choice of simulation-model was to be made. This included not only the right model, but also the language wherein this model should be programmed. A good defined and programmed model is the most important part of the credibility of the simulation alternatives. The goal of this simulation was to minimize the waiting time at the floors and the service time in the elevator.

Data

We received a package of data from OTIS, but this type of data was not useful for our model. It was a kind of logbook with information on the disturbances in the elevator system. The second option OTIS gave us was to put a kind of monitoring system within our elevator system, which counted the weight of the people in the elevator and the input signals on all buttons (both inside as well as outside the elevator). This sounded useful, but it took quite some time for OTIS to get it installed and it would not meet all our requirements (e.g. it did not indicate how many people are waiting). In fact we needed a time-dependent Origin-Destination matrix for all the floors in our building. As with many other transportation problems, such a matrix can not directly be measured, because our present elevator system blocks direct movements from high to low floors and vice-versa. Thinking about this was one of the challenges of the project: we had to take care of our own data collection. We decided to join forces among all participants and set-up a comprehensive measuring scheme, both in the morning and lunch time. We decided to count for every elevator the number of people entering and leaving per floor. This meant that we had no direct information on the number of people waiting on every floors nor on the destination of the people – that was just a too comprehensive task. Accordingly we had to reconcile that information from our measurements.

With only eleven students, this meant one student in each elevator and three at the main floor. This yields a total number of 3 (low-rise large) + 3 (high-rise large) + 2 (small) + 1 (B-floor high-rise large) + 1 (B-floor low-rise large) + 1 (B-floor small) =11 students. Everyone needed to count from 8:30 – 9:30 and from 11:30h – 14:00h each person that arrived at his “department”. Every 5 minutes (with synchronized watches), everyone started with a blank piece of paper. We decided to measure on Thursday November 16^{th}. When we did so, we did not notice much waiting and it turned out to be the exam week for the trimester system. So all these measurements could be thrown away and we had to redo the job. This unlucky event showed that although many people complain about the elevators, there are still many days at which the system works satisfactorily, just like the Dutch Railways. The next measurement day was at November 23^{rd}. This time we had success: many people were waiting! The rescheduling also delayed the measurements from OTIS. So we decided to continue with our own data. We consolidated the counts which gave us a good overview of all the traffic. Next we applied some statistical tests to find out whether the travel demands over the five minute periods could be aggregated into larger intervals with a similar traffic intensity. We started to reconcile the origin-destination matrix in the following way. Hereby, we distinguished between traffic from a main floor (B or T) to another floor, and traffic between two different floors (inter floor traffic). The possibilities were then computed in the following way: Let $h \in H = \{T, B\}$, $v \in V = \{1,2,\ldots,17\}$ indicate the floors. Compute:

$$
\begin{aligned}
&P(h \to h) = 0 \\
&P(h \to v) = \frac{\text{number of people out of an elevator at floor } v}{\sum \text{number of people at all } v} \\
&P(v \to h) = P(\text{no inter floor traffic}) \cdot P(\to h \mid \text{no inter floor traffic}) \\
&P(v \to v) = P(\text{inter floor traffic}) \cdot P(\to v \mid \text{inter floor traffic})
\end{aligned}
$$

Besides measuring the elevator traffic we noticed several other things that effect the performance of the elevator system. If one elevator is out of function, e.g. to be cleaned, the waiting-time increases rapidly. House movers often claim an elevator for some time, thereby increasing the hall waiting-times as well. Furthermore, the actual lift capacity turned out to be much less than the 20 people mentioned in it: with 16 it was already full. Besides these measurements, we also got information from the questionnaire on the internet. First of all, people were asked when the waiting-times (which day of the week and time) were too long and which elevators are involved. Furthermore, we asked one about the most oftenly made movements with the elevators, and one could send emails with suggestions.

