Design and Analysis of a Tool for Planning and Simulating Dynamic Vertical Transport

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Nowadays, most of the main companies in the vertical transport industry are researching tools capable of providing support for the design process of elevator systems. Numerous decisions have to be taken to obtain an accurate, comfortable, and high-quality service. Effectively, the optimization algorithm is a key factor in the design process, but so are the number of cars being installed, their technical characteristics, the kinematics of the elevator group, and some other design parameters, which cause the selection task of the elevator system to be a complex one. In this context, the design of decision support tools is becoming a real necessity that most important companies are including as part of their strategic plans. In this article, the authors present a user-friendly planning and simulating tool for dynamic vertical traffic. The tool is conceptualized for giving support in the planning and design stage of the elevator system, in order to collaborate in the selection of the type of elevator (number, type of dynamic, capacity, etc.) and the optimization algorithm.

Keywords: Vertical transport, elevator, lift, simulation

1. Introduction

Traditionally, the elevator controller implemented dispatch rules that made use of IF-ELSE logical command sets. These dispatch strategies still work reasonably well for small buildings. However, the installation of synchronized elevator groups in professional-use buildings (offices, hospitals, or hotels) and in medium-size or larger buildings is today a usual practice. In fact, the existence of high buildings makes the management of the traffic extremely difficult, as well as the prediction of the effects of the elevator group control and traffic performance.

It has been said that only for morning peak (up-peak) situations, where passengers arrive at the entrance floor and travel to the upper floors, can the elevator traffic be calculated analytically [1]. For other traffic situations, such as interfloor or lunch-peak traffic, the type of controller strongly affects the passengers' quality of service. It is even more unpredictable when nondeterministic methods are used to try to improve the quality of service.

Along this line, numerous algorithms have been designed and patented to improve the passengers' service quality in elevator systems. Most of them include artificial intelligence elements. Among them, we can find algorithms based on learning, such as the controller *Neuros-I* [2] of Fujitec, which is a neural network where the group elevator state and the lift state are inputs for the neural network. The network has previous learning and subsequent adaptive auto-tune online learning. Also, within the learning framework, reinforcement learning algorithms [3] have shown an accurate behavior. They consist of a semi-Markovian process and use an agent team where each agent controls one lift. Under these conditions, two architectures are used: a parallel architecture, where the agents share the network (RL_p, parallel reinforcement learning), and a decentralized architecture, where each agent has its own network (RL_d, decentralized reinforcement learning).

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Fuzzy logic has proved to be a valuable alternative when evaluating a large amount of criteria in a flexible manner. The fuzzy elevator group control system [4] and the fuzzy elevator group controller with linear context adaptation [5] are some examples where diverse criteria are used, such as the $HCWT_i$ (hall call waiting time for the i-lift), the $maxHCWT_i$ (maximum hall call waiting time), the CV_i (capacity of coverability for next calls for the i-lift), and the minimum distance between new calls and the last calls allocated GD_i (gathering degree). Also along this line, genetic algorithms [6, 7] have been used with success to adjust the control settings (a set of criteria) to give robustness to the elevator group control system, within a set of a great variety of control parameters. These works allow adjusting the control settings according to individual floor utilization situations, making use of a combination of car and floor attributes.

Evolutionary systems have also revealed successful capabilities to maximize the efficiency of the elevator system call allocation. Genetic algorithms [8, 9] have been designed within a discrete event simulation that tries to predict the optimal decisions for the car dispatch. Both are short papers with only a brief explanation of the methods used and with an additional difficulty when trying to identify the criterion used for assessing the quality of the solutions (by means of a performance index). However, the authors state the validation and success of the implementation by the representation of diverse figures and graphics. Also, a recent study [10] describes a genetic algorithm to maximize the call allocation efficiency and to reduce the overall system waiting time (the authors name it GAHCA). It is a genetic algorithm based on a hall call allocation strategy to identify the chromosomes of the population individuals. In the article, GAHCA was compared with conventional duplex controllers of the industry in a discrete event simulation scenario.

In fact, the design of such complex control and optimization algorithms in dynamic systems subject to the influence of noncontrollable variables, which are typical in vertical traffic systems, needs decision support tools that help the designer of elevator systems. According to these aspects, simulation becomes a practical tool to demonstrate the validation and accuracy of the methods and techniques as a previous step to the physical and real implementation. Not many papers can be found in this field. The most complete research on the field is due to M.-L. Siikonen (see, among others, [1, 11, 12]), a significant specialist in it and author of several relevant papers. Grötschel et al. [13] provide another technical paper from the Konrad-Zuse-Zentrum für Informationstechnik of Berlin that deals with the elevator simulation problem. Finally, in the previously referred study [10], the well-known Arena© simulation software is used to simulate the effects of the genetic algorithm proposed.

But the controller algorithm is not only a key factor in the design process; the number of cars being installed, their technical characteristics, the kinematics of the elevator group, and some other design parameters also cause the selection task of the elevator system to be a complex one. Along this line, the design of decision support tools is being considered an actual necessity that most important companies are including as part of their strategic plans.

In this article, we present a tool (named SimMP) capable of planning and simulating dynamic vertical traffic. SimMP is conceptualized for giving support in the planning and design stage of the elevator system, in order to collaborate in the selection of the type of elevator system (number, type of dynamic, capacity, etc.) and the optimization algorithm. It is a user-friendly planning and simulating tool that allows navigating through graphical interfaces and appreciating a visual simulation of the system, while obtaining complete and detailed results for the parameters and set of characteristics selected. SimMP is a tool that has been developed for the MAC PUAR S.A. Company (MP) by the Ingeniería de Organización research group of the University of Seville.

The rest of the article follows with the second section dealing with the architecture and functional requirements. It is a detailed section that explains the main facilities of the tool. The third section compares the main simulators known in the vertical transport industry. The fourth section is dedicated to the analysis of a concrete case study, and finally we highlight the main conclusions in the final section.

2. Architecture and Functional Requirements

SimMP has been designed using Borland C++ Builder 6 and must be run on Windows NT or Windows XP platforms. It requires minimum hardware specifications, such as a Pentium 600 MHz or equivalent with 64 MB RAM. With these conditions, a satisfactory performance is expected.

Figure 1 depicts the main aspects of its architecture.

The tool has a database set with adaptable configurations for several types of buildings (with diverse typologies, such as housings, professional uses, etc.), as well as different elevator technologies and functional specifications. A database for feasible traffic is also loaded. However, the user can modify or create new data for all these aspects.

The system includes a set of optimization algorithms. Nevertheless, the user can design any kind of optimization algorithm according to the specifications of the *dll* input file, which allows the correct performance of the simulation engine.

SimMP output includes graphical and text reports that allow the user to select among diverse tests for alternative configurations of the elevator group characteristics and/or the elevator controller.

The tool includes an advanced configuration interface, as well as a quick start option with most of the values preselected. The advanced aspects are detailed and discussed in the next subsections.

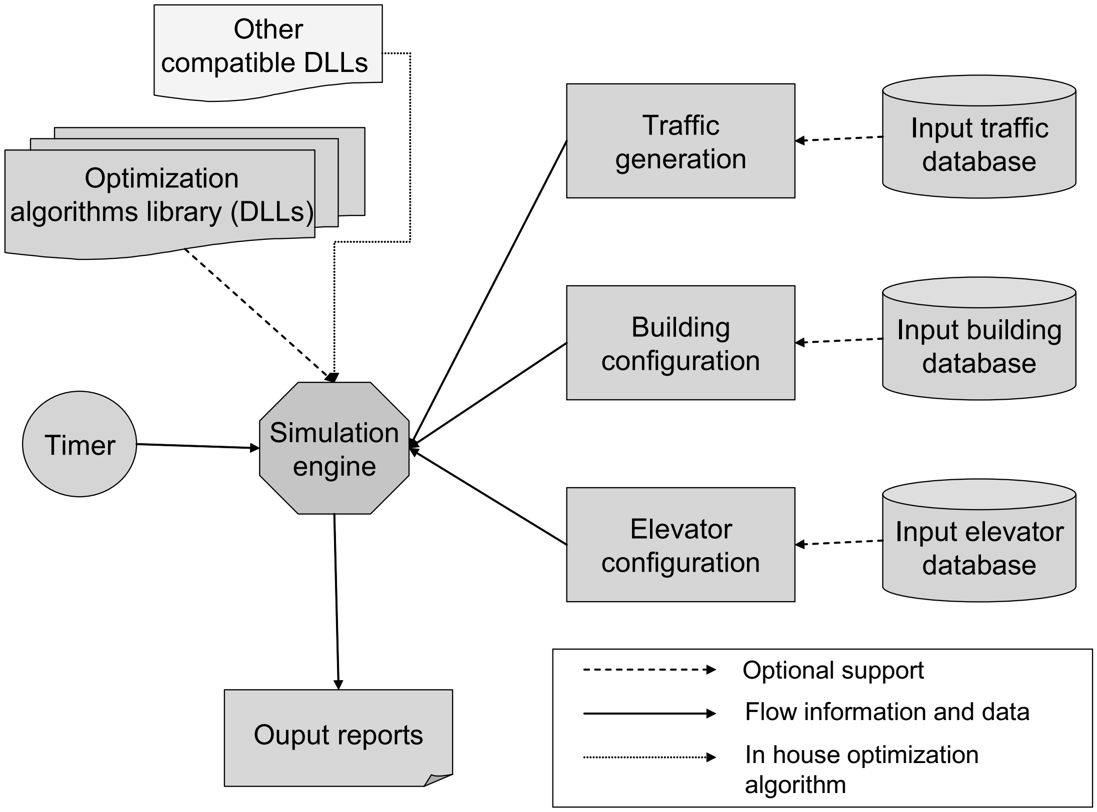


Figure 1. SimMP architecture

2.1 Building Configuration

The building data can be accessed by means of the `Configuration` option in the menu bar and selecting `Building` or by directly clicking on the icon from the tool bar. The building configuration screen is depicted in Figure 2.

