Master thesis to obtain the academic degree

Diplom-Ingenieur

Urban ropeway – material flow study of a ropeway system for the combining transport of people and goods

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Many thanks!

Simon

Statutory declaration

Ich erkläre an Eides statt, dass ich die vorliegende Arbeit selbstständig verfasst, andere als die angegebenen Quellen/Hilfsmittel nicht benutzt, und die den benutzten Quellen wörtlich und inhaltlich entnommene Stellen als solche kenntlich gemacht habe.

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Abstract

The present master thesis deals with an innovative form of passenger and goods transportation in urban areas, which is the application of ropeway systems in those regions. The reason for the research of new ways of mobility is to counteract resulting problems of conventional road traffic like traffic congestions or emissions. These issues are caused by a steady human's desire for individual mobility and ongoing trends of goods transportation and parcel deliveries. By establishing a combined ropeway system in urban areas to transport persons and to carry goods both road traffic sources could be reduced and the situation improved. In order to examine the material flow perspective of such a system the thesis is carried out.

In a first step a comprehensive specification of the urban ropeway system for the combining transport of people and goods is necessary. Out of this investigation the system borders are set as well as the key elements identified. By the creation of a data model and definition of a list of requirements the conceptual model of the urban ropeway system is established. The data model contains the ropeway elements and indicates the relations among them. Beyond that the list of requirements specifies the characteristics of such a complex transport system.

During a subsequent concept phase different network structures and station layouts are found. Out of this research each concept is described in detail and its advantages and disadvantages are listed. The concept pool comprises six possible network structures and seven station layouts. The network structure defines the position of city hubs and distribution units of goods delivery of the system, whereas the station layout set the arrangement of person or goods transfer in each cable car station.

After finishing the specification of the system the conceptual model is implemented into the virtual environment of the material flow software Plant Simulation. The main target of the urban ropeway simulation model is to evaluate material flow parameters like throughputs, throughput times or workloads. Out of these results the ropeway system can be appropriately dimensioned and important insights of a combining system be gained. In addition to the output parameters the ropeway model is built up with various degrees of freedom in order to enable simulations of different scenarios and to ensure the flexibility of quick modifications, if some requirements are changing.

Throughout the implementation a parallel verification process of the simulation model is conducted. The verification reviews the transfer of the conceptual model into a virtual one. As verifying methods the debugger of Plant Simulation, the animation function of Plant Simulation, the variance of input parameters and recording of data with analysis are used. During this iterative process the model is permanently improved and faults diminished.

In a last analysis part one specific scenario is simulated and its results evaluated. This leads to first insights of the material flow performance of such a ropeway system and some templates for further simulation scenarios. Furthermore the approach gives guidance for subsequent examinations.

Kurzfassung

Die vorliegende Masterarbeit befasst sich mit einem innovativen Transportkonzept für Personen und Gütern in urbanen Gebieten. Dabei handelt es sich um den Einsatz von Seilbahnsystemen in Städten. Aufgrund der resultierenden Probleme des konventionellen Straßenverkehrs - wie z.B. Verkehrsstau, Emissionen, etc. müssen neue Formen der Mobilität gefunden und untersucht werden, um dem entgegenzuwirken. Hauptgründe für die alltäglichen Verkehrsprobleme in Städten sind der stetige Wunsch von individueller Mobilität und ein steigender Trend von Gütertransport, vor allem von Paketlieferungen. Mit Hilfe von kombinierten Seilbahnsystemen in Städten, welche Personen und Güter transportieren, würden beide vorgenannten Verkehrsquellen reduziert und eine Verbesserung herbeigeführt. Um dies zu erreichen, untersucht die Masterarbeit materialflusstechnische Aspekte eines kombinierten Seilbahnsystems in urbanen Gebieten.

In einem ersten Schritt erfolgt eine umfassende Spezifikation, die die Systemgrenzen eines urbanen Seilbahnsystems identifiziert. Mit dem Erzeugen eines Datenmodells und einer Anforderungsliste wird das konzeptionelle Modell festgelegt. Das Datenmodell enthält die Elemente einer Stadtseilbahn, sowie dessen Beziehungen zueinander. Darüber hinaus definiert die Anforderungsliste die Eigenschaften und Funktionen.

Mittels einer darauffolgenden Konzeptionierung werden unterschiedliche Netzwerkstrukturen und Stationslayouts identifiziert und dessen Vor- und Nachteile gelistet. Der Konzeptpool umfasst sechs mögliche Netzwerkstrukturen und sieben Stationslayouts. Die Netzwerkstruktur legt Positionen von Cityhubs und Verteilzentren und das Stationslayout die Aufteilung von Personen- und Gütertransfer in den einzelnen Stationen fest.

Nach Abschluss der Systemspezifikation wird das konzeptionelle Modell in der Materialflusssoftware Plant Simulation modelliert. Durch Simulation des Seilbahnsystems werden die maßgebenden Kenngrößen von Durchsatz, Durchlaufzeit und Auslastungen ermittelt. Aus diesen Auswertungen kann ein urbanes Seilbahnsystem adäquat dimensioniert und wichtige Einblicke gewonnen werden. Darüber hinaus erfolgt ein flexibler Aufbau des Softwaremodells, der es ermöglicht Änderungen von Anforderungen oder Strukturen schnell und einfach zu implementieren.

Während der Modellierung erfolgt ein paralleler Verifizierungsprozess des Simulationsmodells, der den Implementierungsvorgang vom konzeptionellen Modell zum Softwaremodell überprüft. Folgende Verifizierungsmethoden werden angewendet: Debugger-Funktion in Plant Simulation, Animation der Materialflussbausteine, Variierung der Eingabeparameter und Datenaufzeichnung mit Datenanalyse. Dieser iterative Prozess entwickelt das Softwaremodell ständig weiter und beseitigt alle vorhandenen Fehlimplementierungen.

In einer Abschlussanalyse wird ein ausgewähltes Seilbahnszenario simuliert und dessen Ergebnisse ausgewertet. Dies führt zu ersten Erkenntnissen der materialflusstechnischen Leistungsfähigkeit des urbanen Seilbahnsystems und bringt Analysevorlagen sowie Anleitungen für weitere Simulationsläufe hervor.

Abbreviations

EU	European Union
CEP	Courier – Express – Parcel: parcel delivery services
MU	Moving unit: mobile object in Plant Simulation to model flow of material
S1-S11	S…Station, 1…station number 1, 2…station number 2 etc.
DES	Discrete event simulation
MGD	Monocable gondola detachable (ropeway construction type)
BGD	Bicable gondola detachable (ropeway construction type)
TGD	Tricable gondola detachable (ropeway construction type)
VDI	Verein Deutscher Ingenieure
CO2	Carbon dioxide
NO2	Nitrogen dioxide
ITL	Institute of Logistics Engineering TU Graz
ISV	Institute of Highway Engineering and Transport Planning TU Graz
tu	Time unit

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1 Introduction

For people in highly industrialized regions mobility is one of the basic desires. Most of them use individual transport vehicles such as cars to reach their daily life destinations. This leads especially in bigger cities to problems. Urban citizens and businesses suffer from air and noise pollutions as well as from traffic congestions. Furthermore conventionally powered vehicles with internal combustion engines have an impact on global warming caused by CO2 emissions. In addition direct and indirect pollutants endanger human health. The key players of pollutants are nitrogen dioxide NO2, very well-known by emissions scandals the last years, and particulates. These substances are blamed to be carcinogenic and harmful for the human body.

The problem of crowded roads will be intensified by the issue of a growing e-commerce sector, as illustrated in Figure 1. Here the expenses for the e-commerce market in Austria over the last twelve years displayed. From the year 2006 to 2017 the spending nearly increased fivefold.

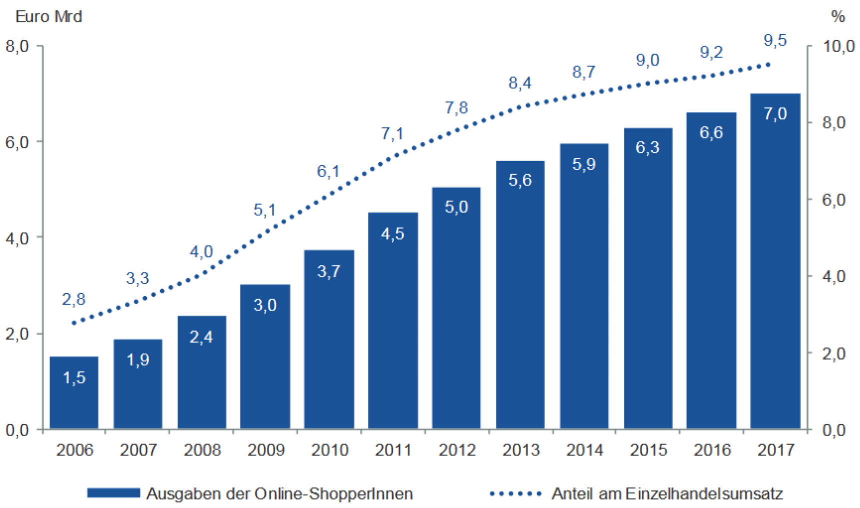


Figure 1: Expenses e-commerce Austria [Ern18]

More expenses in online shopping directly affect the number of parcel deliveries and cause a rise of CEP services (Courier-Express-Parcel). According to the current CEP study of Germany (Bundesverband Paket und Expresslogistik - BIEK) in 2017 a total growth rate of 6-7% p.a. of the consignment volume is predicted. [BIE17]

Most of the time goods are delivered by conventionally propelled vehicles, also in urban areas where alternatives like cargo bikes or electrically driven vans might be feasible as well.

