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DEVELOPMENT OF A SIMULATION FRAMEWORK FOR URBAN ROPEWAY SYSTEMS AND ANALYSIS OF THE PLANNED ROPEWAY NETWORK IN REGENSBURG, GERMANY

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ABSTRACT

To evaluate the performance of a ropeway in an urban environment, simulations of the dynamic passenger transport characteristics are required. Therefore, a modular simulation model for urban ropeway networks was developed, which can be flexibly adapted to any city and passenger volume. This simulation model was used to analyze the ropeway network concept of the German city Regensburg and to determine the expected operating conditions. The passenger volume, different types of persons, their occurrence probability and their destination distribution is depending on the location and daytime and can be defined for each individual station. In an initial analysis, the number of passengers currently occurring in bus traffic were projected onto the ropeway network. To enable climate-friendly and efficient operation, different strategies were developed to significantly reduce the number of gondolas. The best fitting strategies resulted in significant cost savings while passenger comfort, as represented by queue time, remained unchanged.

1 INTRODUCTION

In times of growing population and densely populated cities, the ropeway, with its minimal space requirement due to its independence from road traffic, represents an attractive means of transportation to relieve the inner-city traffic network.

As early as the 19th century, ropeway technology was used to transport material over difficult terrain (Seeber 2010). Besides this first stage, ropeways are known to people mainly from the second stage, (ski-)tourism. The third stage is currently being initiated with the use of ropeways in urban areas. This is becoming more and more relevant, especially because of the ever-growing volume of traffic in larger cities. In Paris, for example, it has already been decided to build a ropeway (Surrer 2022), while Stuttgart (Kaufmann 2022) and Munich (Korte 2022) are also looking more specifically at such a concept.

The German city of Regensburg also has a concept for an urban ropeway network for public transport. The basic design of the ropeway system has already been determined by a project group at the Regensburg University of Applied Sciences. A star-shaped ropeway network consisting of three independent ropeway lines as well as the position of the associated stations was defined under legal aspects. In the following technical specification, rope sags, required diameters, position, height of the necessary cable supports and the minimum gondola distance on the rope were calculated. In order to evaluate the impact on Regensburg's public traffic and thus the actual usefulness of the planned ropeway network, the analysis of passenger

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flows is essential in next planning steps. A simulation was designed to address passenger flows occurring in ropeway systems.

The primary objective of this project was the development of a modular simulation tool for ropeway systems in urban areas. The simulation model is intended to be applyable for ropeway systems in any city and its specific configuration (e.g. number, type and position of stations, gondola speeds, network-layout, etc.) and for any passenger volume. It is important to mention in this context that the simulation model in its current version can relatively easy be adapted modularly for any city, but this requires model-specific software knowledge of the user in order to make various small but necessary adjustments in the software environment. The integrated user interface is designed to allow the adjustment of all relevant simulation input parameters simply and to visualize the results, but not to modify the ropeway network structure itself. To realize the planning tool, the discrete-event material flow simulation software *PlantSimulation* was used. It allows programming in the object-oriented language *SimTalk* (based on *C++*) and already contains the basic objects (vehicle, path, material, etc.). Another reason for using this software was the availability of a license at the university.

The main part of the research work consisted in the modeling of a realistic person behavior and passenger volume, depending on daytime and location of the specific station. For this purpose, different groups of persons with individual attributes were created, whose start and destinations are statistically assigned (Table 3). The developed simulation model was then used to analyze the planned ropeway network for the city of Regensburg. Therefore, the passenger volume at each individual station was determined with the help of known boarding numbers from the current local bus traffic. For the analysis of the ropeway system, different key performance indicators (Section 3.3) were generated, which quantify the passenger comfort as well as the efficiency of the ropeway network. The results are used to increase the acceptance of such transportation systems among politicians and general public by demonstrating tangible and conceivable transportation indicators (such the average waiting time, for example). Based on these analyses, efficient operating strategies resulting in a significant reduction of the required number of gondolas were developed (Section 5.3).