Alternatives

As described in the first part, we had to come up with several alternatives for the present situation. This depended on the infrastructure of the building, and the technical possibilities of the elevators. The latter was reasonably large for the large elevators, we could almost adjust every (real) setting for the elevator, such as door closing time, idle floor,

Scenario	Configuration	Idle-floor
1	Current configuration; Change -floor at 6	Low-rise: B, B, 3; High-rise: B, B, 6
2	Low-rise T-3, High-rise 3-17; Change-floor at 3	Low-rise: B, B, 3; High-rise: B, B, 3
3	Low-rise T-5, High-rise 5-17; Change-floor at 5	Low-rise: B, B, 3; High-rise: B, B, 5
4	Low-rise T-7, High-rise 7-17; Change-floor at 7	Low-rise: B, B, 3; High-rise: B, B, 7
5	Low-rise T-8, High-rise 8-17; Change-floor at 8	Low-rise: B, B, 3; High-rise: B, B, 8
6	Low-rise T-9, High-rise 9-17; Change-floor at 9	Low-rise: B, B, 3; High-rise: B, B, 9
7	Low-rise T-9, High-rise 6-17; Change-floor at 6, 7, 8 and 9	Low-rise: B, B, 7; High-rise: B, B, 8
8	All elevators stop al all floors (door closing time 11 s.)	B, B, B, B, 3, 14
9	All elevators stop al all floors (door closing time 13 s.)	B, B, B, B, 3, 14
10	All elevators stop al all floors (door closing time 14 s.)	B, B, B, B, 3, 14
11	3 elevators stop at T, B and even floors, 3 elevators stop at T, B and odd floors	Even: B, B, 8 Odd: B, B, 7
12	2 stop at even, 2 at odd, 2 at all floors; Change -floor at 7, 8, 9	B, 8, B, 7, B, 8
13	2 Low-rise T, B, 1 -5; 2 Middle -rise T, B, 5 -13; 2 High-rise T, B, 13 -17; Change-floor at 5 and 13	B, 3, B, 7, B, 13

Table 1: List of alternatives to be investigated by simulation

etc. It was also possible to let different elevators stop at specific floors only. For the small elevators, less was possible. Because these elevators were to be renovated anyway, we only investigated one alternative for these elevators, namely another idle floor for both these elevators. Table 1 lists the alternatives for the large elevators which were to be investigated by simulation.

Simulation modelling

The next step was to build a simulation model. The three student groups looked at several ways to program it. There was a choice between a simulation program and a general purpose language. One group chose the first option, and modeled the problem in the simulation language Arena®. Another group chose the general purpose language Delphi® and the last group tried its luck in the general language Visual Basic®.
In all cases it was agreed to use the same input files. That is, from the data analysis we constructed a nonhomogeneous Poisson model describing the arrivals of people at the various floors. It was agreed that from this model we would generate ten sets of some 2000 people arriving at various moments at the different floors and that every program and every scenario within it would consider the same set of people, thereby reducing the variance considerably.

Modeling the problem in Arena was tried for several weeks, but the program did not support the needs the students had. Therefore this group continued with the data-analysis while the other two groups continued programming in the general purpose languages.

We made the simulation event-driven, which means that the simulation model reacts on each event, takes care of that and continues with the next event (notice that in this way it is difficult to change already taken decisions later). This made it possible to change many things in the settings of the program, and all the proposed alternatives could be easily tested.

In short, we will look at the several simulation elements used. First, collections like elevator-numbers, directions, time-horizons, floors in building, floors where an elevator can stop and states of the passengers are defined. Second, the entities are people and elevator (server) are defined. People with attributes arrival time, starting floor, destination, waiting time, service time, number of stops and time when the destination is reached. The elevators have as attributes number, position, direction, capacity, idle floor, number of persons in elevator, and the identities of these persons. The resources for the simulation are a group of elevators, serving the same waiting queue. These queues had as attributes floor, direction and number of persons with their own ID. The events in the model are the arrivals of persons and the stops of elevators. The global variable is the time, to make an event driven simulation work. The main decision which has to be taken in the simulation is the allocation of a waiting person to an elevator. One may say that the elevator which reaches the person first should be the one, but it is not that simple, as also the direction of the elevator and the destination of the person are of importance.