When looking at the pollution and road traffic situation in Austria one hotspot is Graz. As a result of the topography, where Graz is located in a large valley, the citizens are confronted with quite high concentrations of pollutants. This is additionally enforced by the sustained trend of a growing population and rising road traffic. Figure 2 exemplifies the topographical situation of the valley of Graz from the north. This condition makes it very difficult to meet the current limits of the European and national laws of immission control.

Figure 2: Large valley of Graz – Immission [Lan16]

In consequence to the increasing traffic amount in cities and the impacts for citizens and economy the European Union (EU) formed a policy to achieve a clean urban transportation and traffic system. The EU clarified with the strategy "European Urban Mobility" two deadlines with the years 2030 and 2050.

Major points in this paper concerning private transport, transportation of goods and emissions are: [Com17]

- Until 2030 halving the use of conventionally fuelled cars in cities and till 2050 no use of conventionally fuelled cars in urban areas any more.
- Achieving a CO2 free logistic in major urban centres by 2030.
- Cutting transportation emissions by 60% compared to the year of 1990 until 2050
- Promotion of sustainable urban mobility forms like walking, cycling, public transport and new ways of car use and car ownership. [Com17]

This ambitious roadmap on urban mobility in Europe cities leads to new approaches for achieving the targets of the European Union. One innovate concept in terms of public transportation is the use of ropeways, also called cable cars. In some Latin American cities like Caracas (Venezuela), La Paz (Bolivia) or Rio de Janeiro (Brazil), Figure 3, urban ropeways have proven to be well operating public transport systems. In European cities the number of ropeways is negligible, although cable cars will offer new possibilities in terms of transportation.

Figure 3: Urban ropeway system Rio de Janeiro [Dop16]

In order to evaluate the potential of urban ropeways as a public transportation system and as a logistical system for delivering goods into the city, this master thesis delivers indicators and information. All findings of the executed work are directly linked to the geographical, social and demographical situation of Graz.

1.1 Task

The overall task is to define and model an urban ropeway system for the combining transport of people and goods using material flow software. With the virtual urban ropeway model important parameters of cable cars in cities as well as material flow potentials of such systems can be determined.

- First part of the thesis is to outline the characteristics of urban cable cars. With the evaluation of the essential elements and their relations among each other the system will be specified. Furthermore the clarification of the system boundaries is needed to isolate the ropeway system from non-relevant influencing factors. This process of specification supports the definition of the key requirements and input data of urban ropeway systems. Moreover, data acquisition has to be done to feed the system with all relevant information.

- After the specification process the next task is the concept phase. During this project step different concepts of ropeway routes are compared and evaluated, as well as various structures of the ropeway network and various station layouts defined. The development process leads to concrete concept solutions of the urban ropeway system.

- The third part of the thesis includes the whole implementation of the defined system into the material flow simulation tool Siemens Plant Simulation. With the representation of the conceptual model in a virtual environment the whole analysis of an urban ropeway system is eased. Therefore parameters of material flow systems like throughput rates and throughput times of people and goods, but also workloads of elements in the system can be determined.

- Fourth assignment is the verification process of the urban ropeway model according to specified simulation verification methods. By verifying a defined scenario the simulation model is checked towards the right and qualitative implementation of the conceptual model into a virtual one.

- The fifth and final task includes first analysis and evaluations of a specific ropeway arrangement. These results should give guidance for further simulation runs and help to get first indicators of the potential of an urban cable car for the combining transport of people and goods in the Austrian city of Graz.

1.2 Outline

The master thesis is subdivided into chapters in order to enable a quick and comprehensible view on the content.

First part is the introduction phase at the beginning with some thoughts and facts on the traffic situation in cities as well as remarks on parcel deliveries in Austria. Furthermore the task and targets of the thesis are described in detail.

The second chapter contains some theoretical basis in order to get background information on the topics of material flow, urban ropeway systems and simulation processes in general.

In the third one the urban ropeway project is explained and all initial conditions are listed. It is more or less the problem analysis of the master thesis. In addition a project plan presents the steps to achieve the claimed targets.

Chapter number four includes all realised project steps, starting with the system specification over the implementation of an urban ropeway system as well as the model verification and subsequent analysis of simulation results.

The concluding chapter of the thesis contains a summary of the whole content, a conclusion on the results and an outlook for further investigations on the topic.

2 Theoretical basis

In this chapter necessary background information regarding material flow calculation, urban ropeways and simulation processes is provided. This will help to get a better and faster understanding for the modelling steps of an urban ropeway system.

2.1 Material flow calculation

In logistics the material flow theory describes the sequence how goods are passing according to technical and organisational aspects. The following formulas refer to discrete objects (cargo), which are moving in regular and irregular time steps in a network of transport routes. A material flow network consists of sources and drains where objects enter and leave the system. In between these sources and drains processes treat the objects, as shown in Figure 4. [Arn07]

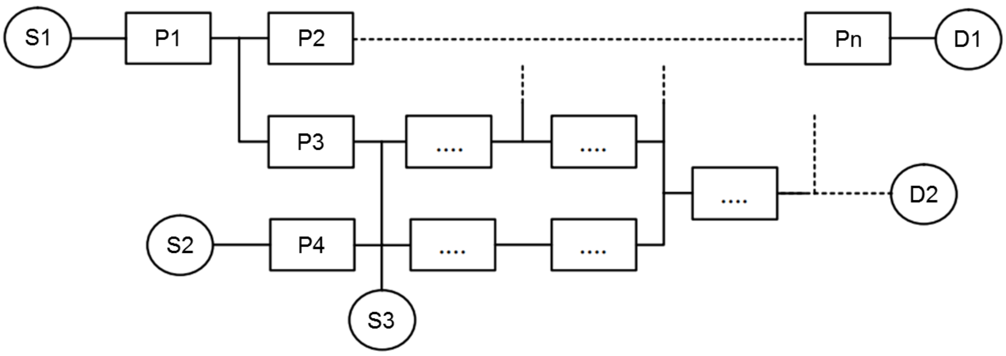


Figure 4: Material flow network, (S source, D drain, P process) [Arn07], own representation

- S ... Source
- D ... Drain
- P ... Process

In a material flow network the processes are partly serial and partly parallel arranged according to system specifications. An increase in flexibility will rise the degree of cross-links between the specific parts in the network and the theoretical calculation and analysis become more complex and difficult. [Arn07]

The most important output parameters and calculation techniques in terms of material flow are the throughput calculation, cycle time calculation and the queuing theory. These calculation formulas and methods are described in the next chapters 2.1.1 and 2.1.2.

2.1.1 Throughput calculation

The throughput calculation is defined as the evaluation of flow intensity and throughputs within a material flow system. In contrast to continuous flows of homogeneous bulk material (gases, liquids etc.), the material streams in logistics deal with discontinuous individual quantity units, termed loads.

Discrete material flow

The throughput of loads is dependent to the load distance s and the mean velocity of the load v. The definition of such a system is shown in Figure 5.

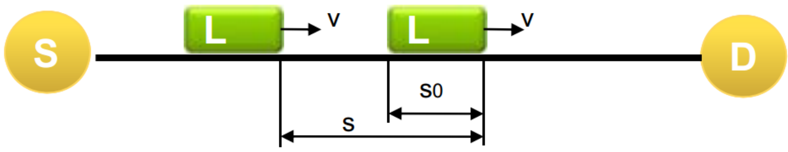


Figure 5: Material flow: throughput calculation [Jod17]

- Ln ... Load element n
- Ln-1 ... Load element n-1
- s ... distance between loads
- s_0 ... length of transportation unit
- v ... mean velocity of the load elements

The operational throughput λ is defined as follows:

$$\lambda = \frac{v}{s} \qquad [\frac{\mathbf{loads}}{\mathbf{tu}}] \qquad \text{Equa. (2- 1)}$$

Equation Equa. (2- 1) of the throughput calculation express the number of loads passing the system per time unit with a mean velocity of v. This mean velocity results from a maximum speed v_{max} and the time needed for the acceleration and deceleration of the transported units. Such a typical velocity-time curve is shown by Figure 6.