2 RELATED WORKS AND RESEARCH QUESTIONS

Compared to conventional public transport systems such as buses or trams, ropeway technology still attracts less attention in urban areas. Even though ropeways have increasingly become the focus of public attention in recent years, they are hardly taken into account in transport planning. Reasons for that are already discussed in relevant literature e.g. (Kremer 2015) and (Reichenbach and Puhe 2016). In (Tiessler and Engelhardt 2019) the acceptance of a possible urban ropeway in munich among the population was analyzed using a self-conducted survey. The citizens were asked to select their prioritized combination of local transportation options in twelve different scenarios. Some reports have also been written about the general operating of urban ropeways. In (Wagner and Kabel 2018) the most important aspects and possible usage of ropeways, the role in public transport for society and ecology, economy and also the fundamental technology are described. Mister Seeber (Seeber 2010) discusses similar aspects around the urban use of ropeways and also goes into detail about some already realised projects. Furthermore, the technology of ropeways is already sophisticated enough to be used in cities, as shown in (Lagerev and Lagerev 2019).

Another attempt to represent the complex operation characteristics of a ropeway and its passengers was carried out by (Fedorko and Neradilov 2018). They also included a realistically reproduction of the entry and exit process of persons in the stations. However, in contrast to this approach, they mainly focused on correctly predicting the absolute number of passengers and estimating the actual days of operation over a year (taking into account interruptions due to planned technical shutdowns, repairs, or environmental factors). Simulation models reproducing the dynamic operation of a ropeway with more complex passenger models are not available at the moment. But this kind of analyses are necessary to estimate waiting times and capacities during operation. Currently, simulations for transportation planning in urban areas are almost exclusively carried out for conventional transport such as cars, buses and trams. The open source software *SUMO* (Lopez et al. 2018) offers the possibility to simulate complex operations of different public transport systems. A software for the exclusive simulation of passenger transportation by bus, is offered by FLS GmbH (Hartel 2022). The concept, however, is not a classical scheduled bus traffic, but a so-called "Transportation on Demand". Buses are ordered to a requested starting location via software using a smartphone. In practical ropeway planning, often only the maximum passenger throughput is used for dimensioning the system. But thereby no daytime or location dependencies are taken into account. This does not adequately represent the complexity of the real system and can easily lead to efficiency losses due to overdimensioning on specific lower utilized stations or general wrong dimensioned systems.

In this context, due to the increased demand for urban ropeways, there is a need for a detailed and simulation solution to realistically model ropeway systems. This paper focuses on the analysis of dynamic passenger flows in the ropeway network and the resulting effects on passengers, the actual users of the ropeway. There was also a particular focus on maximizing the flexibility of the simulation and on implementing a suitable input interface in order to be able to adjust the database for different analyses as easy as possible. The simulation enables the user to answer questions already in the ropeway planning phase that could previously only be approximated, such as critical times of the day, maximum waiting times, average total travel times of the different routes or the utilization distributions over the various stations.

The planned ropeway network for Regensburg will then be modeled in terms using the developed simulation model. The question here is whether or how the planned ropeway network can handle the current passenger volume in Regensburg. Furthermore, it has to be investigated at which number of passengers the system reaches its capacity limits, i.e. according to the queuing theory (Arnold and Furmans 2019) a critical point is reached and the queue times at the stations increase overproportionally. Another objective of this study is to show how the investment costs can be reduced through intelligent operating strategies. The goal was to keep the passenger comfort, which is defined by low queue times and high frequency of the gondolas in the stations.

3 DEVELOPMENT OF A GENERIC SIMULATION MODEL FOR URBAN ROPEWAYS

At the beginning of planning an urban ropeway up to the implementation, it is not possible to rigidly define the stations and the line route directly due to the number of high influencing factors and legal circumstances. Therefore, the focus of the development was on the modular, changeable and parametric structure of the ropeway simulation, so that it can be flexibly applied to any cities and line configurations.

3.1 Basic Objects and General Structure of the Simulation

In order to fulfill these requirements, it is useful to define a few parameterizable basic elements as follows: *station*, *gondola*, *rope*, *person*. The simulated ropeway network is built to scale on a city map implemented in the simulation background by using the basic elements *station* and *rope*.

In the station, persons can start (*person source*) or end (*person sink*) their journey. After entering the station (creation in the *person source*), people are guided via walkways to the boarding areas. At the boarding areas they can enter the gondolas and start their ride towards their individual destination. Since the ropeway network includes separate lines, people may have to change the ropeway line at certain stations. People who arrive at their destination or need to change the line will leave the gondola at the exit area of the current station. They are then guided via walkways to the entry zone of another line or to the *person sink* if the destination is reached. The station type (end, middle station) as well as the position in the line network is assigned parameterized via global attributes. These station types can be flexibly set by implementing gondola turning frequencies. This frequency specifies the number of gondolas that should change their direction at a station. The three possible station types can be seen in Figure 1.