The building can be configured manually or by selecting an available configuration. To do so, a display changes `manual` to the list of available configurations.

In the case of selecting a user configuration, the system allows the following to be stated:

- Number of floors
- Number of entrance doors (i.e., the option of considering different boarding gates for one specific car). For example, in this case, several buildings (or different parts of the same building) are being served by the same elevator group.
- Typology of building. SimMP considers different types of buildings: housing, office, housing with offices, hotel, hospital, shopping centers, and so on.

After that, each floor's characteristics can be selected:

- Name of the floor. It can be the basement, the ground floor, the attic, or any other floor
- The position of the floor (e.g., the height in meters with respect to the ground floor)
- The separation of the floor with respect to the other adjacent floors. The tool warns the user in case of separations lower than 2 meters with yellow color and red color for separations lower than 0 meters.
- Data relative to the entrances (note that more than one can be acceptable for each car)
  - Typology (housing, office, hotel, etc.) of the entrance
  - Potential population in the entrance access

Another option for a quick generation is using the button `Create Building`. In this case, a menu is displayed, and the user is only required to select the number of floors, number of basements, generic separation between floors,

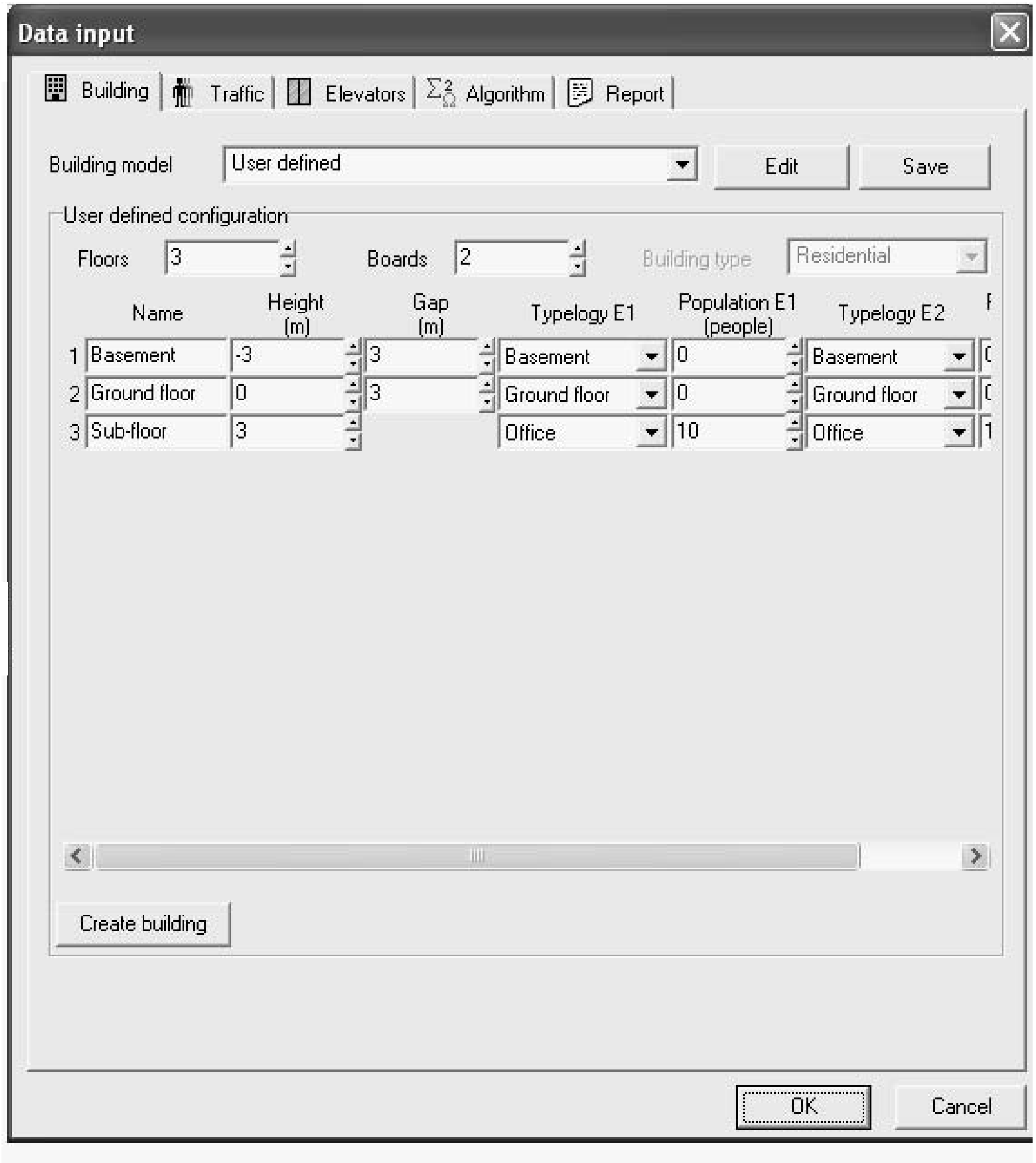


Figure 2. Building configuration screen

typology of the building, and average population by floor. Figure 3 shows the quick building generation button.

Finally, every configuration can be saved with a file extension *.edi*, and every saved configuration can be edited.

2.2 Traffic Generation

The traffic data are accessed by selecting `Configuration` in the menu bar and then the option `Traffic` or directly by clicking on the icon from the tool bar. The traffic configuration screen is shown in Figure 4.

The screen is divided in two different sections. The first one corresponds to the passenger characterization, and the second one is concerned with the traffic pattern definition.

In the passengers' section, the average weight, the door crossing time for entering and leaving the cars, the capacity factor that prevents passengers from loading the elevators up to their rated capacity, and the stair factor for those passengers preferring the stairs to the elevators should be selected.

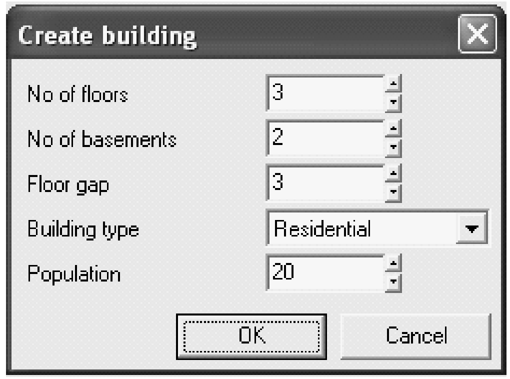


Figure 3. Quick building configuration

The traffic pattern configuration can be constructed in a simple mode or in an advanced one, as follows.

The *simple mode* defines only up-peak, down-peak, or lunch-peak traffic rates. The up-peak pattern consists of a traffic main stream from the ground or basement floors to the rest of floors. The down-peak pattern consists of a main stream from the floors to the ground and basement. Finally, the lunch-peak pattern takes place at the lunch hours with a mix of the up-peak and down-peak situations. Figure 5 depicts the options for the lunch-peak case. In the figure, the up-peak and down-peak rates are selected, and the percentage traveling to the basement or ground floor must be stated.

Also, the configuration of the traffic can be selected using the peak pattern option. Unlike the constant arrival rate option, the peak pattern option allows the traffic characterization by means of a function constructed from the peak rate (maximum arrival rate in passenger/minute or percentage of the population per floor every 5 minutes), the basic rate (constant arrival rate for the simulation period), and the peak width (peak duration expressed in minutes). Figure 6 shows the screen for this option.

The *advanced mode* allows a more detailed description of the traffic. The user must select the arrival rate of passengers every 5 minutes per floor. After that, their destinations must be selected for each floor and entrance, as a probability percentage. It should be done for every 5-minute interval of the simulation period, but a fast-fill option can be used: the option consists of completing the data for the first 5-minute interval and then extending the same pattern to the rest of the intervals. Figure 7 depicts the screen options. The tool warns the user when the sum of the percentages is not 100% (with diverse colors).

To generate the traffic, we followed the *CIBSE Guide D* for transportation systems in buildings [14], which states the commonly accepted rules to design building services from an engineering perspective. It states as generally accepted that a Poisson process reasonably approximates the arrival of passengers (individuals) at a lift landing station. This gives the following result:

$$p\,(n)_{i,j} = \frac{\left(\lambda_i \mathrm{INT} d_{i,j}\right)^n}{n!} e^{-\lambda_i \mathrm{INT} d_{i,j}}, \qquad (1)$$

where $p\,(n)_{i,j}$ is the probability of n passengers wanting to travel from floor i to floor j during the time interval INT, where INT is the system interval when the arrival rate is equal to λ_i. Here it is important to note that the nonstationary Poisson traffic is created by thinning a Poisson stream, which is generated with the maximum arrival rate found in the observation interval (see, e.g., [15]).

When calculating probabilities, to determine the probability of an event happening, it is sometimes easier to calculate the probability of the event not happening and subtracting this from the unit. So, let

$$p_{i,j} = p\,(0)_{i,j}\,, \qquad (2)$$

which is the probability of no calls from the ith to the jth floor in the time interval INT.

From equation (1),

$$p_{i,j} = e^{-\lambda_i \mathrm{INT} d_{i,j}}. \qquad (3)$$

Applying this result, formulas for the probable number of stops and the lowest and reversal floors are derived (see *CIBSE Guide* [14] for details), as well as the calculus of the round-trip time.

The case of the simple mode uses one unique maximum arrival rate (λ) for the whole simulation period, and the advanced mode allows different maximum arrival rates (λ), one for every 5-minute slice. These suppositions are a common base for all vertical traffic simulators. In particular, we have followed in these aspects the same specifications of the Elevate™ software [16].

Finally, every configuration can be saved with a file extension *.tra*, and every saved configuration can be edited.