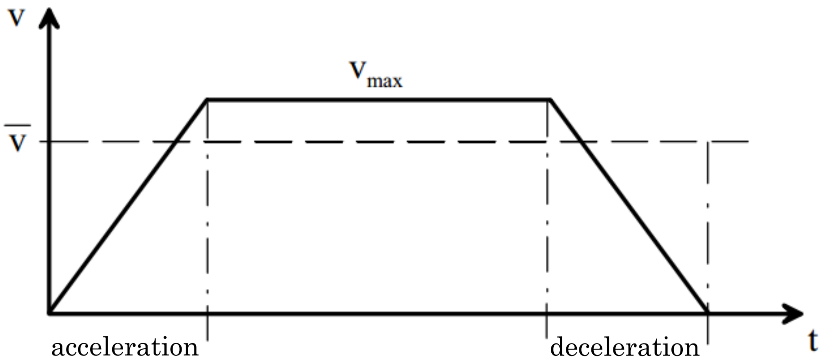


Figure 6: Velocity-time curve transport unit [Arn07], own representation

Additionally the operational throughput λ is defined by the mean cycle time τ:

$$\lambda = \frac{1}{\tau} \qquad [\frac{\mathbf{loads}}{\mathbf{tu}}] \qquad \text{Equa. (2- 2)}$$

The maximum throughput μ is calculated with the velocity of the load unit and the length of the transportation unit and defined as follows:

$$\lambda max = \mu = \frac{v}{s0} \qquad [\frac{\mathbf{loads}}{\mathbf{tu}}] \qquad \text{Equa. (2- 3)}$$

In practice the operational throughput is equal or smaller than the maximum throughput which defines Equa. (2- 4):

$$\lambda \leq \mu \qquad \text{Equa. (2- 4)}$$

The utilization ρ can be expressed according to the definition of the operational throughput Equa. (2- 1) and the maximum throughput Equa. (2- 3) by:

$$\rho = \frac{\lambda}{\mu} \leq \mathbf{1} \qquad \text{Equa. (2- 5)}$$

The throughput and efficiency of a material flow network refers to a specific time unit. The length of the time unit depends on the basic requirements, usually of an hour [h]. For an appropriate dimensioning of logistics systems the throughput and demand are determined in the peak hour of the planning period. [Jod17]

2.1.2 Queuing theory

The queuing theory defines different models to calculate specific parameters of queuing systems like the queuing length, waiting times or number of units in the system. It is used for stationary processes (steady-state condition).

In material flow systems waiting times have a large portion on the throughput time of a unit. Reasons for waiting times are:

- Failures in processes or uncoordinated order sequences
- Changes in production or demand
- Process-related times between production steps
- Changes of sequences in material flow due to sorting, picking etc.
- Etc.

The appropriate analysis of the queuing lengths (number of units waiting) and waiting times is essential in dimensioning of logistic networks to determine the right buffer sizes and minimize inventories. This leads to a reduction in costs and a smooth logistic process. [Arn07]

The general queuing model is defined, as Figure 7 shows:

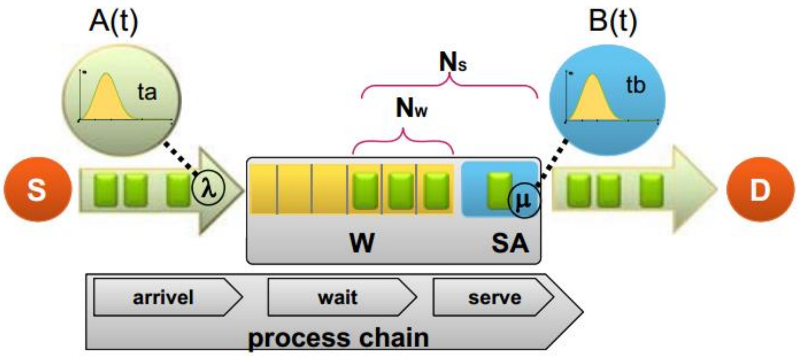


Figure 7: Queuing model definition [Jod17]

- A(t) …arrival process
- B(t) …service process (= waiting and serving)
- S …Source
- D…Drain
- W … Waiting queue
- SA … Service area
- Nw… units waiting [#]
- Ns… units in system [#]

In queuing theory the process chain is subdivided into three areas: arrival, waiting and service. The last two areas waiting and service form together the queuing system. Loads arrive from a source S with an arrival rate λ at the system border and enter the waiting zone. The arrival rate λ is determined by the expected value E(ta) of the interarrival time *ta,* as equation Equa. (2- 6) defines. [Jod17]

$$\lambda = \frac{1}{E(ta)} \qquad [\frac{\text{loads}}{\text{tu}}] \qquad \text{Equa. (2- 6)}$$

The service process B(t) is defined by the service rate μ, whereas μ is determined by the expected value E(tb) of the service time *tb*, Equa. (2- 7).

$$\mu = \frac{1}{E(tb)} \qquad [\frac{\text{loads}}{\text{tu}}] \qquad \text{Equa. (2- 7)}$$

The rate of utilization ρ of the queuing system with only one service station is defined as the quotient from arrival and service rate:

$$\rho = \frac{\lambda}{\mu} \qquad \text{Equa. (2- 8)}$$

If the queuing system has multiple service stations *m* then the utilization is defined as:

$$\rho = \frac{\lambda}{m * \mu} \qquad \text{Equa. (2- 9)}$$

In a stable system (equilibrium state) the condition $\rho < 1$ must be fulfilled.

For the clarification of the different queuing models the Kendall notation defines four parameters:

A | B | m | xxxx

- A ... arrival process A(t)
- B ... service process B(t)
- m ... number of parallel and identical service stations
- xxxx ... control strategy, operating sequence in waiting area. Most important queuing disciplines: FCFS First-Come-First-Serve, LCFS Last-Come-First-Served, SIRO Service-In-Random-Order. [Jod17]

According to this notation both the arrival process A(t) and the service process B(t) can be specified by various distributions, as displayed in Table 1.

Table 1: Kendall notation, queuing theory [Jod17]

Notation	Explanation
M	Exponential distributed time intervals [tu/#] or Poisson distributed time intervals [#/tu] $E(t) = 1/\lambda$, $\sigma(\tau) = 1/\lambda$
D	Dirac distribution used for cycled processes with constant meantime Ta or constant service time Tb $E(t) = T$, $\sigma(\tau) = 0$
G	General distribution, mathematical distribution form is unknown. General distribution defined by parameters: E(t) and Var(t)

Belonging to the queuing theory the most important output parameters are defined by the “law of Little”. According to the “law of Little” the average value of units in the system *Ns* Equa. (2- 10) can be calculated like the average queue-length *Nw* Equa. (2-11).

$$Ns = \lambda * ts \qquad [\#] \qquad \text{Equa. (2- 10)}$$

$$Nw = \lambda * tw \qquad [\#] \qquad \text{Equa. (2- 11)}$$

The sojourn time, average time units spend in the queuing system, is defined with the equation:

$$ts = tw + \frac{1}{\mu} \qquad [s] \qquad \text{Equa. (2- 12)}$$

2.2 Urban ropeways

Ropeway systems have a long tradition and humans using them for years to transport goods over obstacles such as rivers or gorges, as well as to transfer persons in touristic areas for skiing or hiking. Recent technical developments offer ropeways new fields of applications e.g. in urban regions as a public transportation mode, as illustrated in Figure 8.

Figure 8: Urban ropeways; Ankara (left), Hong Kong (right) [Lei18]

2.2.1 Construction types

Based on the construction characteristics of ropeways two different types of cable cars are used for public transportation:

- Hovering cable cars
- Driveway linked cable cars

Figure 9: Hovering cable car (left), driveway linked cable car (right) [Lei18]

Figure 9, on the previous page, displays the two different ropeway construction types. Especially for the examined gondola project for Graz the hovering cable car with a circulating driving mode is taken into account and therefore further explained.

Circulating ropeway system

An electric engine propels a steel cable (rope) at a steady and efficient speed. On this rope gondolas are mounted which enables a system to move people or goods. Figure 10 displays the working principle of such a detachable circulating system:

The gondolas are attached to the cable (moving with rope speed) when travelling between stations. In case of entering a station and moving through a station the gondolas are detached. So the speed of rope can be hold at a constant level while the gondolas can be decelerated. The reduced velocity enables a comfortable alighting and boarding process. When leaving the station the cabins are accelerated up to rope speed and the gondolas move to the next station. [Mon10]