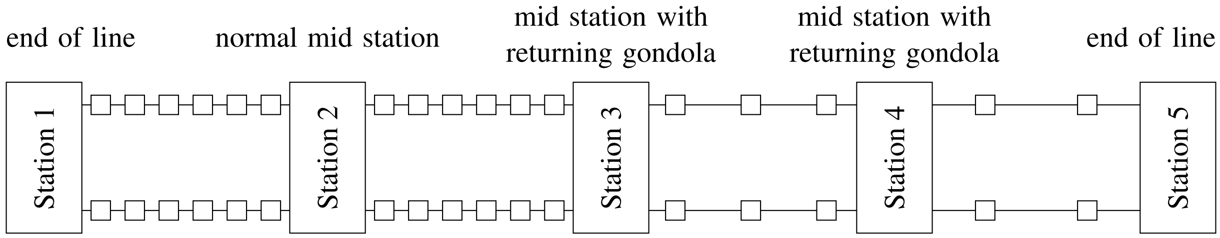


Figure 1: Scheme of the different station types.

Stations of the type *mid station with returning gondola* can be used to set different gondola frequencies in the various rope sections of a line in order to achieve a demand-based supply of gondolas to the stations. This allows the numbers of gondolas to be reduced in terms of economic station utilization (Section 5.3.2).

The gondolas move between the stations at a constant speed that can be defined globally per line. They decelerate to a significantly reduced speed when entering the stations by decoupling from the rope to enable the entry or exit process. The definable distance between the gondolas with fixed capacity is ensured when leaving the station.

The persons are generated at the *person sources* according to a depending on the daytime definable passenger volume (Section 4.2.1). Individual attributes (destination station and person type, Section 4.2.2 and 4.2.3) are then assigned to the persons. The person type contains the required seats inside the gondola, the walking speed as well as the time needed to enter or exit the gondola. The attribute assignment of the persons is done for each station according to individually definable probabilities (Table 3). In addition, time stamps are related to the persons after all relevant events (e.g. time of gondola entry).

3.2 Entry and Exit Process of People in Stations

An essential requirement is the modelling of the real behavior of individual persons. The developed algorithm describing the methodology of the gondola exit process is shown in the following flowchart (Figure 2).

As observed in reality, people for example arbitrarily get into free gondolas instead of filling the foremost available gondola to maximum capacity. Thus, gondolas are often not fully seated when they leave the station, despite high passenger volumes, which results in a certain loss of capacity of the overall system. Among other things, this correlation of random gondola selection is implemented in the simulated entry process.

Phenomena such as the effect of group formation while entering the gondolas or the overtaking of faster people in the queue are not considered here. Furthermore, people do not know at entry whether the gondolas will change direction at future stations. As a result, people may have to make an additional gondola change before reaching their destination (attribute *mustExit* = true, Figure 2). This leads to a longer total travel time, which is also reflected in the calculated characteristic values, representing a worst-case scenario.

3.3 Input and Output Parameters for the Simulation Model

In order to use the simulation as a tool for the analysis and optimization of ropeway networks, a user interface was developed which allows the global specification of all relevant parameters for the system behavior. This allows parameter studies to be carried out, the simulated ropeway system to be adapted to the underlying database, and potential operating strategies to be analyzed.

Figure 3 shows an overview of the input and output parameters. These can be set during or before the simulation by the user. The output data is stored in tables and can be visualized in graphs at runtime of the program.