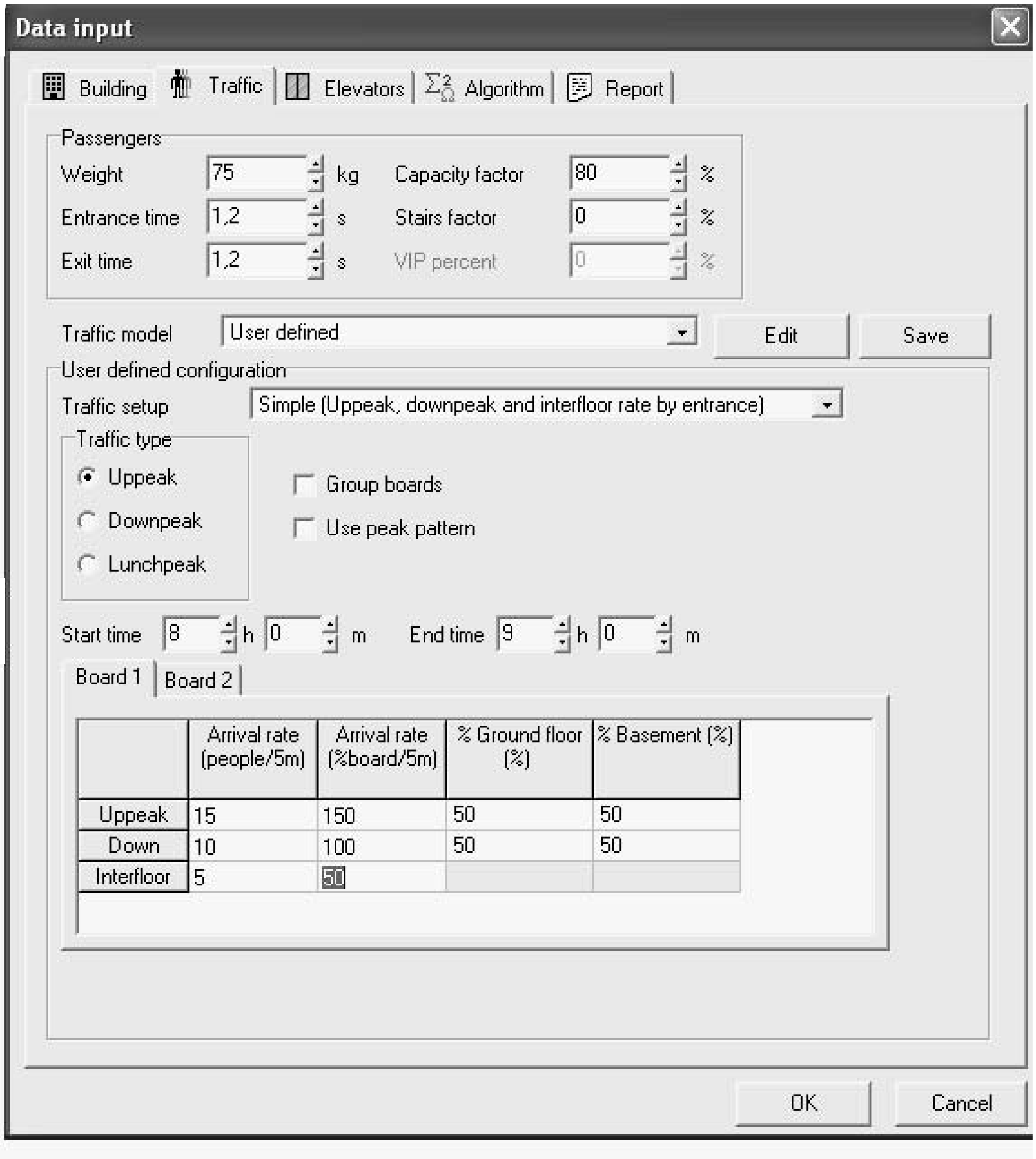


Figure 4. Traffic configuration screen

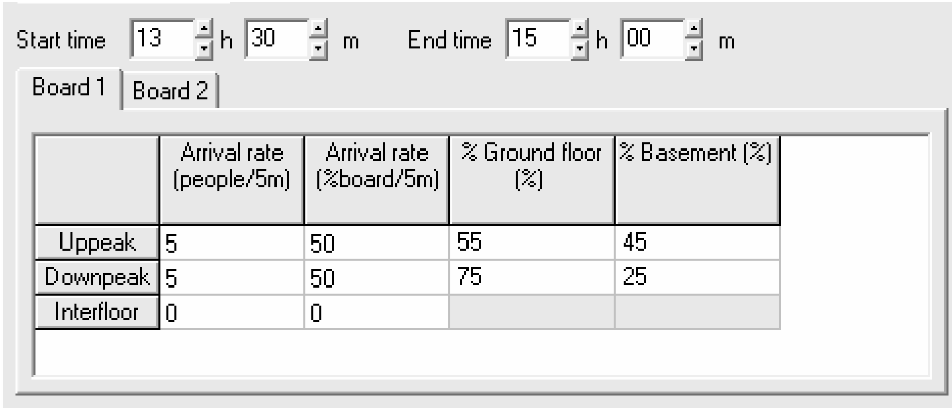
2.3 Elevator Group Configuration

The elevator group data are accessed by selecting `Configuration` in the menu bar and then the option `Elevators` or directly by clicking on the icon from the tool bar. The elevator group configuration screen is shown in Figure 8.

The control box, located on the top-left side, allows the selection of the number of elevators in the group for the simulation. The tool can also be used to select different options for the elevator group. Then the system simulates all the options providing the different results.

This screen also allows the selection of floors with access forbidden. The button *Closed Board* is located on the top-right side.

The rest of the screen states the main parameters of the elevator group. The tool allows editing an existing configuration, and it also allows selecting the following:

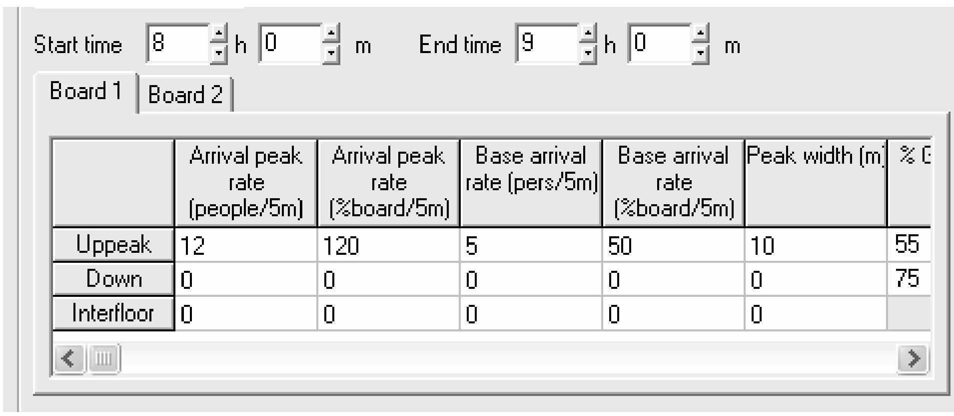


Start time 13 h 30 m End time 15 h 00 m

Board 1 | Board 2

	Arrival rate (people/5m)	Arrival rate (%board/5m)	% Ground floor (%)	% Basement (%)
Uppeak	5	50	55	45
Downpeak	5	50	75	25
Interfloor	0	0		

Figure 5. Lunch-peak traffic configuration using constant arrival rate



Start time 8 h 0 m End time 9 h 0 m

Board 1 | Board 2

	Arrival peak rate (people/5m)	Arrival peak rate (%board/5m)	Base arrival rate (pers/5m)	Base arrival rate (%board/5m)	Peak width (m)	% G
Uppeak	12	120	5	50	10	55
Down	0	0	0	0	0	75
Interfloor	0	0	0	0	0	

Figure 6. Up-peak traffic configuration using peak pattern

- *Capacity* of the elevator. Different capacities can be used to test the different options.
- *Door times*. The door preopen and door open times indicate the instant when the elevator car is level at a floor to the instant when the doors are fully open. Door dwell 1 indicates the time that the doors wait until closing if the passenger detection beam across the door entrance is not broken, and door dwell 2 indicates the time that the doors wait until closing after the broken passenger detection beams are cleared.
- *Kinematics* of the elevator group. The tool considers two different types: two-speed and 3VF kinematics.
  - Two-speed kinematics is characterized by the starting delay (the interval between the door closed and the start of the car), the nominal speed (maximum speed in steady state), the slow speed (reduced speed when approaching the destination floor), and the slow time (time interval with the elevator traveling at low speed). Figure 9 depicts the kinematics for this case.
  - 3VF kinematics is characterized by the starting delay (the interval between the door closed and the start of the car), starting acceleration, nominal speed (maximum speed in steady state after accelerating), stopping deceleration, slow speed (speed after the deceleration stage), and the slow time (time interval with the elevator traveling at low speed). Figure 10 depicts the kinematics for this case.

Finally, every configuration can be saved with a file extension *.asc*, and every saved configuration can be edited.