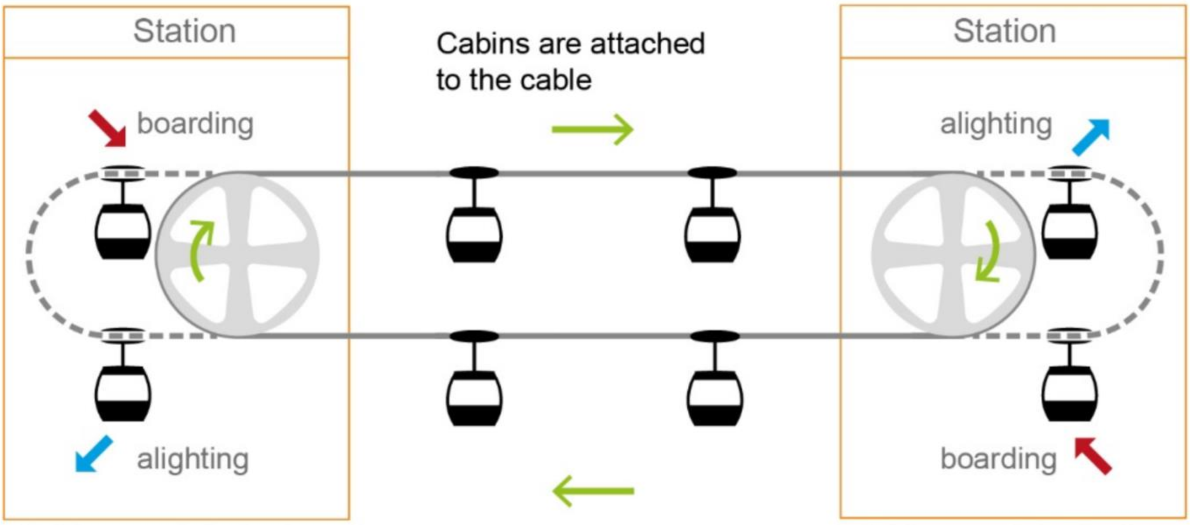


Figure 10: Circulating ropeway system operation mode [Dop18], own representation

The circulating ropeway system can be further classified into groups based on the number of ropes as Figure 11 on the subsequent page shows. The classification groups are:

- MGD: Monocable gondola detachable
- BGD: Bicable gondola detachable
- TGD: Tricable gondola detachable

Additionally each type is further described by material flow parameters:

- Transport capacity of persons per direction in one hour
- Maximum rope speed
- Carrier capacity of the gondolas

MGD: Monocable gondola detachable

BGD: Bicable gondola detachable

TGD: Tricable gondola detachable

Figure 11: Detachable gondola types [Lei18], own representation

MGD:

- One rope which acts simultaneously as a carrying and hauling rope

- Transport capacity: up to 4.500 pph and direction
- Speed: up to 6 m/s
- Carrier capacity: up to 10 persons

BGD:

- One hauling rope and one carrying rope

- Transport capacity: up to 6.000 pph and direction
- Speed: up to 8,5 m/s
- Carrier capacity: up to 35 pers.

TGD:

- One hauling rope and two carrying ropes

- Transport capacity: up to 6.000 pph and direction
- Speed: up to 8,5 m/s
- Carrier capacity: up to 35 pers.

[Lei18]

2.2.2 Field of application in urban areas

In urban areas ropeways can solve various problems of conventional public transportation systems. Due to their flexibility in design and different construction types, cable cars provide wide ranges of applications. On the one hand establishing an areal public transportation network e.g. in developing regions (Latin America), where still no conventional transit mode exists or at the other hand extending or feeding a still existing public transportation system. Illustration Figure 12 displays the general application modes of urban ropeways in combination with conventional systems like busses, trams, metros or light rails. Furthermore Figure 12 outlines the issues most cities are confronted with.

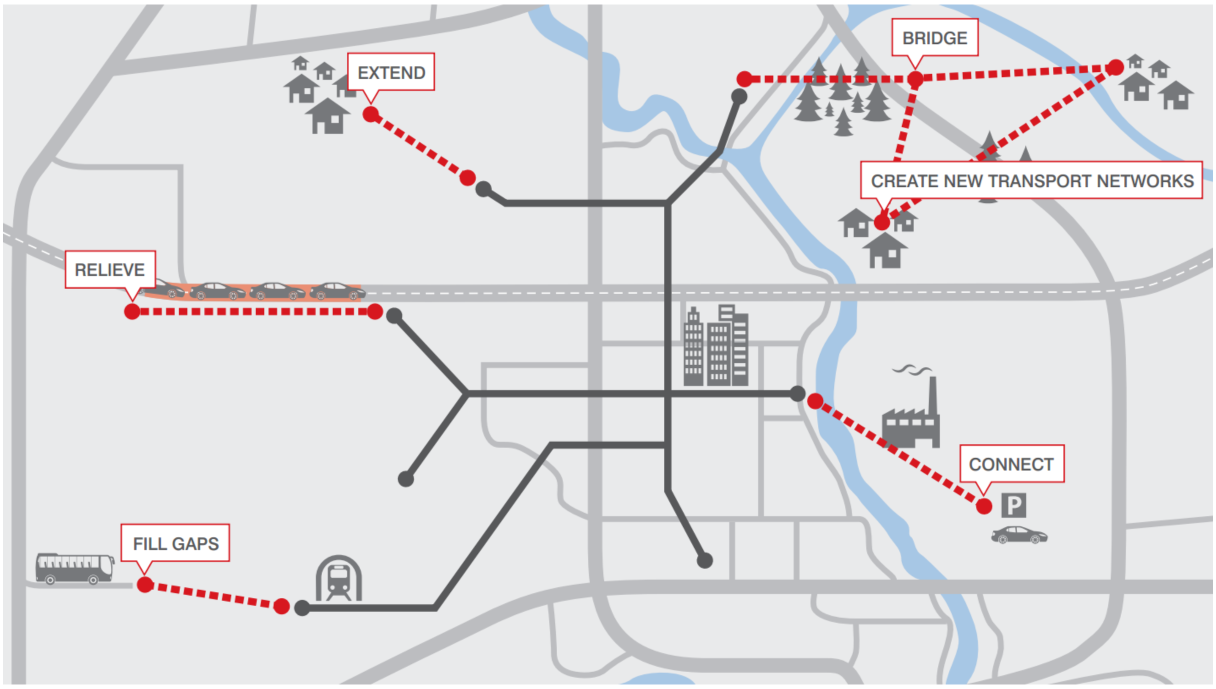


Figure 12: Urban ropeways field of applications [Dop18]

- **Extend**: Extend existing public transit routes (bus, rail, subway etc.), which end due to financial or topographical reasons.
- **Relieve**: Using ropeways to mitigate traffic congestions in areas, where existing transport systems reach their limits and no additional space is available.
- **Fill gaps**: Connecting facilities and infrastructure, which often generate traffic e.g. hospitals, train stations.
- **Bridge**: One of the key characteristics of ropeway system is to easily overcome obstacles. In case of too high investment costs or conventional transport cannot pass, ropeways can be used to cross these barriers like hills, gorges, rivers or human made infrastructure e.g. highways.
- **New transport network**: Linking up several ropeways to a new transportation network, where still no infrastructure exists.
- **Connect**: Connect facilities which belong organisationally together, but are distributed over the city. Examples are university campus, factory sites or exhibition grounds as well as facilities with car parks. [Mon10]

2.2.3 Characteristics & benefits

This subchapter includes the main characteristics and resulting benefits of ropeways in urban areas. [Mon10] [Kre15]

- High capacity, short cycles:
  The short cycles between two gondolas make a timetable obsolete. Ropeways appear for their customers very reliable. Furthermore short cycles minimize waiting times and a high transport capacity is possible. An additional benefit is that the transport capacity can be modified over the day (workload oriented) by attaching and detaching gondolas from the system.
  Figure 13 illustrates the operating ranges of different public transportation modes in terms of transport capacity over the length of the transport system. Circulating cable cars are best suited for system lengths of 5-7 kilometres and transport capacities around 5000 persons per hour and direction against others. Longer distances are also technically feasible, but transit modes like undergrounds or tramways fit in terms of traffic and economic better.