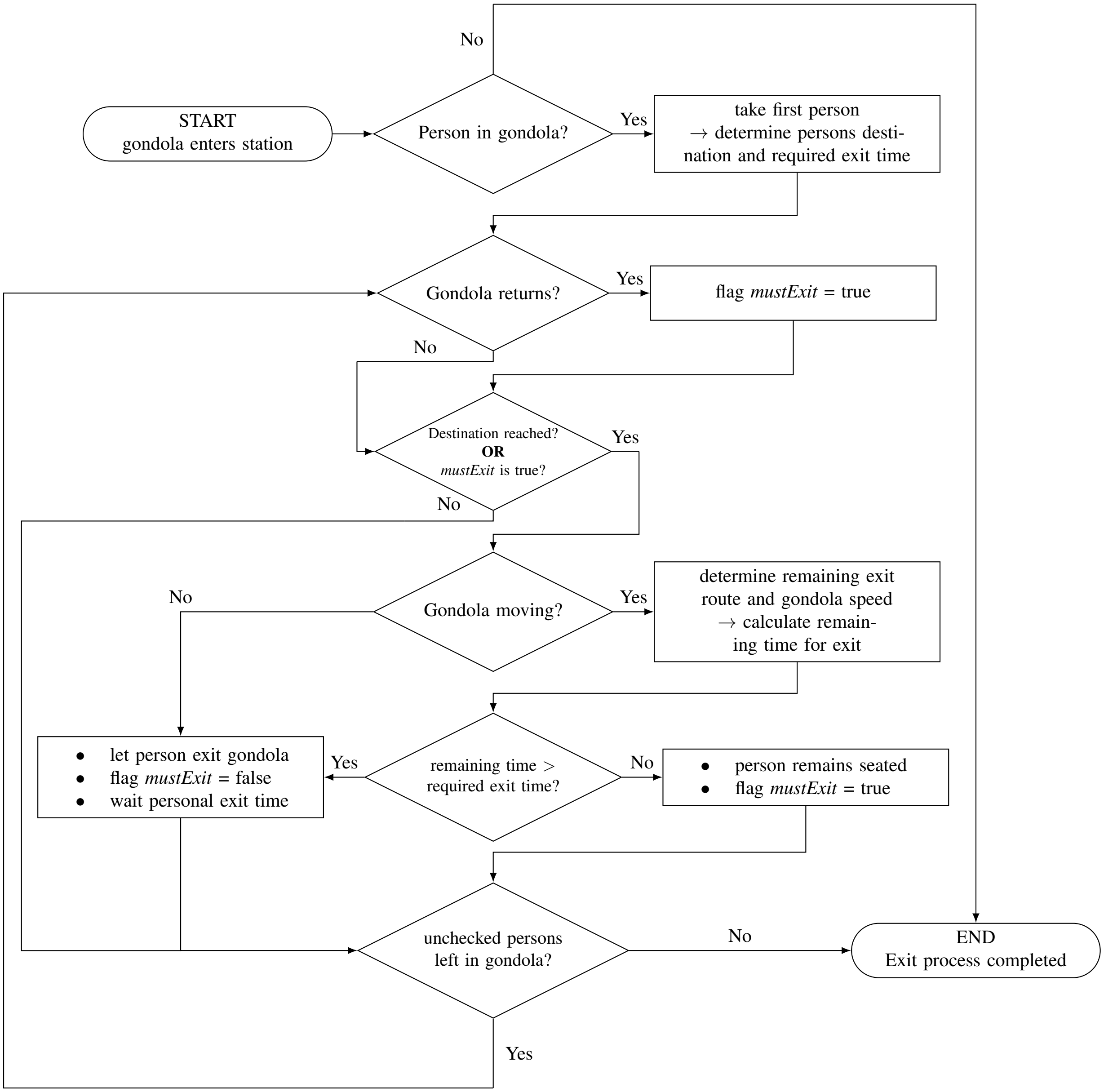


Figure 2: Flowchart of exit process.

The current station- and direction-related kpi (key performance indicators) queue time, passenger throughput and gondola utilization are displayed in the simulation in real time at each station. The user can define a custom time interval of the day, over which the characteristic values are evaluated as average values. Also, minimum maximum and standard deviation are displayed. The characteristic values are stored in tables for the simulated day, from which charts of the daily trends can be created directly in the software.

The tracked data of all passengers is also provided in a global data storage after their transportation. This enables a detailed tracking of each individual person. The time stamps of the passengers are then used to calculate characteristic values such as transfer time, walking time, net travel time, total queue time, etc. The significant parameter is the total travel time, which is also calculated as a daily average for all possible transport routes and displayed in a source-destination matrix.

INPUT

- Passenger entry frequency per Station and Daytime
- Scaling factor of the total passenger entry numbers
- origin-destination matrix
- Definition of different types of persons and their station-related occurency probability
- Gondola capacity, distance and speed outside and inside of the station
- Gondola turnaround frequency per station

OUTPUT

- Station- and direction-related kpi:
  - Gondola utilization
  - Queue time
  - Passenger throughput
- Number of persons transported
- Number of gondolas in the ropeway network
- Daily average of total travel durations for each possible route
- tracked timestamps of all transported persons

Figure 3: Input and Output parameters.