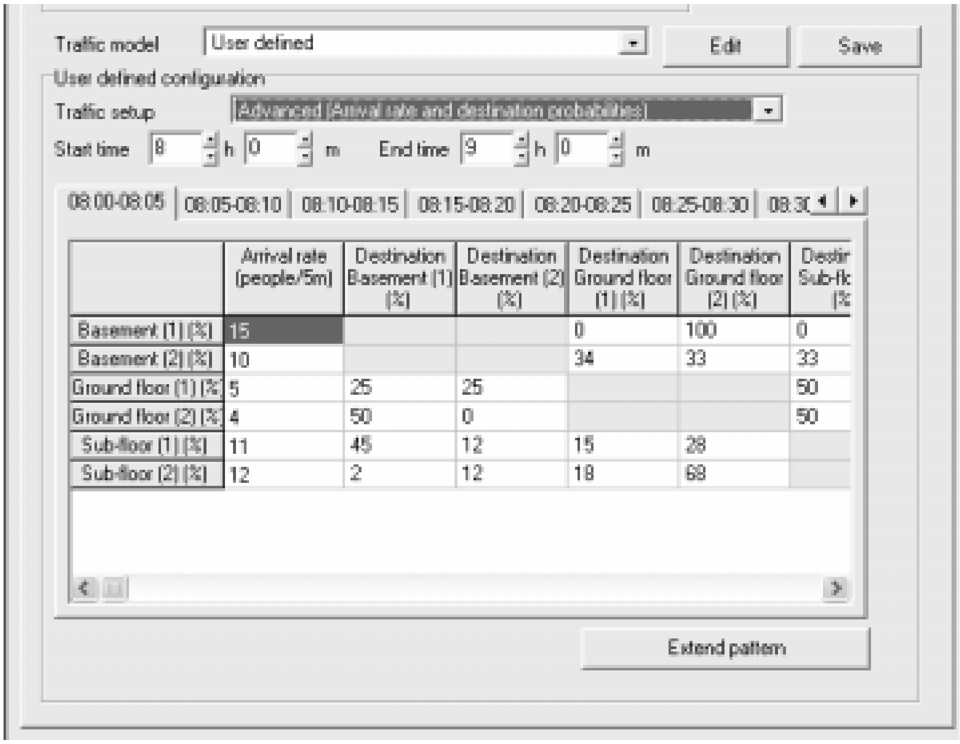


Figure 7. Traffic pattern advanced configuration

2.4 Optimization Algorithm Configuration

The optimization algorithm configuration is accessed by selecting `Configuration` in the menu bar and then the option `Algorithm` or directly by clicking on the icon from the tool bar. The screen is shown in Figure 11.

The screen has a display that allows selecting the set of algorithms from the dynamic link library or selecting any other *dll* input file with the appropriate format.

Figure 11 shows the configuration parameters for one algorithm from the Microbasic® algorithms family. The option includes the down-collective, up-collective, or full-collective options powered with up-peak or down-peak additional controls together with a longest waiting time control.

2.5 Animation Zone

Once the data have been introduced in the simulation and planning tool, the animation starts by clicking on the *play* icon from the tool bar. Figure 12 shows an instance of the simulation screen. The screen allows monitoring the evolution of the building's vertical transport life for the time period simulated.

The top-left side of the window gives information related to the timer, round-trip time (RTT), and average waiting time (AWT) for passengers whose calls have already been answered. The top-right side gives information related to the physical location of the cars, their speeds, and load.

In the middle of the screen, a friendly image of the simulation scenario is displayed. The visual information includes the queues to the entrances of the floors, the number of passengers traveling in the cars, and the evolution of the cars through the building.

On the lower side, the simulation's progress and the basic configuration data being simulated are shown.

The animation can be controlled by pausing the simulation, forwarding, rewinding, accelerating, and decelerating, so the processing can be accelerated at maximum in seconds. Also, zoom and adjusting buttons are available.

2.6 Output Text and Graphical Report

The report configuration is accessed by selecting `Configuration` in the menu bar and then the option `Report` or directly by clicking on the icon from the tool bar. When configuring the report, the user should indicate the specific reports to be generated (see Figure 13).

The options include the following:

- Global results:

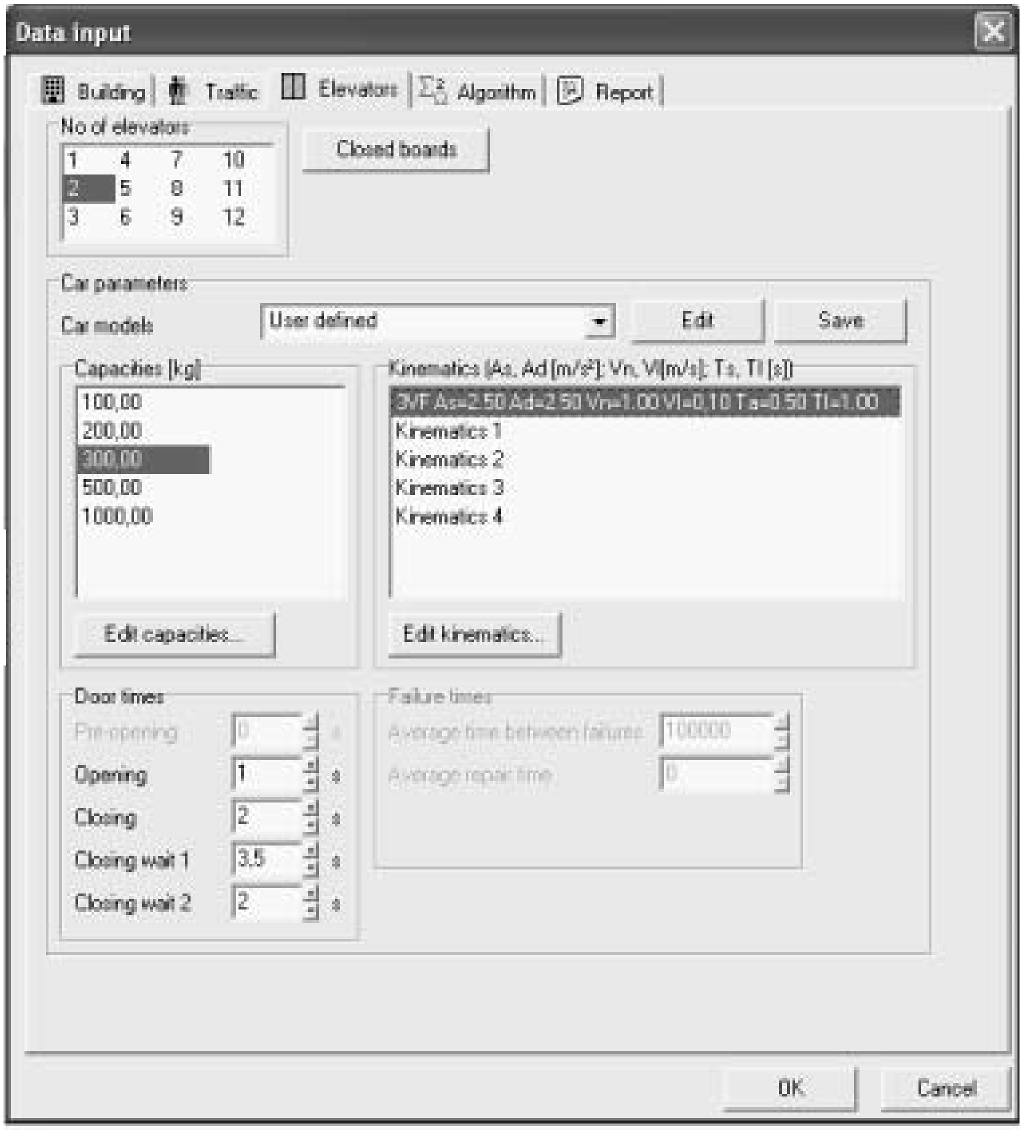


Figure 8. Elevator group configuration screen

- *Waiting time*. It is the average time for passengers whose calls have already been served.
- *Trip (or journey) time*. It is the time of passengers traveling inside the car.
- *System (or total) time*. It is the average time of passengers who have already completed their journey. It includes the waiting time plus the trip time.

• Elevator results:

- *Position*. It shows the position of the elevator during the simulation.
- *Load*. It shows the load transported by the elevator during the simulation.

• Floor results:

- *Queue size*. It indicates the queue size for each floor entrance.
- *Arrival rate*. It indicates the arrival rate at the entrances of the floor.

The report screen includes possibilities for filtering the results according to a bounded longest waiting (or system)