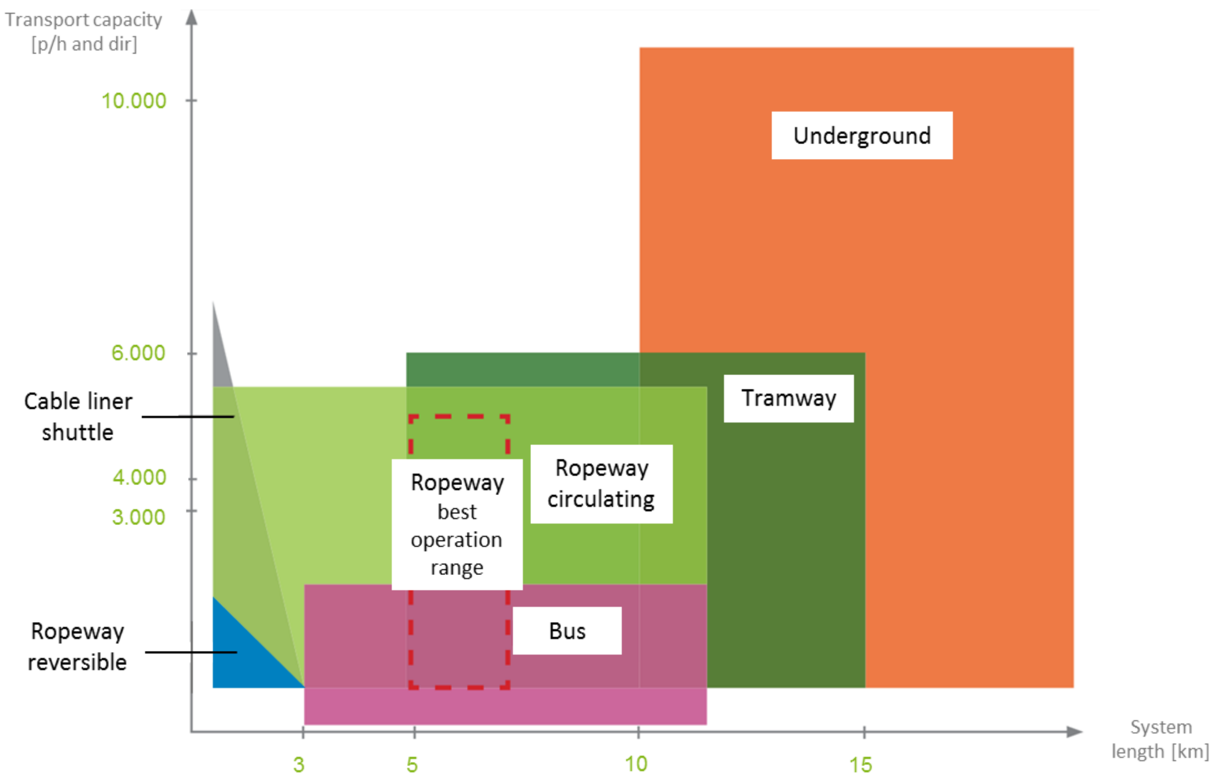


Figure 13: Operating range of public transport systems and ropeways [Mon10], [Kre15], own representation

- Separate driveway:
  Pillars and ropes form the routes of ropeway system, where the driveway is independent and not disturbed by the conventional traffic. This new transportation level allows ropeways to solve congestion and space problems in highly frequented and highly populated areas.

- Fully automated operation:
  The cabins move without additional need of steering or control from station to station. No drivers in individual gondolas are needed, which minimizes the personal costs. Only staff in the different station is needed to observe the overall operation.

- Economic and ecological benefits:
  Integrating an urban ropeway system in cities needs low space in terms of infrastructure. This is possible due to the use of pillars and long spans. In comparison to other public transport modes ropeways cause less costs to build, and to operate. Furthermore the construction period is much shorter.
  Belonging to the ecological point of view cable cars can be operated economically friendly because electrical current is used as driving power. Therefore the system generates no local emissions. Actual operating technologies ensure low noise emissions too, whereby the system can be driven at lower noise levels than busses or tramways.

2.3 Simulation process – Plant Simulation

In this subchapter the basics of simulation studies are explained as well as the most important features of the used simulation software Plant Simulation are listed. For further information on the topic the bibliography list provide useful references.

2.3.1 Definition of simulation process

The norm institute VDI, number 3633, defines the term simulation as the replication of a dynamic process in a model to gain knowledge about this specific real system. In addition, the simulation process describes the preparation, modelling, analysis and realisation of directed experiments. This approach is defined by the reference process for modelling and simulation of material flow system by the ITL institute as the following Figure 14 displays. [Tru17]

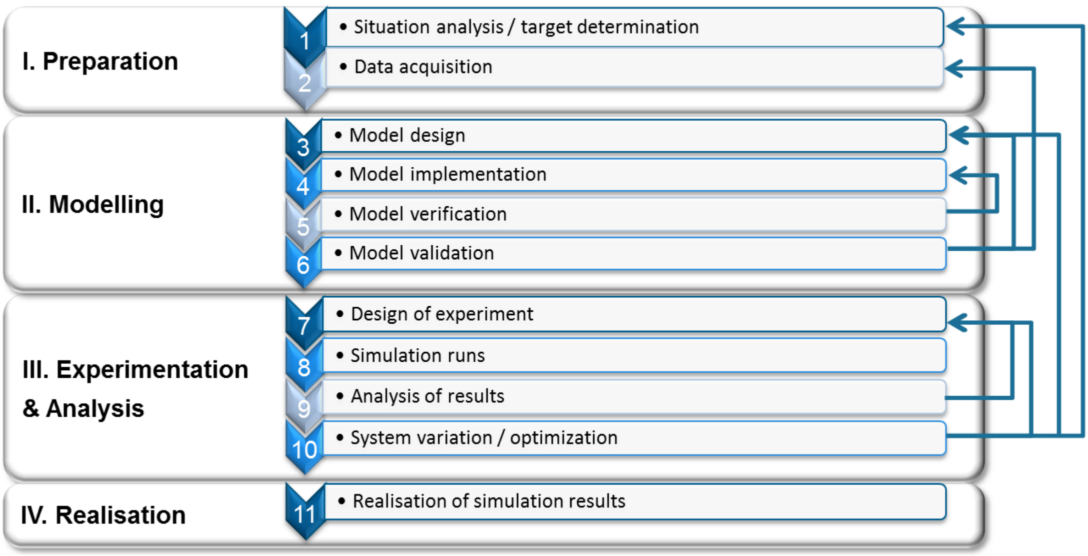


Figure 14: ITL reference process simulation studies [Tru17], own representation

The guidance with the ITL reference process helps to structure a simulation study and also makes obvious that developing a simulation model and simulating a system is a cyclic and evolutionary process. So iterative steps are necessary to refine and modify the model to get results in a proper way. For the subsequent modelling and simulation process of the urban ropeway system, the first three sections of the ITL reference process: preparation, modelling, experimentation & analysis play a major role.

2.3.2 Discrete event simulation

A discrete event simulation, as used in the simulation software of the ropeway model, takes those points in time (events) into consideration, which are of importance to the further course of simulation. This implies that the system behaviour is simulated if the state of the system is changed due to events. In logistics such an event may be a part entering a station or leaving it. Any movements of the specific part between those events are not relevant to the simulation. A big advantage of discrete event simulation is the high performance in contrast to time-oriented simulation (time passes continuously). [Mes17]

2.3.3 Siemens Plant Simulation

Plant simulation is software for the analysis of dynamic material flows which uses the technique of discrete event simulation. It is completely object oriented and is capable to model large and complex systems. The object oriented approach uses classes. A class has a predefined attribute structure. When inserting a class into the model frame a new individual object is generated called instance. This instance has the same structure of attributes as the class. The definition of the instance attributes is made individually according to its requirements. In Plant simulation classes and instances are referred both as objects. In contrast of the derivation of a class it is also possible to duplicate it with the difference, that duplication is an identical, separate copy of the class without inheritance. [Mes17]

The basic principle of the object-oriented programming is displayed in Figure 15.

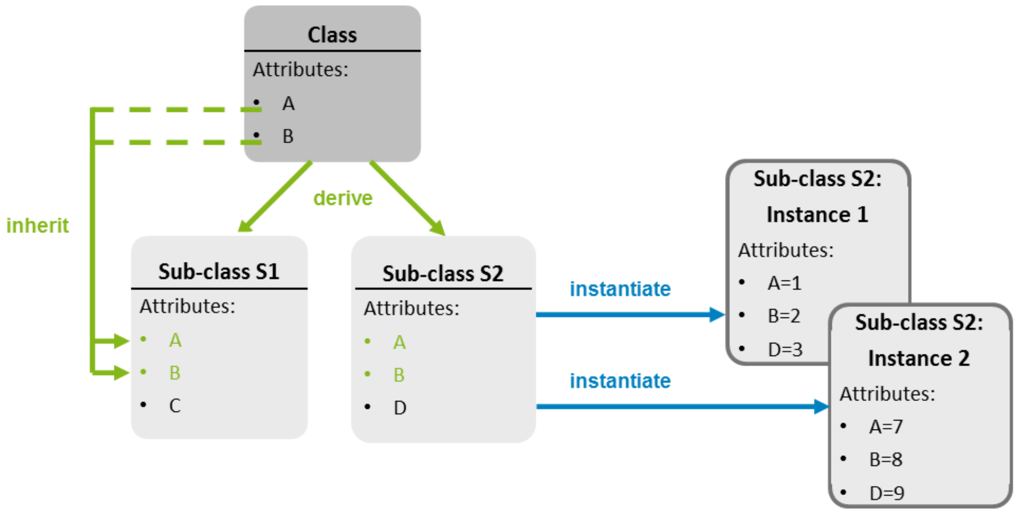


Figure 15: Plant Simulation object-oriented principle [Mes17], own representation

From the class two sub-classes S1 and S2 are derived. The Attributes A and B from the class are inherited. Also two instances from the sub-class S2 are made: Instance 1 and Instance 2 with the defined attribute structure A, B, D but with an individual set of attributes. Plant simulation provides a number of object classes in a class library in order to build up the material flow network. It is also possible to copy or create new classes.