One can calculate how long it may take for all elevators to reach that person and take the one with the shortest time. In this one has to take into account a possible turning of the direction of an elevator (for which a time penalty is used). Moreover, as OTIS indicated to us, it is advantageous to use already moving elevators above non-moving elevators as those may then react on a second call. We therefore also introduced a time penalty for non-moving elevators. In the simulation it is quite useful to allocate an elevator directly upon the call of the person. In reality this is e.g. done in the Far East where people can then be warned long ahead of the position of the coming elevator. It may happen however, that due to some new events, e.g. another person calling the elevator, the original elevator is no longer the earliest to reach the original call. Hence one might opt for a changing of the allocation. This is called cancellation and it is also really applied in western countries. The problem however, is when to do the cancellation and when to fix the allocation. This gives some problems in the simulation, but both groups managed to incorporate it. Finally, there are also two other concepts of importance. The first is the choice of the base floor. Both elevator systems in the H-Building use the terrain floor as base floor. This means that the elevator first always go to that floor before turning. This gives strange situations of elevators going down and letting people out at the ground floor while there are people waiting there to go up. They often try to peep into this elevator, to find out that it first goes down (without any other persons) before going back to the ground floor. This double opening of the doors is often a severe annoyance in the small elevators. Another choice of the base floor would resolve this problem. The

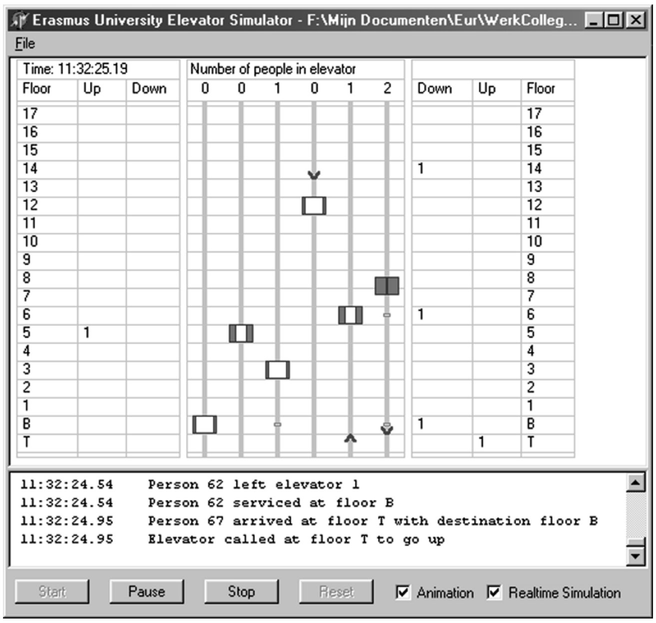

Figure 1: screen shot of one of the programs

second concept is empty positioning, that is, what should the elevators do when being empty without a call. Theoretically (see e.g. Egbelu and Wu (1998)) it can be shown that it is better to choose certain positions so that a next call can quickly be served. For the small elevators it is currently the terrain floor and the 11th floor (it is not optimal to stay at the same position). This concept is also used in more complex transportation systems (like taxis) and is generally much more difficult to determine than over here. As the time was limited the groups just assumed that the elevators were spreading out evenly over the building. As the large elevators were quite busy during lunchtime, the concept did not have much effect for them.

The standard simulation aspects were applied in the running of the programs (see Kelton et al. (1998) and Law and Kelton (1991)). A start-up and cool-down period of 5 minutes was used. Ten runs were made, and this was enough due to a low variation between the several runs. After a verification and validation of the model, we looked at the several alternatives we defined. The simulation was animated and in figure 1 one finds a screen dump of one of the programs (made by Peter-Jan Roes).

Results from the Questionnaire and the simulation

We will now discuss some results of the questionnaire, followed by the results of the simulation. The questionnaire was filled in by 93 staff members and 264 students. Staff have their own floor between 6-17, students are to find at the third floor (PC Lab) and sometimes at the fifth (student associations). Most of the time, the current change-floor was considered to be the best possible. But the option of no change-floor at all (this yields every elevator stops at every floor) was opted for as well. The lunch-time is found to be the worst time of the day to use the elevators. More staff than students complain about the elevators, which means that the waiting time for the high-rise is probably more irritating.