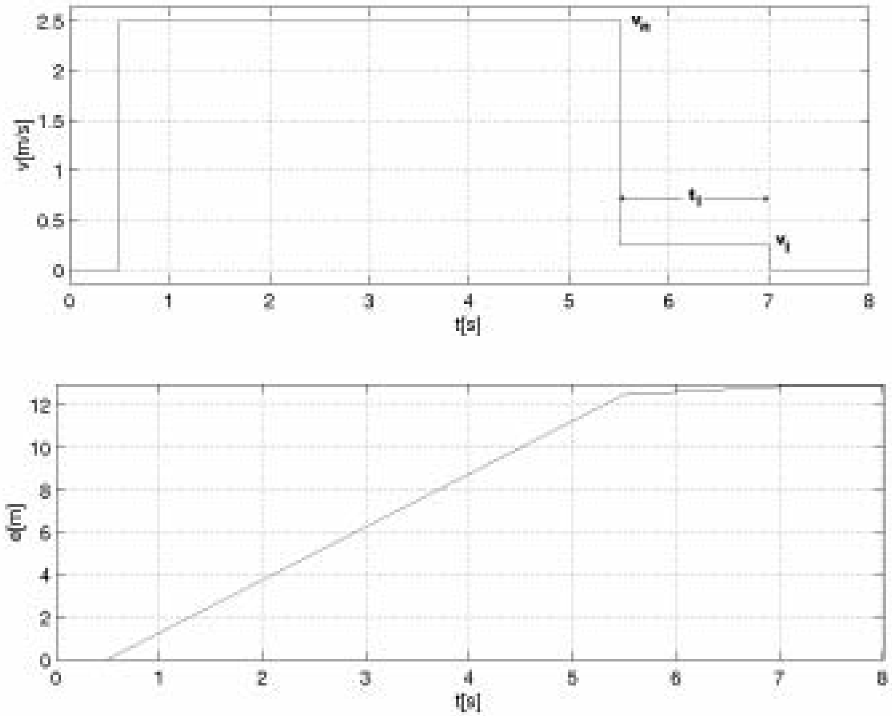


Figure 9. Speed (upper graphic) and distance for two-speed kinematic

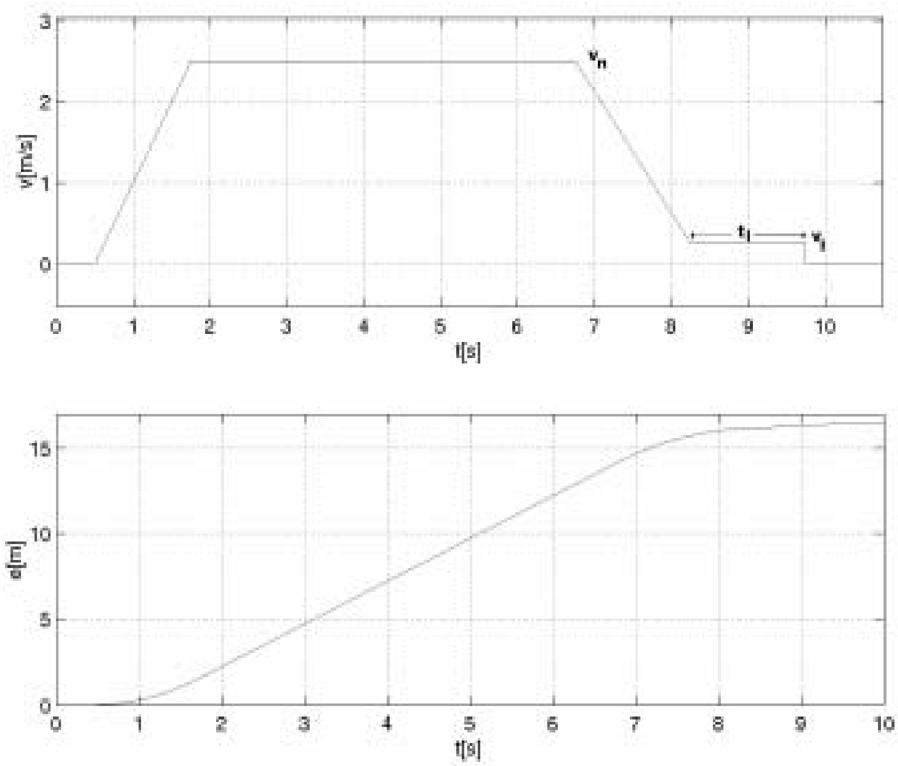


Figure 10. Speed (upper graphic) and distance for 3VF kinematics

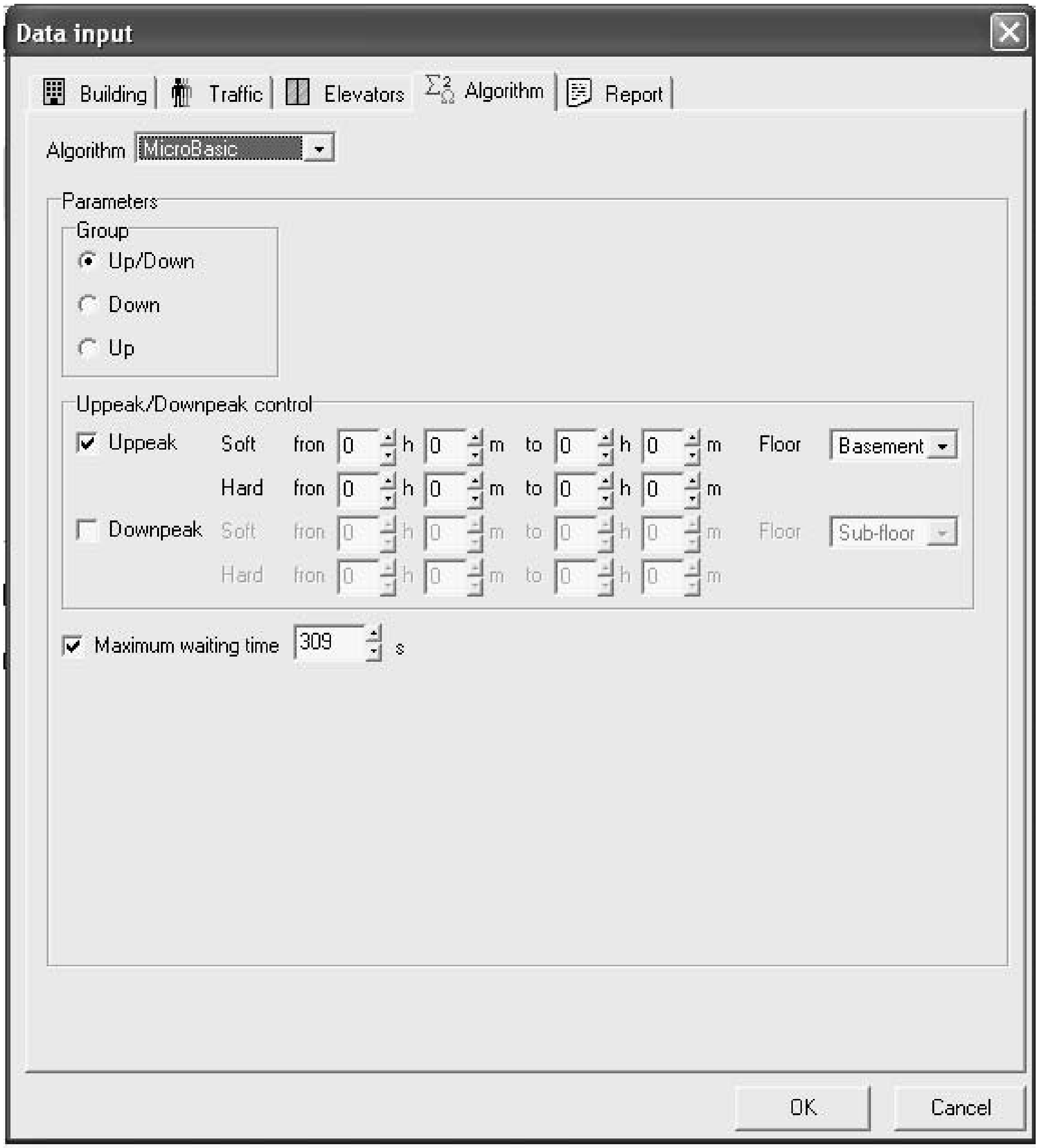


Figure 11. Control and optimization algorithm configuration screen

time and sorting the results by AWT or average system time (ATT). The report file can be saved as a *pdf* file.

An example of the report output is described in section 4, which is dedicated to a case study.

3. A Comparison between SimMP and Other Vertical Traffic Simulators

In this section, we compare SimMP with three other vertical traffic simulators. One of them is freeware (Personal Computer—Lift System Design [PC-LSD], developed at the University of Manchester Institute of Science and Technology), and another is a commercial software (Elevate™, commercial software from Peters Research, Ltd.). An exhaustive comparison between Elevate™ and PC-LSD can be found in Barney [17], and for a detailed description about Elevate™, see Caporale [16]. The Elevate™ software is mainly based on Dr. Peters's developments, and it is commercialized by Peters Research, Ltd. The main characteristics of Elevate™ are introduced in Peters [18].

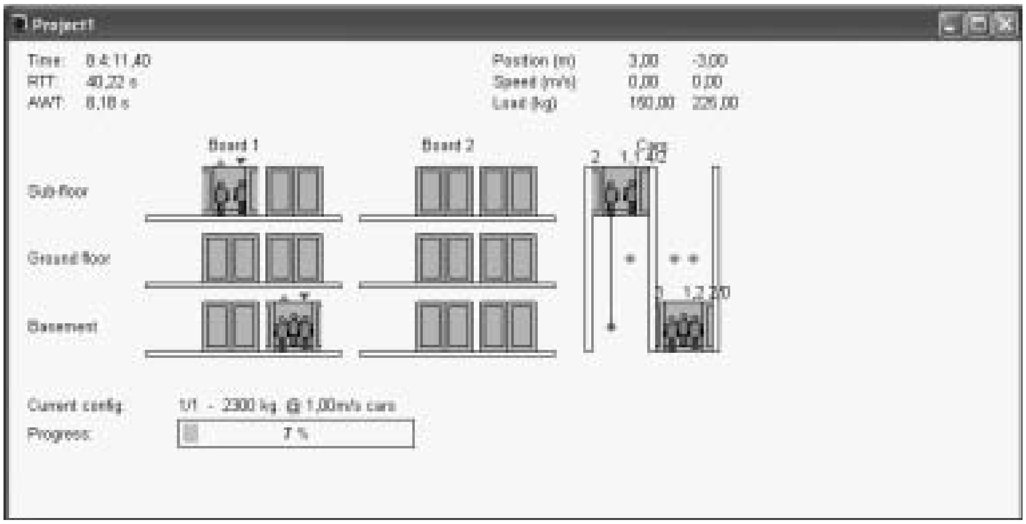


Figure 12. Animation zone: simulation screen

The rest of the simulators are the property of private companies. Along this line, we have included ALTS (Advanced Lift Traffic Simulator) in the analysis, a simulator that was created by KONE Corporation in cooperation with the Systems Analysis Laboratory of the Helsinki University of Technology. From 2001 to 2003, KONE developed BTS (Building Traffic Simulator), a new tool that improved ALTS and that included building evacuation analysis. We include the comparison for ALTS/BTS with respect to the characteristics that have been published related to these simulators since the tool is the property of a private company and is not open to public domain. Finally, we include our SimMP.

Table 1 summarizes the main characteristics of the different simulators analyzed.