The desktop of Plant Simulation provides various toolbars and docking windows. Figure 16 on the following page displays the standard desktop. The basic elements are:

- **Class library:** Provide all object classes of Plant Simulation in a tree format. Folders can be added, moved or copied by the user.
- **Frame:** The building process of the model takes place here. Objects are inserted into the Frame to model a material flow system.
- **Toolbox:** All object classes are listed and structured. Via drag and drop the objects can be inserted.
- **Console:** Information window to the software user. Information about the executed actions of Plant Simulation is displayed. [Mes17]

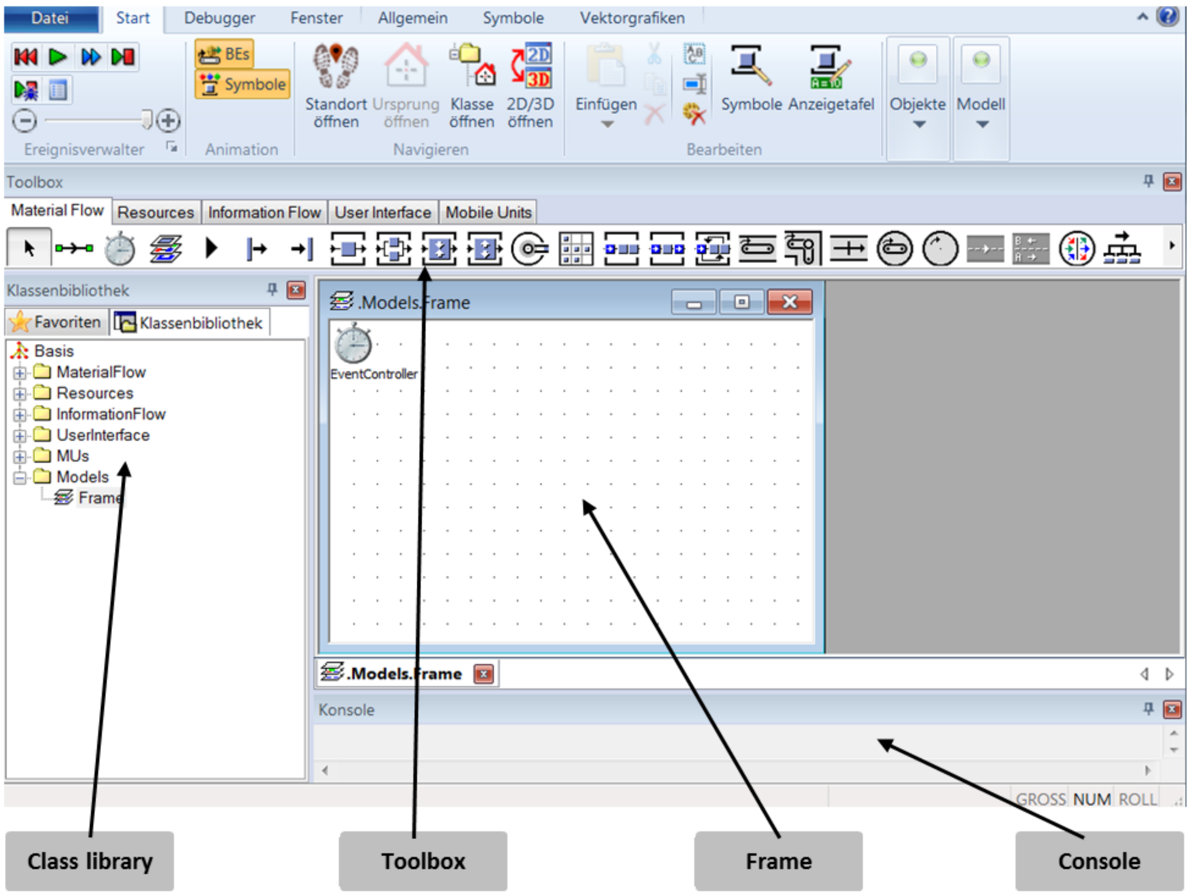


Figure 16: Plant Simulation 11 TR2 default desktop and basic elements

For the modelling process of the urban ropeway system software release Tecnomatix Plant Simulation 11 TR2 is used. Additional helpful information on the material flow software of Plant Simulation is provided by Steffen Bangsow [Ban11], Martijn Mes [Mes17] or by lecture documents of the ITL institute 309.016 [Tru17].

3 Urban ropeway – start & planning

The third chapter describes the initial conditions as well as the planning phase of the master thesis. Furthermore the structure of the project including the material flow study is defined and the individual project steps are presented.

3.1 Start and initial conditions

During the project ROPEWAY_POT*[1] in the year of 2016 by an engineering office, the technical university of Graz and the public transportation operator of Graz first investigations about an urban ropeway system for Graz were made. The study was dealing with surveys belonging to traffic, demand analysis and possible potentials of a ropeway system for the city. The main results are:

- Different routes for an urban ropeway in Graz
- Estimation of the amount of potential customers using the city cable cars
- Potential approval of an urban ropeway system within the current multimodal public transport in Graz

3.1.1 Initial condition – route

The project ROPEWAY_POT has defined five different routes and system arrangements for an urban cable car in Graz and their potential for transporting different customer groups. In expert interviews with the engineering office Planum Fallast and the ITL institute of TU Graz route "3-S_Lang – PF1.1" was selected to be further analysed. This route consists of eleven stations and runs at the following course as Figure 17 displays.

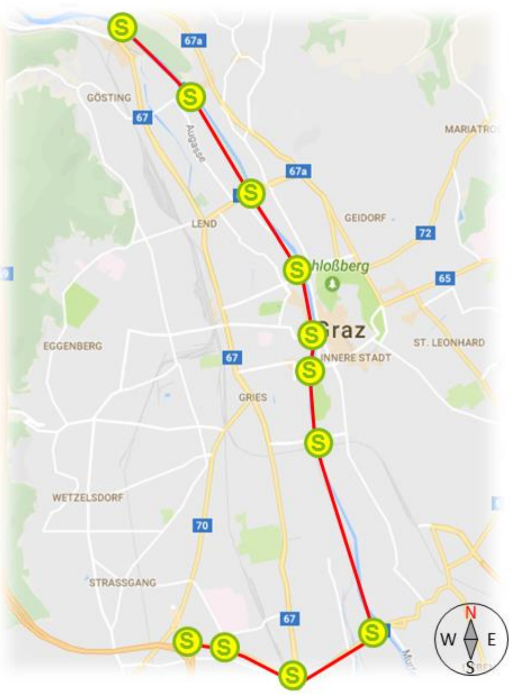


Figure 17: Network route ropeway system "3-S_Lang – PF1.1"

*[1]ROPEWAY_POT: FFG Project - Potential der Stadtseilbahn im multimodalen Stadtverkehr / 2014-2016 / IBV Fallast, Holding Graz Kommunale Dienstleistungen GmbH, ISV TU Graz

Starting point in the North is a P&R facility at Weinzödlbrücke then the route is alongside the river Mur till Puntigamer Brücke, where the course change the direction to the West until the traffic hub at Webling. In the succeeding Table 2 the defined network route "3-S_Lang – PF1.1" is further specified by its stations, its lengths between the stations and the accumulated length from North to South.

Table 2: Network route ropeway system "3-S_Lang – PF1.1" – system specification

No.	Station name	Length between stations [m]	Accumulated length [m]
1	P&R Weinzödlbrücke	1173	
2	Arlandgrund	1746	1173
3	Grabengürtel	1232	2919
4	Keplerbrücke	913	4151
5	Andreas-Hofer Platz	497	5064
6	Gebietskrankenkasse	828	5561
7	Bertha-von-Suttner Brücke	2777	6389
8	P&R Puntigamer Brücke	1483	9166
9	NVK Puntigam	742	10649
10	SCW	495	11391
11	P&R Webling		11886
			11886

3.1.2 Initial condition – potential customers

The results from the project ROPEWAY_POT refer to a scenario in the year of 2025, so the input is based on forecasts of traffic and transport in the future. Users of the ropeway system are classified into seven customer groups:

- Commuters using P&R facilities
- Work citizens
- Shopping citizens
- Spare time activities citizens
- Adventure tour citizens
- Tourist overnight stay
- Tourist on a day trip

For each group the potential to use the ropeway system was analysed. The cable car runs with a cycle time of 42 seconds between two gondolas and one cabin has a transport capacity of 35 persons. This yields in a theoretical transport capacity of 3000 persons per hour and per direction.

Moreover the operating hours of the ropeway system is set to 05:00 till 23:00 o'clock. According to the structure with eleven stations, a TGD ropeway system and the set technical parameters a total potential of 30495 persons per workday is estimated. A more detailed view on the total potential is listed in Table 3. Here the numbers of persons entering a specific station in the network "3-S_Lang – PF1.1" are defined.

Table 3: Number of persons entering a specific station network "3-S_Lang – PF1.1"

No.	Station name	Persons per weekday
1	P&R Weinzödlbrücke	2969
2	Arlandgrund	1027
3	Grabengürtel	2527
4	Keplerbrücke	3609
5	Andreas-Hofer Platz	5614
6	Gebietskrankenkasse	3817
7	Bertha-von-Suttner Brücke	2893
8	P&R Puntigamer Brücke	3791
9	NVK Puntigam	1064
10	SCW	633
11	P&R Webling	2551
	total	**30495**

The numbers in Table 3 point out a high concentration of persons entering the stations in the inner city especially Keplerbrücke, Andreas-Hofer Platz and Gebietskrankenkasse as well as at the three P&R facilities at the North Weinzödlbrücke, South P&R Puntigamer Brücke and South-West P&R Webling.