4 URBAN ROPEWAY SIMULATION MODEL FOR THE SPECIFIC USE-CASE REGENSBURG

The developed simulation model (Section 3) is now applied to the city of Regensburg in order to investigate the already defined ropeway system and especially its operation with all necessary boundary conditions. Based on the following assumptions, various simulations were performed in order to evaluate the planned ropeway network.

4.1 Assumptions and Boundary Conditions

In order to load the ropeway simulation model with realistic passenger numbers, the passenger volume of the current local public transport system (in this case local bus transport) are used as a basis. According to the guidelines for ropeway planning (Schrf and Sondermann 2018), passengers who switch from individual transport to local public transportation because of its increased attractiveness and passenger volume due to tourism must also be taken into account. Since no data (from surveys or studies) is available to quantify the latter two aspects, this work is based exclusively on the known passenger numbers of public bus transportation. The additional passenger volume due to individual traffic or tourism is represented relative to the known database by multiplication with a determinable factor.

In order to represent a ropeway system that can be implemented in reality, some technical conditions were defined in coordination with ropeway producers. In the ropeway network, gondolas with a capacity of 10 passengers are shuttled on the rope at an adjustable speed from 0 m/s to 6 m/s. If a gondola enters a station, the speed is slowed down to 0.3 m/s to allow passengers to board. Due to the technical design of the system with regard to the expected loads, a minimum distance of 60 m between the gondolas beyond the stations was specified. The main focus in determining the line layouts were to span as less private property as possible in order to fulfill legal aspects.

4.2 Data Source of the Passenger Volume

To integrate the traffic data collected in Regensburg into the simulation, a cooperation was established with the *Departure Mobility* of the Regensburg's municipal utility. In a 500 m corridor around the defined ropeway network, entries and exits at the bus stops were registered and assigned to the respective ropeway stations. On average, the counts resulted in a total of 54,062 entries and exits per day in Regensburg. This results in a number of 27,031 passengers in the traffic area of the planned ropeway network per day.

4.2.1 Daily Profiles of the Passenger Volume

The absolute entry numbers for each station per day could be determined from the named data source. In order to represent a realistic, time-of-day-dependent passenger volume at the individual stations, individual daily profiles were defined for each station. These are based on analyses of the different stations in terms of their local environment and include aspects such as opening hours of station-related facilities (universities, shopping centers, train stations, etc.) or usual working hours. This time-of-day dependent passenger volume is specified in the simulation for each station, discretized in a 15 min frequency. Table 1 shows an example of the daily profile of a ropeway station (in this case: Regensburg University of Applied Sciences).

Table 1: Adjustable daily profile of the passenger volume at a station.

Daytime	**Boardings per hour**
06:00 a.m.	5
...	...
11:15 a.m.	155
11:30 a.m.	160
11:45 a.m.	170
12:00 p.m.	165
12:15 p.m.	165
12:30 p.m.	200
...	...
11:00 p.m.	5
Total boardings per day	**2005**

4.2.2 Start and Destination Probability by Source-Destination Matrix

In addition to the total number of passengers per station, the destination has to be defined for each person entering the station. This is described with a source-destination matrix for each individual station that indicates the probability of a person being transported from station A to station B. In the specific use case Regensburg, the probabilities based on data collected from *Stadtwerke Regensburg* were determined empirically.

In the simulation, a destination station is determined for each passenger based on the source-destination matrix. Table 2 shows an extract of this matrix. The sum of the probabilities of a row in the matrix has always to add up to one, because each person is always assigned a destination.

Table 2: Part of the source-destination matrix.

				Destination			
		...	**Line 1 Station 3**	**Line 1 Station 4**	**Line 1 Station 5**	...	**Total**
	...	...	...	...	...	...	100 %
Departure	**Line 2 Station 4**	...	10 %	7 %	4 %	...	100 %
	Line 2 Station 5	...	13 %	6 %	5 %	...	100 %
	Line 2 Station 6	...	12 %	**6 %**	4 %	...	100 %
	...	...	...	...	...	...	100 %

For example, according to Table 2, a person who entered the 6th station of the 2nd line will go to the 4th station of the 1st line with the probability of 6 %.

4.2.3 Probability of Occurrence for the Different Types of Persons

People in reality differ especially in their individual behaviors and characteristics, such as in their choice of seat or their maximum walking speed. To reproduce this behavior as realistically as possible, six types of people were defined, characterized by three main properties (Table 3).