Table 1 compares the characteristics of the three simulators that we have been able to find explained in depth in the scientific literature. However, there are other simulators that are the property of private companies. OTISPLAN® from Otis [19] is an online elevator planning tool used by Otis sales associates that comprises three major applications: (1) single-group performance tool for calculating up-peak round-trip time, interval, and handling capacity; (2) multiple-group optimization for determining good banking arrangements for high buildings requiring two or more groups; and (3) dispatcher performance simulation for evaluating performance of individual Otis controllers against two-way and down-peak traffic. However, most of the parameters that are marked in Table 1 are not specified, so we have not been able to include it in the comparison table. Also, Schindler Lifts, Ltd. has been involved in simulators for elevator systems. Project HILS (Hardware-in-the-Loop Simulator for Elevator Systems) is an example of the company's activity in this field. However, not much information has emerged from these types of initiatives in scientific publications.

4. Case Study

To experiment some of the facilities of SimMP, we consider a case study in this section. Let us consider the case of a building with seven levels (including the ground floor, a basement, and five floors, with the first one dedicated to offices and the rest for residential use). The population per floor is 10 people and 40 people in the office floor.

The traffic considered is lunch peak for a time interval between 13:30 and 15:30 hours (a typical Spanish lunch schedule). The arrival rate for the up-peak stage is equal to 20 passengers every 5 minutes, and the arrival rate for the down-peak phenomenon is equal to 10 passengers every 5 minutes. The passengers' transit time is considered equal to 1.2 seconds, and a capacity factor of 80% has been considered. We do not consider a stair factor for this case study. This arrival data were lightly varied to appreciate modifications in the expected results. After examining the results, we could note that the elevator group systems evaluated were robust enough with respect to changes in the arrival data.

We want to analyze the effects of installing two or three cars for the elevator group. We consider a 300-kg capacity for the cars. The kinematics selected is 3VF, with a nominal starting delay equal to 0.5 seconds, speed equal to 1 m/s, low speed 0.10 m/s, acceleration and deceleration equal to 2 m/s^2, and slow time equal to 1 second. The door-open time is equal to 1 second, the door-closing time is equal to 2 seconds, the door dwell 1 is 3.5 seconds, and the door dwell 2 is 2 seconds.

Table 1. A comparison of simulators

Item	**PC-LSD**	**Elevate^{TM}**	**ALTS/BTS**	**SimMP**
System characteristics				
Operating system	DOS	Windows	Windows	Windows
Language programming	FORTRAN IV	Visual C++	Standard C++	Borland C++ Builder 6
Special PC requirements	No	No	No	No
Quick starting option	No	No	NA	Yes
Building configuration				
Number of floors	25	100	No limit	30 (including extensive facilities)
Interfloor distance	No	Yes	Yes	Yes
Floors with special conditions	No	Yes	Yes	Yes
Several entrance to the cars	No	No	NA	Yes
Traffic configuration				
Special traffic flows (up peak, down peak, etc.)	Yes	Yes	Yes	Yes (including lunch peak)
Simple definition of destinations	Yes	Yes	Yes	Yes
Advanced definition of destinations	No	Yes	Yes	Yes
Floor populations	Yes	Yes	Yes	Yes
Passengers transfer times	Yes	Yes	Yes	Yes
Stair/capacity factors	No	Yes	Yes	Yes
Elevator configuration				
Number of lifts	8	12	No limit	12
Floor entrance forbidden option	No	No	NA	Yes
Lifts of different capacities	No	Yes	NA	Yes
Several kinematics	No	Yes	NA	Yes
Advanced door openings	Yes	Yes	Yes	Yes
Control and optimization algorithm configuration				
Traffic control algorithms	Collective Nearest car Dynamic sectoring Hall call allocation ETA (lowest estimated time of arrival) Stochastic control	Collective Dynamic sectoring Hall call allocation ETA Elevate proprietary algorithms	KONE proprietary algorithms (among others, enhanced spacing principle, KONE genetic algorithms)	MP proprietary algorithms (among others Microbasic, PDCU, MP Genetic Algorithms) and any other compatible with dlls
Simulation				
Visual simulation	2D design/basic movements	2D design/basic movements (cars- directions)	Advanced 3D design plus 2D basic movements (cars-directions)	Advanced 2D design/passengers-cars-directions-queues-doors
Simulation with several configurations in series	No	No	Yes	Yes
Select time slices	No	Yes	Yes	Yes
Output reports				

Continues on next page

Table 1. *Continued from previous page*

Summary of input data	Yes	No	Yes	Yes
Printed output	Yes	Yes	Yes	Yes
Exportable options	Yes (word processor)	Yes (Microsoft Excel®)	Yes (Microsoft Access®, Microsoft Word®)	Yes (portable document format, Adobe®)
Graphical report	Waiting time graphs Trip time graphs Car spatial graphs Car load graphs Percentile graphs Number of calls graphs	Waiting time graphs Trip time graphs Car spatial graphs Percentile graphs	Waiting time graphs Trip time graphs Car load graphs They claim to have several graphical options, but we do not have constancy of which type	Waiting time graphs Trip time graphs Car spatial graphs Car load graphs Car occupation graphs Percentile graphs Queue graphs Waiting time in floor entrances graphs Number of calls/arrival graphs