3.1.3 Initial condition – potential approval

The pre-project ROPEWAY_POT concludes that a ropeway system in Graz has potential concerning transport capacities and can be an attractive transit mode especially for the user group's commuters, citizens and tourists. This may solve current and future public transportation problems.

Despite the results from the pre-project further investigations are necessary to get more detailed information and outcomes whether an urban ropeway system can improve the traffic situation in Graz and to identify the major benefits of an urban ropeway system. These positive results about city cable cars for Graz led to the kick off point for the master thesis.

In contrast to the pre-project in 2016 the present material flow study of an urban ropeway includes a combination of two different ropeway users. Either the gondolas transport people or they transport goods into and out the city. This delivering system of goods will be an innovate approach to reach stricter regulations of emissions in cities and will distribute the costs to a broader user group. Therefore the material flow study analyses the theoretical amount of goods, transported by cable cars, in combination with an attractive transport mode of people.

3.2 Project structure

Regarding to the detailed description of the tasks of the thesis in chapter 1.1 the objectives to deliver are:

- Detailed definition of an urban ropeway system referring to system borders, system characteristics, system requirements
- Development of concepts for the different elements in an ropeway system
- Implementing the ropeway system into the material flow software Plant Simulation
- Verification of the ropeway model
- Analysis of defined system scenarios

In order to achieve these listed objectives the whole development process is subdivided into some project steps as Figure 18 displays. This strategy gives guidance throughout the material flow study of the urban ropeway system.

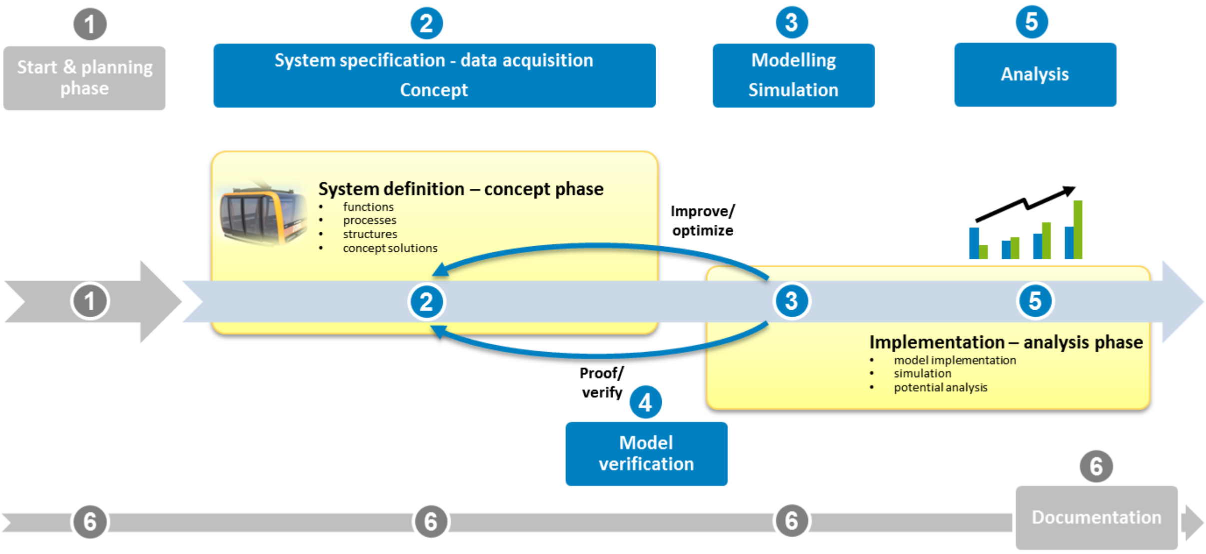


Figure 18: Project steps of the material flow study urban ropeway

As illustrated in Figure 18 the study of city cable car is subdivided into six main project steps:

1. Start & planning:
   During this phase a comprehensive literature research about urban ropeway systems, public transport in cities and future cargo delivery is done. Further basic knowledge about the simulation software Plant Simulation is gained.

2. System specification – data acquisition – concept:
   The second phase provides the specification of the ropeway system, where the functions, processes and structures are defined. In addition necessary input data for a material flow study is acquired and concrete concept solutions are specified.

3. Modelling & simulation:
   The modelling step includes the transfer from the determined ropeway system into a software model and involves the whole building process; definition of software modules, cross-linking of modules and programming of methods.

4. Model verification:
   This project phase is done during the entire third phase of modelling & simulation. The model verification ensures that the defined system functions, parameters and the abstracted model from the second step are correctly transferred into the simulation model. It is more or less an iterative process.

5. Analysis:
   The analysis includes the evaluation and assessment of predefined simulation scenarios and forms the basis of further ropeway simulations.

6. Documentation:
   The sixth step records and documents all relevant results throughout the thesis.

Figure 18 of the project steps and the explanation of the phases indicate that different steps may overlap during the master thesis. These iteration loops are necessary to improve and optimize each step. A further reason is that problems and new insights occur for the first time in a later phase and adoptions have to be made then.

4 Urban ropeway model

Chapter number 4 presents the procedure to achieve the defined objectives in chapter 3.2, as well as the results from the project phases 2 to 5 of the material flow study of an urban ropeway system. The outcomes of the first start & planning phase are already documented at the beginning of the thesis in chapter 2 and in chapter 3.

4.1 System specification – data acquisition – concepts

The second project phase contains three different development processes these are the specification of the system, the acquisition of input data and the definition of potential concepts.

4.1.1 System specification – abstraction

For a material flow calculation and simulation it is essential to specify the system which is treated. This specification includes the analysis of the key factors or elements. Target of the specification process is to identify which components an urban ropeway system for the combining transport of people and goods has, as well as to set the system borders. Due to these requirements the top-down method was chosen. With the top-down method the specification starts with the overall system and according to the level of detail further subsystems are formed. When specifying a system top-down it enables a quick overview of the elements and their correlations inside the system. The procedure of the top-down method is exemplified in Figure 19.

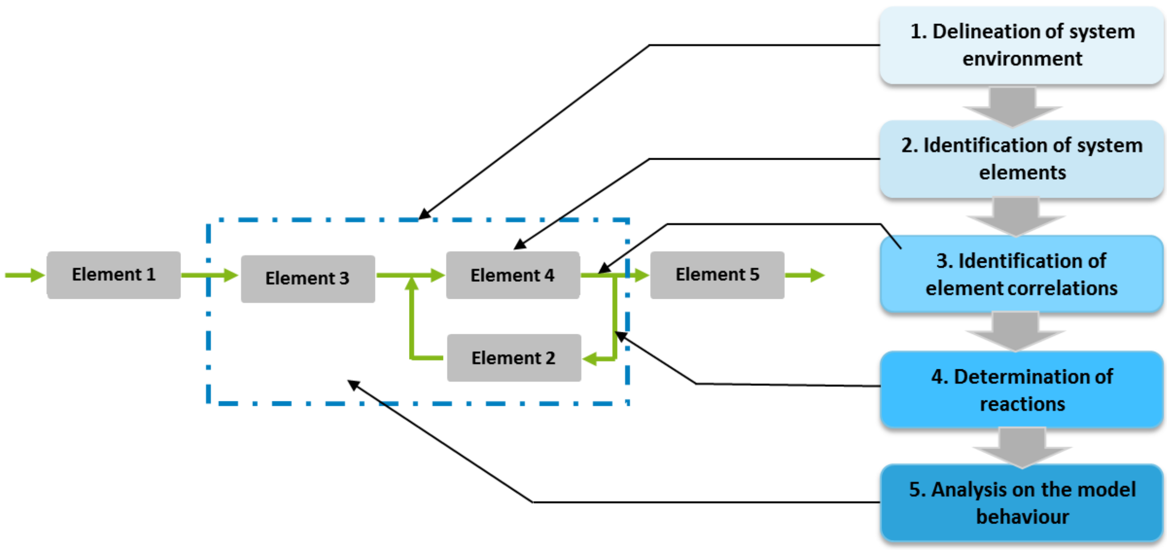


Figure 19: Top-down method [Tru17], own representation

According to the five process steps of the top-down method the urban ropeway system was described.

The first specification was done by an abstraction of the urban ropeway system, as Figure 20 shows.