Scenario	Waiting time (s)	Lift time (s)	Service time (s)	Max (waiting.time)	# stops
1	44.03	48.56	92.59	335.38	2.82
2	117.22	59.15	176.37	1643.75	3.57
3	55.45	50.97	106.42	480.48	2.99
4	44.59	48.38	92.97	309.14	2.80
5	45.05	47.71	92.76	298.77	2.49
6	46.41	47.19	93.6	269.06	2.72
7	45.61	46.74	92.35	288.16	2.69
8	**30.23**	48.10	**78.33**	**177.97**	2.77
9	40.55	56.32	96.87	239.97	2.95
10	47.64	60.90	108.54	312.06	3.04
11	56.51	45.08	101.59	310.45	2.50
12	45.61	46.74	92.35	288.16	2.69
13	56.14	**42.80**	98.94	352.26	**2.35**

Table 2: The results of one of the groups

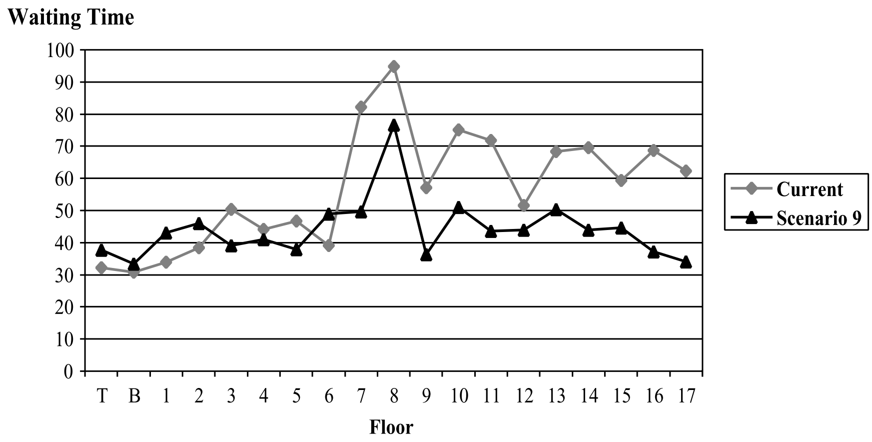

Figure 2: Waiting time over all the floors in these two different scenarios

Once the programming was finished (which was again a tough job, but nicely done by the programming cracks) the results were obtained quickly. In table 2 we show the results of one of the groups. The results of the other group were some 20% (!) higher, due to some small differences in the assumptions (e.g. a non-constant door opening time, etc.). Yet the ranking of the alternatives appeared to be the same for both groups. This shows again that one should not put great faith into the absolute outcomes of simulation programs!

Scenario 8 – no partitioning, indicating that the elevators could stop at all floors, turned out to have the lowest waiting and the service time. Yet this implies that people may have to move some distance to catch an elevator. If we increase the door closing time with two more seconds (scenario 9), the no-partitioning option is still best. But if we increase it with another second (scenario 10), then the current scenario (scenario 1) is not that bad at all. This scenario then yields a better service time (4 seconds off). An advantage of the no-partitioning concept is that the waiting time is better divided over the different floors. This may also be an explanation why the no-partioning is that good as some authors (e.g. Newell 1998) state that partioning is in general to be preferred over non-partitioning. This is shown in figure 2, where we can see the waiting time over all the floors in these two different scenarios.
We can see that there is not very much difference between the scenarios where the elevator changes from low-rise to high rise at different floors (scenario 4 – 7). If we look at the even-odd-all division, there is not much difference with the current scenario.

For the small elevators it appeared that the theoretical waiting time was reasonable, some 20 seconds, while the average lift time was some 27 seconds. By changing the base floor to ground these times could be reduced with some 10%. Yet if one elevator is not able to work, the waiting time increases to 80 seconds. Hence we concluded that no other actions were needed (apart from changing the base floor to ground) as long as elevators are not taken out of service during peak hours.

Follow-up

After a presentation of each of the student groups to each other, we scheduled an appointment with the faculty director. We gave him a presentation of 30 minutes, where we've shown the results of this research. For our work done in the elevators (the counting of users of the elevators) and the whole research, we received a book token of 100 guilders each. This was very generous of the faculty-director, and we sure do hope that he will use the results of this research. A month later, there was an appointment with OTIS. Here, we give about the same presentation. At the moment of writing, the elevators are being overhauled. The reaction of the university's technical department (MTB) was somewhat reserved, as if they did not expect anything good from students.

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