These are the entry/exit time to/from the gondola, the maximum walking speed in the stations between the gondola and the entry/exit of the station and the number of seats required within a gondola. This makes it possible to include a diverse range of passenger types in the simulation. In this way, for example, people with strollers or wheelchair users are also included.

The occurrence probability of these person types can be defined individually for each station (Table 3). For example, people defined as *slow* or *very slow* are more likely to appear at old people's homes and hospitals. For the use case in Regensburg, the area around the stations and their special aspects were analyzed. Probabilities of the types of people expected to be there were set.

Table 3: Definition of different types of persons and their occurency probability.

Table 3.1: Gobal definition of the different types of persons and their characteristics.

Different types of persons	**Time of exit /entry [s]**	**Walking speed [m/s]**	**required seats**
very slow	4.00	0.30	2
slow	3.50	0.35	1
Mother with child	3.00	0.35	3
Wheelchair user	2.50	0.40	4
normal	2.00	0.70	1
fast	1.50	0.80	1

Table 3.2: Probability of occurence definable for each station.

Different types of persons	**Probability of entry**
very slow	0.028
slow	0.050
Mother with child	0.070
Wheelchair user	0.002
normal	0.500
fast	0.350

5 INVESTIGATION AND IMPROVEMENT OF THE EFFICIENCY OF THE PLANNED ROPEWAY NETWORK IN REGENSBURG

Chapter 3 explained how the developed simulation software was applied to the use case Regensburg and in which structure the data had to be implemented. Now, the planed ropeway network for Regensburg will be analyzed with the kpi mentioned in 4.2. In addition, the potential for optimization is identified and improvements are made regarding the efficiency and cost-effectiveness of the ropeway network.

5.1 Analysis of the Ropeway Network for the Current Public Transport Passenger Volume

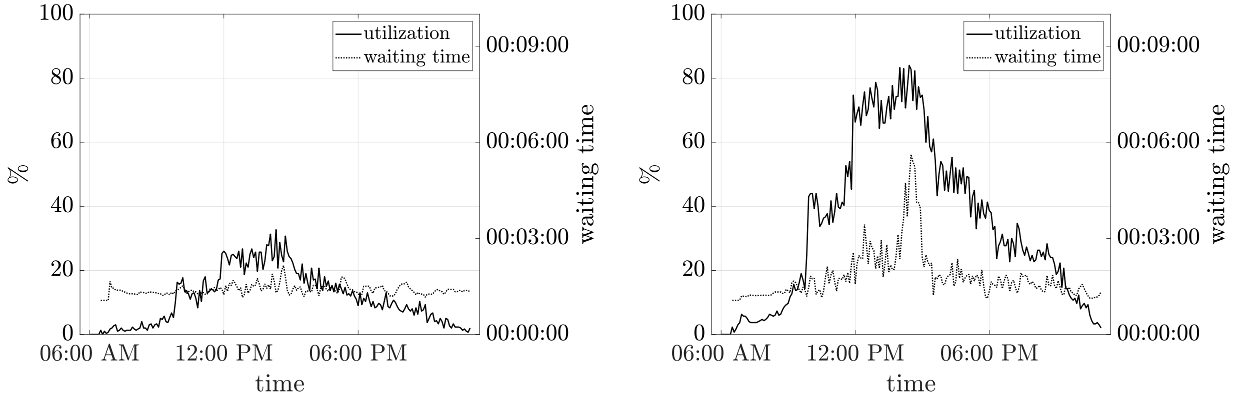
Using the data of the current public transportation system for the passenger volume, the maximum loaded station of the system (defined as *reference station*) reaches a gondola utilization of about 30 % at peak times. The throughput at this reference station amounts to a maximum of about 1,150 persons per hour, which corresponds to about 32 % of the maximum possible value (Figure 4 (a)). In conclusion, it can be seen that the ropeway system has significant capacity reserves for the given configuration and waiting times at all stations are over the whole day negligible.

5.2 Identification of the Limits of the System by increasing the Volume of Passengers

As described (Section 5.1), significant capacity reserves were identified for the given passenger volume. Therefore, the passenger volume is now increased until the critical point is reached at the *reference station*.

In terms of passenger comfort, the following boundary condition is required: *The maximum waiting time for passengers at the stations must not exceed 8 minutes*.