NA = Not Available

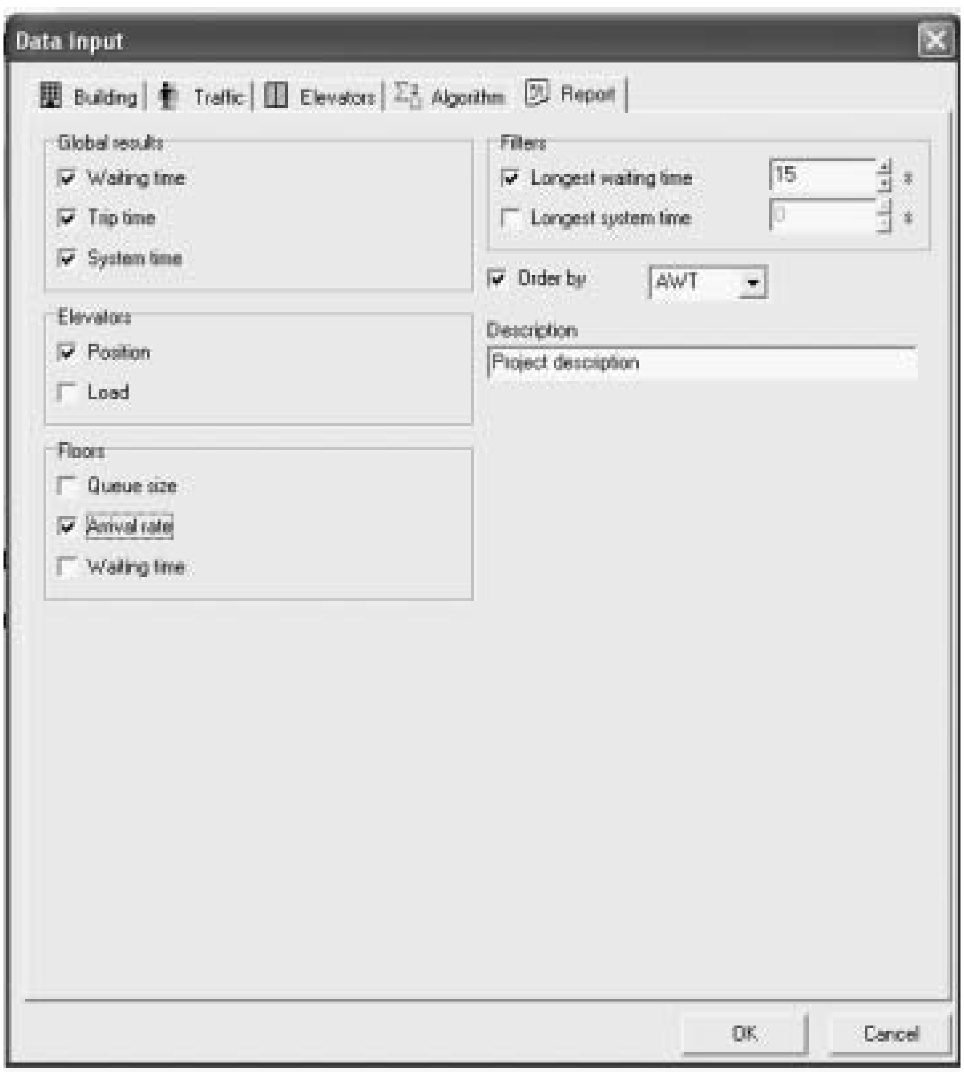


Figure 13. Report configuration screen

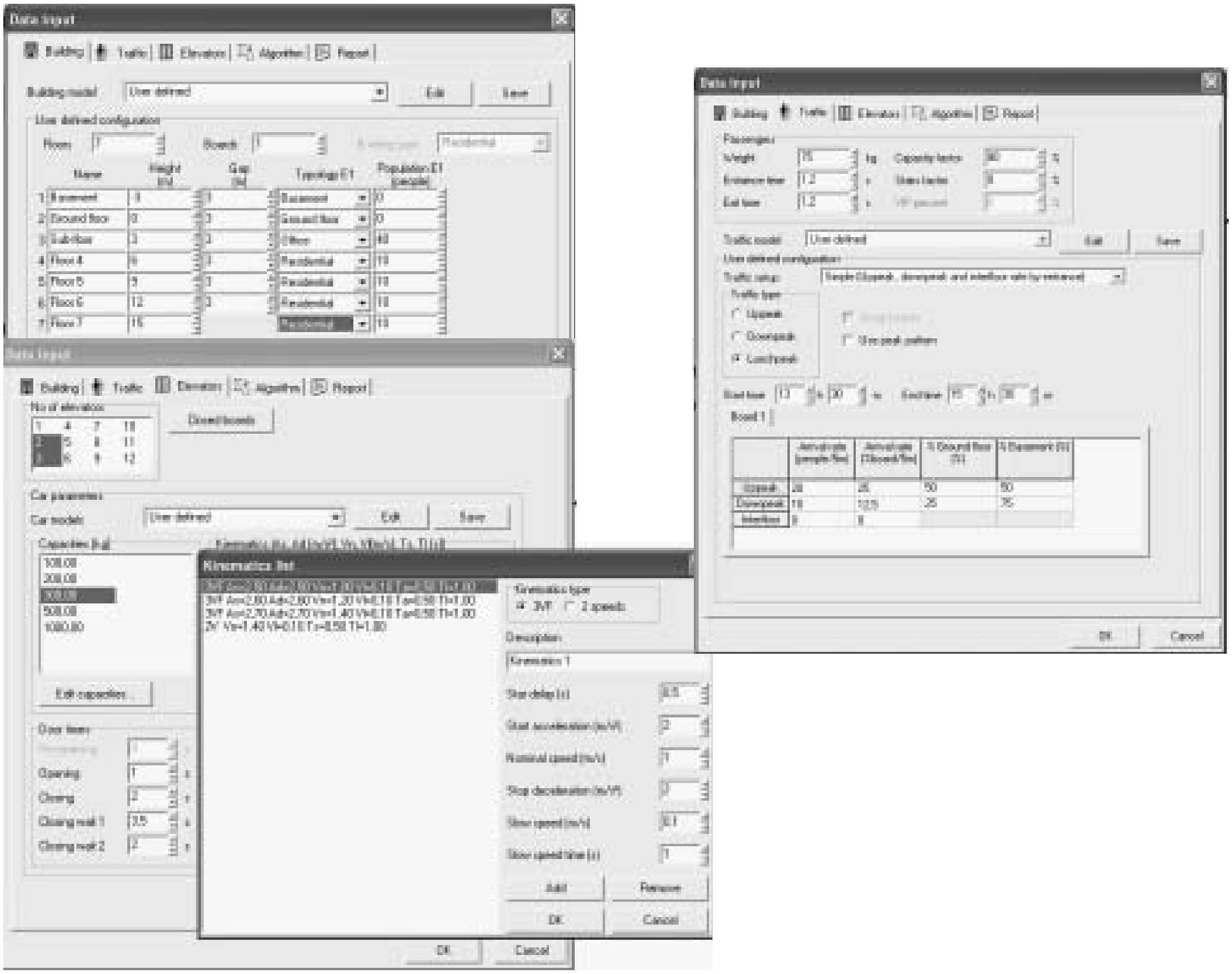


Figure 14. Input data for the case study

Finally, the optimization algorithm is the lowest estimated arrival time (ETA) algorithm. Figure 14 depicts the input data in the main screens.

The report is divided into a text report and a graphic report. The text report starts with the summary of the simulation results. For the more extensive case, it includes the AWT, the longest waiting time (LWT), the average system or total time (ATT), and the longest system time (LTT). After that, the number of starts (which is used as an energy consumption indicator), the kinematics parameters, and the number and capacity of the elevator group are shown. The summary is displayed for the total number of different configurations analyzed. It must be considered that several configurations can be analyzed in a same simulation test to allow the planning of the vertical transport system. The text report includes the data of the building, the traffic configuration specifications, and the optimization algorithm tested. The summary of the simulation results is shown in Table 2.

To eliminate the random effect, we carried out 200 replications and observed a maximum deviation in the results provided by the application lower than 5%. Even more, we were able to check the results provided by the tool with respect to the results from the real tests in the physical test tower of the company, appreciating a close accuracy between real-life tests and the simulation tool.

Attending to the tool results, we can appreciate that configuration 2 offers better performance than configuration 1. However, the results from configuration 1 are also good and allow reducing the investment in another lift (it is a configuration with two lifts). So for this case, we will select configuration 1 with an average waiting time equal to 28.55 seconds, which is a good waiting time, and a longest waiting time not higher than 272.09 seconds (4.5 minutes).

Table 2. Summary of the simulation

Project description (Project1)
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Vertical Traffic Simulator

Version 1.02

SIMULATION SUMMARY

Config.	*AWT (s)*	*LWT (s)*	*ATT (s)*	*LTT (s)*	*No of starts*	*Nominal and slow speed (m/s)*	*Accel. and decel. (m/s²)*	*Start delay (s)*	*Slow speed time (s)*	*No of elevators*	*Capacity (kg)*
2	**14,98**	**145,03**	**37,61**	**163,82**	1149	1,00; 0,10	2,50; 2,50	0,50	1,00	3	300,00
1	**28,55**	**272,09**	**55,30**	**287,40**	770	1,00; 0,10	2,50; 2,50	0,50	1,00	2	300,00

BUILDING

Floors	*Boards*	*Population*
7	1	80

TRAFFIC

Config.	*Throughput*
2	702
1	645

ALGORITHM

Basic

It is important to note that lunch-peak traffic is the most critical situation in vertical traffic because it includes the up-peak and down-peak traffic effects. However, the results should be checked with other traffic situations (as pure up-peak or down-peak traffic, as well as interfloor traffic).

Once we have stated these restrictions, to follow with the case study, we select configuration 1 for the case. Therefore, we will show the results for this configuration in the next graphic report. Typically, the graphic report consists of three different parts: a global results part, an elevator results part, and a floor results part.

Starting with the global results part, the report indicates the detailed configuration being analyzed, and it shows the average RTT as well as the AWT, LWT, AJT (average journey time), LJT (longest trip time), ATT, and LTT. It also indicates the numerical values of the percentage of passengers—10%, 50%, and 90%—with respect to all these times. Graphical information is shown for all these results. Figure 15 depicts the global result report.

Figure 15 shows that less than 5% of the passengers have to wait for more than one minute, which represents good waiting time results. Moreover, the results prove that the algorithm was processing in the order of microseconds as the average time.

Continuing with the elevator report, the average RTT for each specific elevator is shown, as well as the total distance covered by the elevator (including the total distance and the distance for up and down traffic), and the number of trips (including the total traffic, as well as the up and down traffic).

In the second part of the report, the transported passengers, the average load, and the average occupation are reported. Graphical information is depicted for all the data, and Figure 16 shows the results for the case. RTT was equal to 50.28 seconds for lift 1 and 50.47 seconds for lift 2, that is, less than 1 minute for the two cars. The average load was 90.91 kg for lift 1 and 89.66 kg for lift 2 (i.e., approximately 1.2 passengers per journey). A total of 325 passengers were transported by car 1, and the car was started 385 times. With respect to car 2, 320 passengers were transported, and the car needed 394 starts.

Finally, the floor result report indicates the values related to the queue sizes for each selected floor, as well as the arrival rates and the waiting times in floors for each car. Also, the number of calls per floor is calculated. To give an example, in Figure 17, we show the results for the ground floor. That is the most complex floor due to its intensive use during the up-peak effect. But the data for the rest of floors were also calculated and information reports are available, in the same line as the ground floor case. The graphic shows the results of queue sizes in the ground floor (longest queue equal to 5 and average queue less than one passenger), average arrival rate to the ground floor (8.63 people every 5 minutes), and AWT in the ground floor (AWT = 14.78 seconds and LWT = 67.08 seconds).

5. Conclusion and Further Research

Today, most of the companies developing elevator group systems are focusing their research efforts on tools capable

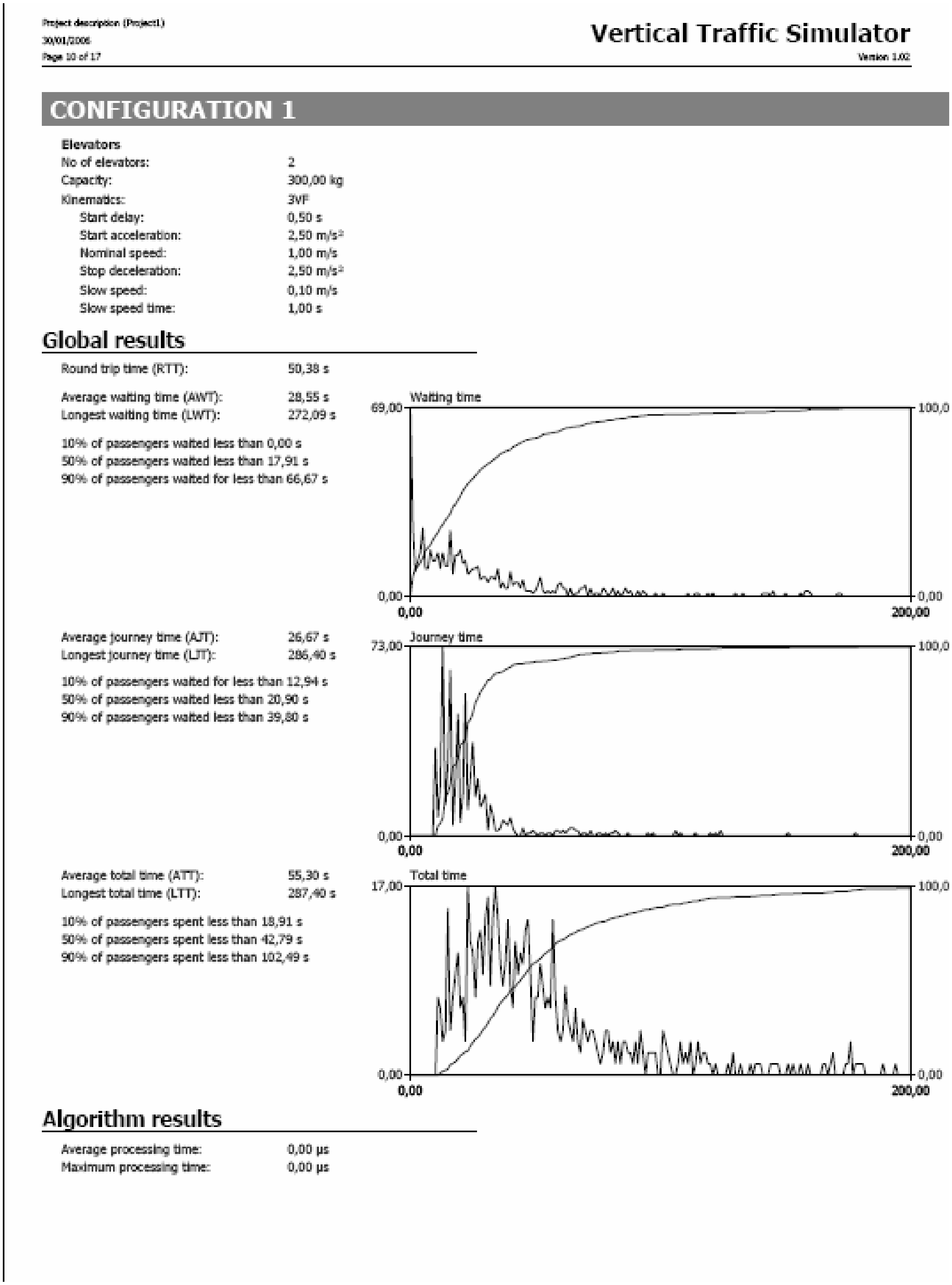

Figure 15. Average waiting time (AWT), average journey time (AJT), and average system time (ATT) graphical results