Thus, the passenger volume can be multiplied by a factor of about 3 without neglecting the just mentioned boundary condition. The resulting gondola utilization and waiting time at the selected *reference station* are shown in Figure 4 (b) and compared with the utilization and waiting time for the actual passenger volume, displayed in Figure 4 (a).



(a) current passenger volume

(b) triple passenger volume

Figure 4: Utilization in % and waiting time in min:sec at the reference station for current passenger volume (a) and triple passenger volume (b).

As shown in the figure, a waiting time of almost 6 minutes occurs at a maximum gondola utilization of about 80 %.

5.3 Improvement of the Ropeway Network Efficiency

It has been demonstrated that the ropeway network in its current configuration and operating strategy is overdimensioned for the Regensburg use case. This is mainly due to the low utilization and the relatively high number of gondolas currently in use. The primary objective of the following improvement approaches is to reduce the investment and operating costs of the ropeway network in Regensburg in order to achieve a cost-effective operation of the system.

Therefore, in the following sections, two possibilities are shown to reduce the number of gondolas used and also balance the two aspects of passenger comfort and energy consumption. By reducing the number of gondolas on the rope, investments can be reduced. Since less mass has to be moved with the rope, the energy requirement of the system can also be decreased. The number of gondolas on the rope has a direct impact on the minimum possible rope diameter, which leads to a further cost reduction of the entire system (Briem 2021).

5.3.1 Increasing the Gondola Distance on the Rope

The first possibility to increase the efficiency of the ropeway network and to reduce the number of used gondolas is to increase the distance between the gondolas on the rope. This distance can be set globally for each of the three lines. Accordingly, the total number of gondolas on the rope is reduced, the overall capacity of the ropeway network decreases, while the utilization of the individual gondolas increases. To identify a reasonable gondola spacing in the system, the original distance of 60 m was experimentally enlarged in 20 m increments until the queue time at the reference station increased significantly.

A favorable gondola distance could be determined to about 200 m, taking into account the boundary condition mentioned in chapter 5.2. This results in a reduction of the gondola numbers from 634 (60 m distance) to 210 (200 m distance).

5.3.2 Implementation of Reversing Gondolas in Specific Stations

By increasing the gondola distance on the rope, the total number of gondolas used in the system could be significantly reduced. Figure 5 shows the resulting gondola utilization daily averages of all stations of one of the three ropeway lines. A clear gradient in utilization can be recognized here from station 1 to station 6, which is due to the different passenger volume of the specific stations. Thus, the passenger volume in the central stations of the ropeway line (station 1 to about 3) is significantly higher, since more boardings are recorded in the inner-city area of Regensburg (main station and university). At the outer edge of the line (stations 5 and 6), the ropeway reaches the outskirts of Regensburg, where significantly fewer people are transported.

In order to avoid or reduce the described utilization gradient over the line, the gondola frequency has to be set individually at each station. This can be realized by implementing mid stations with reversing gondolas (according to Section 3.1, Figure 1). A line configuration that leads to a low number of gondolas and a balanced utilization distribution was determined empirically. To additionally meet the known queue time boundary condition, the general gondola distance has to be adapted from 200 m to 170 m.

The result of the gondola utilization adjustment across all stations of the ropeway line is visualized in Figure 5. It shows that the utilization gradient could be noticeably reduced, while complying with the defined boundary condition. Furthermore, this operating strategy applied to all lines reduces the number of required gondolas in the entire network from the previously mentioned 210 to just 150 gondolas.

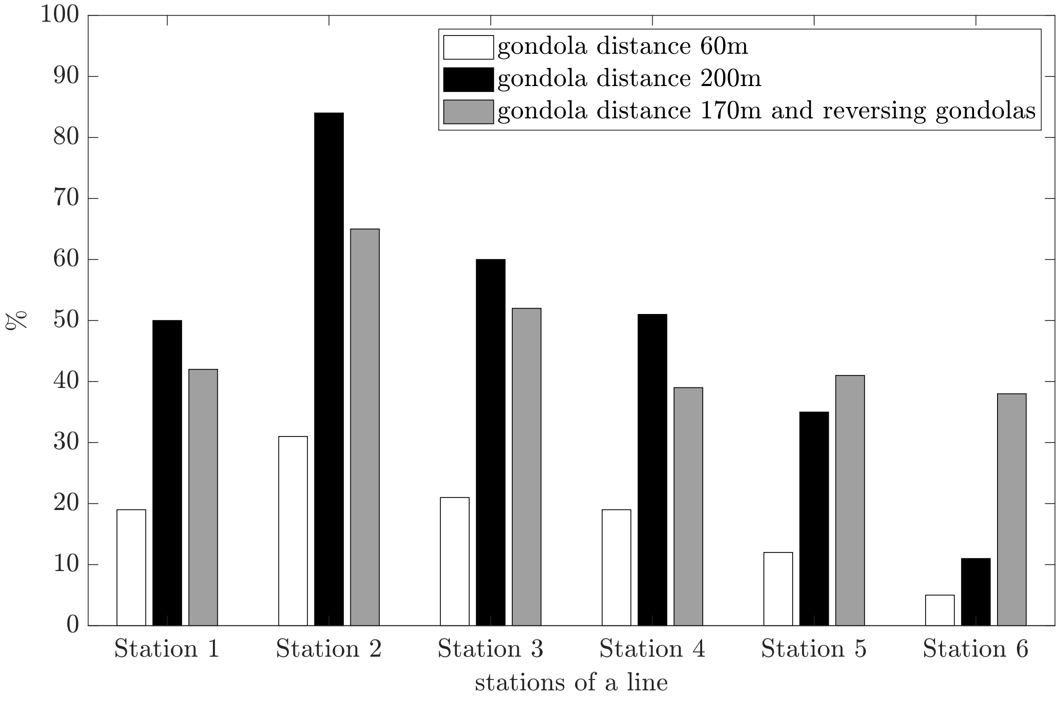


Figure 5: gondola utilization on the stations of one line for different operation strategies.

Another positive aspect can be seen at the central (in Regensburg heavily loaded) stations of the ropeway lines. At these stations it is possible that the entering gondolas are already fully seated and only a few people are leaving the gondola. This means that passengers can no longer or only with relatively long waiting times board the gondolas at this station. Reversing gondolas provide additional empty gondolas for entering persons, as gondolas are emptied before reversing. This configuration increases the comfort for newly entering passengers, but decreases the comfort for passengers who are forced to leave the gondola due to a gondola reversal. This loss of performance is accepted in the context of the simulation in order to create a worst-case scenario. In real operation, it is therefore conceivable to mark the reversing gondola already at previous stations with the planned gondola reversal station in order to avoid the additional forced alighting of passengers.

6 DISCUSSION AND CONCLUSIONS

A simulation model for urban ropeway networks was developed in the software PlantSimulation. The focus was on the modular structure of the software, which allows ropeway networks of any configuration and system size to be built virtually on a city map. In general, the simulation consists of the elements: station, gondola, rope and passenger (Section 3).

For the data input, different types of passengers can be defined in a graphical user interface and their occurrence probabilities can be set individually for all stations. Furthermore, the start and destination probabilities of the passengers as well as the passenger volume can be implemented time-dependently for each station. The user can also set the minimum distance between two gondolas and their speed on the rope to simulate different operating strategies. As an output, the user receives kpi (Section 3) to analyze the performance and efficiency of the ropeway system. These key indicators can be displayed station-related for a defined time period in real time. It is also possible to view information on the number of passengers already transported and the number of gondolas in the system.

In a further step, the simulation tool was used to virtually model and simulate the planned ropeway network for the German city of Regensburg. The number of passengers in this city was also analyzed, based on the number of entries and exits at surrounding bus stops. By analyzing local characteristics, it was possible to determine the types of passengers occurring at the stations.

Using the implemented key indicators, differences in utilization of the stations could be detected and capacity reserves in the system identified. For the city of Regensburg, it was found that the cable car has high capacity potential in the designed configuration and could handle about three times the current passenger volume.

To ensure cost-effective operation of the ropeway network, optimization of the number of gondolas used was performed. For this purpose, the distance between the gondolas were significantly increased and gondola turning points were implemented at selected stations. On the one hand, this significantly reduces the number of gondolas and on the other hand it helps to avoid undesired load differences and other effects discussed in Section 5. As a result, the total number of gondolas in the system could be reduced by approximately a factor of four while passenger comfort remained unchanged.

In order to achieve a high quality of the simulation results, a reliable data basis is essential. Regarding the implemented passenger data for the city of Regensburg, it remains to be mentioned that these can be further fine-tuned in the future and, moreover, additional data sources could be taken into account. In addition, further passenger surveys and public transportation usage analyses could be performed.

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