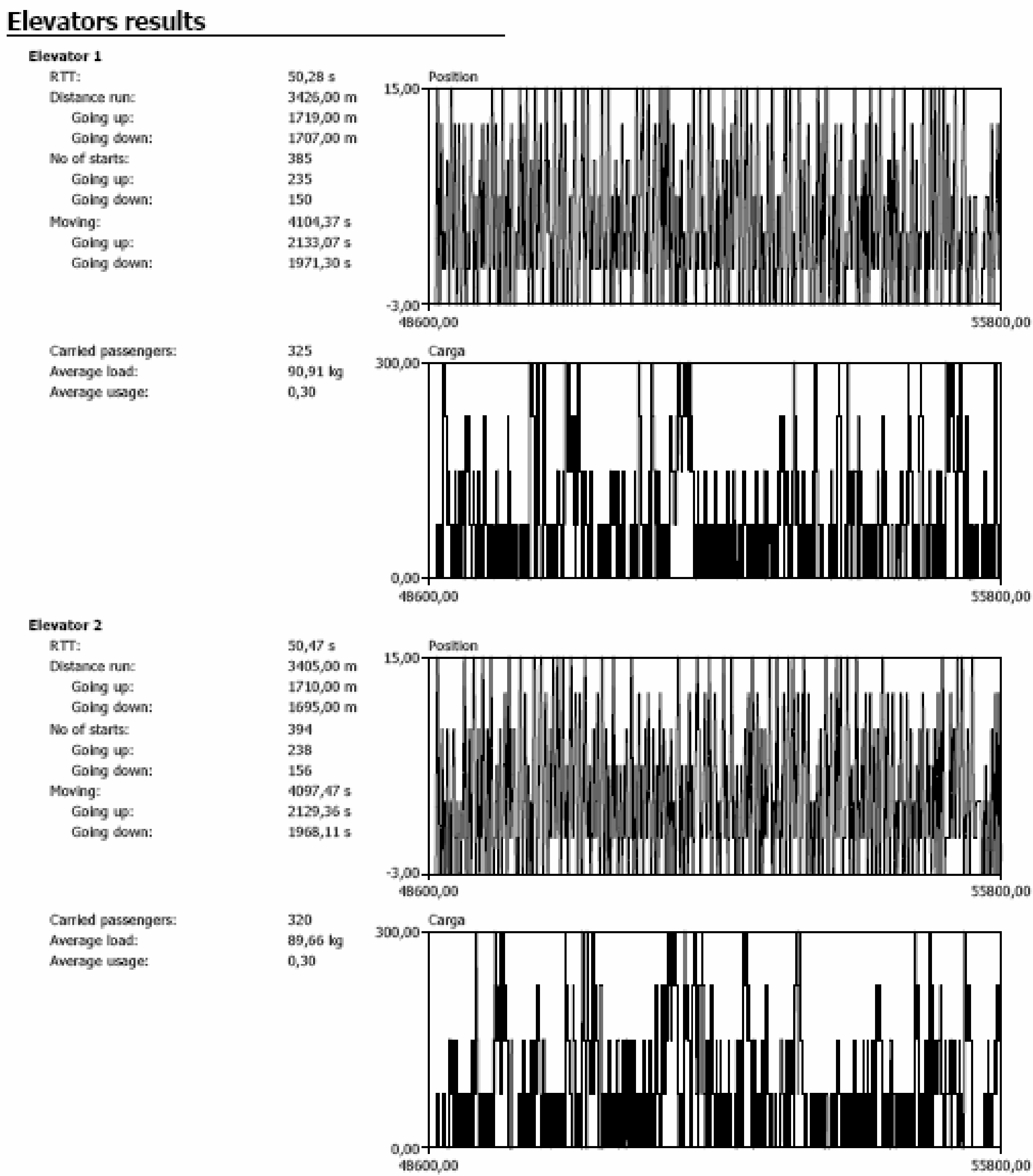

Figure 16. Elevator graphical results

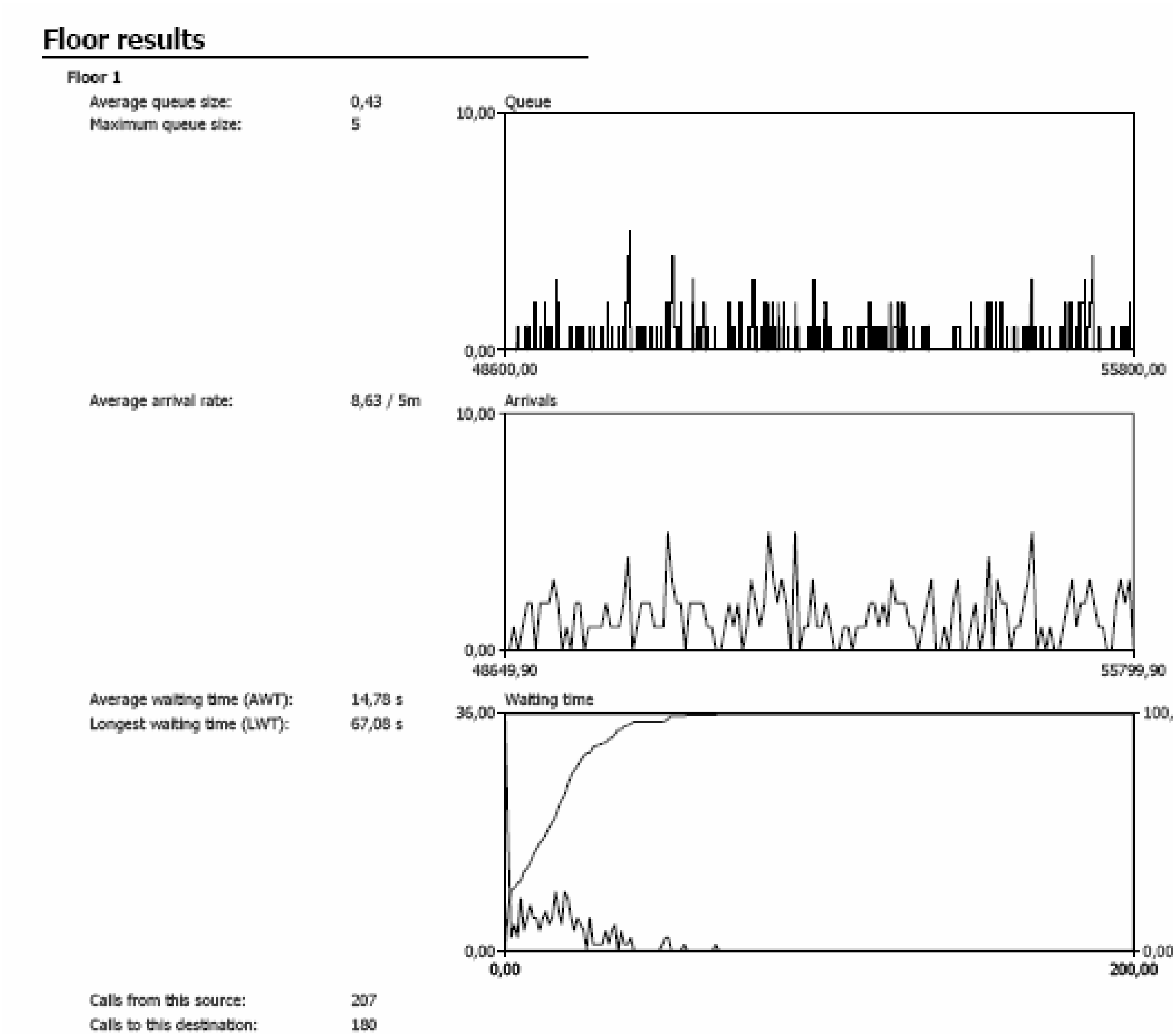

Figure 17. Graphical results for ground floor

of providing support for elevator system design processes. SimMP takes part in this context. The objective of SimMP is to provide not only a simulation tool but also a tool capable of helping designers in the vertical transport system design process. The tool allows selecting the number of cars to be installed, the kinematics group, the technical characteristics of the elevator group and of each specific car, and the optimization algorithm, among several other options accordingly with the building profile.

This user-friendly tool covers most of the needs of vertical transport system designers, compared with other tools. In many cases, it even provides a wider scope than the existing ones.

As further research, we continue working together with MP on the control and optimization scope, trying to integrate components of advanced artificial intelligence into the controllers of the system. The objective is to design an intelligent controller capable of providing improved solutions for extremely complex cases of vertical transport in buildings. However, the implementation of such type of algorithms in real controllers has to be done carefully to maintain the response time of the algorithm within bounds.

With the objective of testing the suitability and feasibility of the algorithm controller, SimMP will play a decisive role.

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