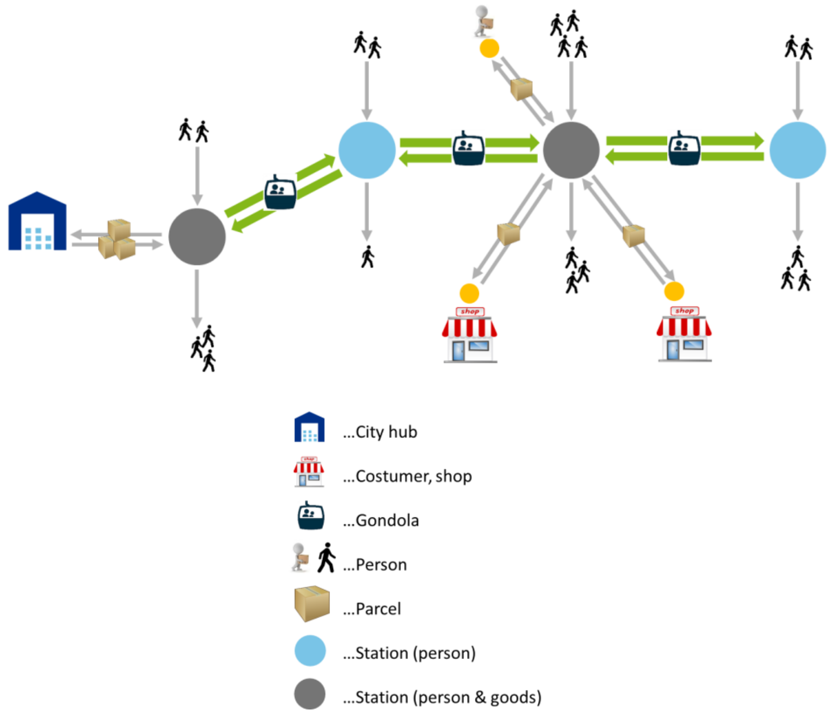


Figure 20: Urban ropeway system abstraction

Out of the abstraction process the key components, which have major impact on an urban ropeway have been identified. These components are:

- City hubs: Facilities, where the transportation process of goods into the city starts. These infrastructures are located outside the inner city in order to reduce the traffic in town.
- Consumer, shop: Customers of the parcel delivery service. The consumers and shops get their goods just like with conventional delivery services POST, DPD, DHL etc. with the difference, that the goods are delivered by the ropeway system into the city and then distributed by economically friendly vehicles like cargo bikes.
- Gondola: Gondolas are the transportation unit either for people or goods. The cycle time of gondolas directly influence the throughput capacity.
- Person: Users of the system; during operating hours persons enter and leave the ropeway stations. Further persons may pick-up their goods at predefined stations.
- Parcel: The ropeway system carries the needed goods of citizens, shops and companies into the inner area of the city.
- Station: The stations are points in the system, where people can leave or enter the gondolas and where goods are loaded into or unloaded from the gondolas. Not every station in the system is able for the handling of goods because of economic reasons.

A further outcome from abstracting the urban ropeway system is a pre-definition of the system border. The border of the cable car system and the environment acts as an interface. The processes outside the border aren't of relevance for further investigations. Inside the system all elements have influence on the analysis results and have to be characterized in a proper way.

4.1.2 System specification – data model

In order to characterize the elements inside the system and also to give a more detailed description of an urban ropeway, a data model is used. The data model demonstrates the fundamental model structure and is the conceptual model for the modelling process into Plant Simulation. Figure 21 displays the data model for a combing system of transporting people and goods.

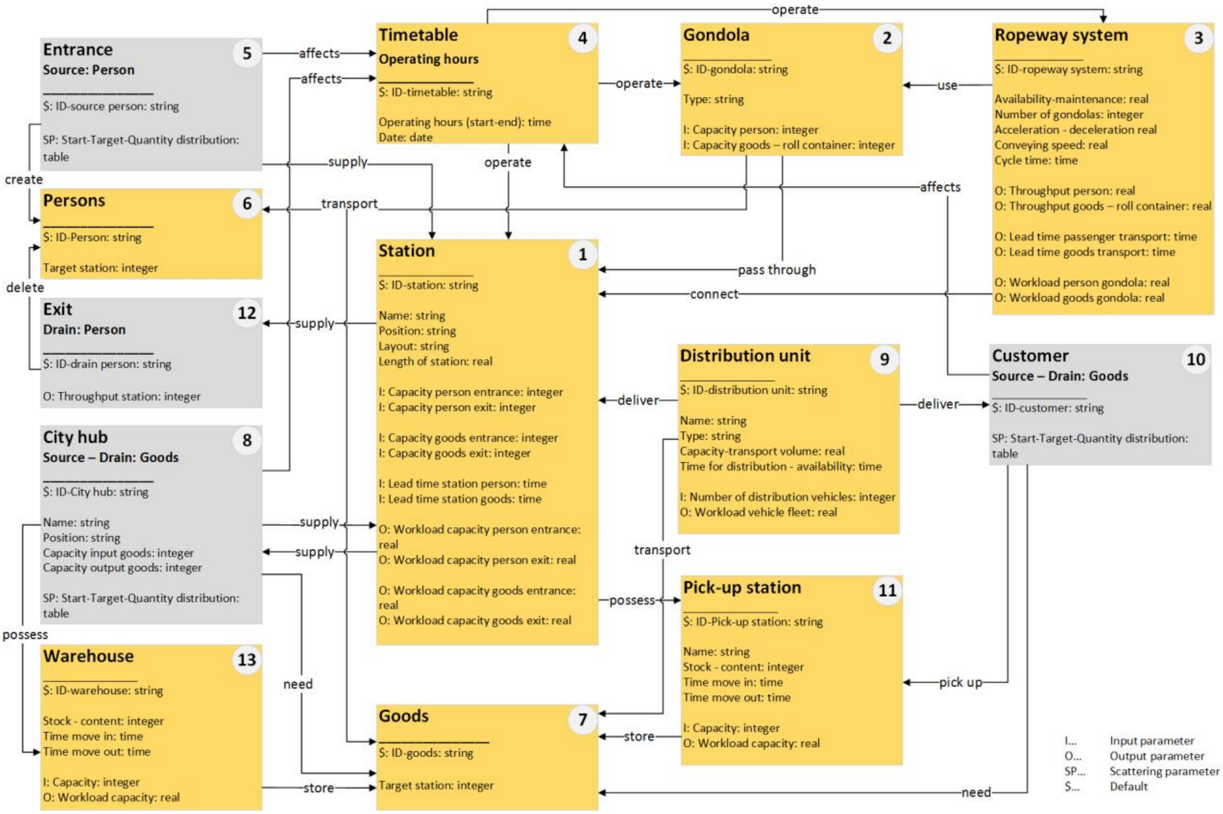


Figure 21: Data model urban ropeway

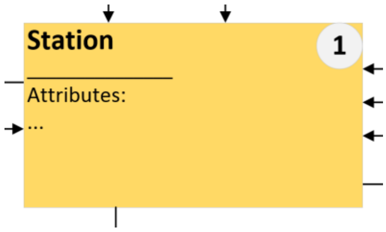
The data model consists of three basic notations:

- Classes: Entities in the system, which represent a component or element.
- Attributes: Each class has attributes, which characterize the class and describes it. Attributes are distinguished between input parameters, output parameters, scattering parameters and default or unique parameters. In addition to that the data type of each attribute is defined to ease the later implementation process into the material flow software.
- Relation: Indicates the correlation between two classes.

The different colours yellow and grey point out, whether the class is an interface to the environment or not. Grey classes are at the system borders, whereas yellow classes don't have a contact to the surroundings. So the data model also specifies the border of the system.

In Table 4 the station class of the data model is exemplarily described by its illustration, attributes and relations, whereas relations are allocated in From – To direction. The full and detailed description of every class is attached in the appendix.

Table 4: Data model description - class station

Class	
Attributes	**Relations**
	
▪ $: ID-station: string ▪ Name: string ▪ Position: string ▪ Layout: string ▪ Length of station: real ▪ I: Capacity person entrance: integer ▪ I: Capacity person exit: integer ▪ I: Capacity goods entrance: integer ▪ I: Capacity goods exit: integer ▪ I: Lead time station person: time ▪ I: Lead time station goods: time ▪ O: Workload capacity person entrance: real ▪ O: Workload capacity person exit: real ▪ O: Workload capacity goods entrance: real ▪ O: Workload capacity goods exit: real	▪ Station – Exit: From the Station persons leave the system via the Exit. Station supplies the Exit with persons. ▪ Station – City hub: From the Station goods leave the system via the city hub. Station supplies the city hub with goods. ▪ Station – Pick-up station: A Station may possess a Pick-up station depending on the network structure where people pick-up their goods.

The number of classes and its various attributes and relations point out a high complexity of an urban ropeway system, which is capable to transport people and goods. Moreover a high amount of parameters have to be defined to get results out of an analysis. To find these input parameters a list of requirements is necessary, as explained in the next subchapter.

4.1.3 System specification – list of requirements

The list of requirements categorises and analysis the general indicators to consider for developing and operating a city cable car system. It is more or less a full description of all parameters influencing the ropeway system. Beyond that it provides different variants or versions of parameters and their conceptual solutions.

The specification of the list of requirements is a process of different project stages: system specification, concept phase and modelling. So the list was permanently adopted and extended. To have a structured approach when defining the various parameters, the list is subdivided into three levels:

- Service
- Structure
- System

Figure 22 demonstrates the divisions of the requirements list.

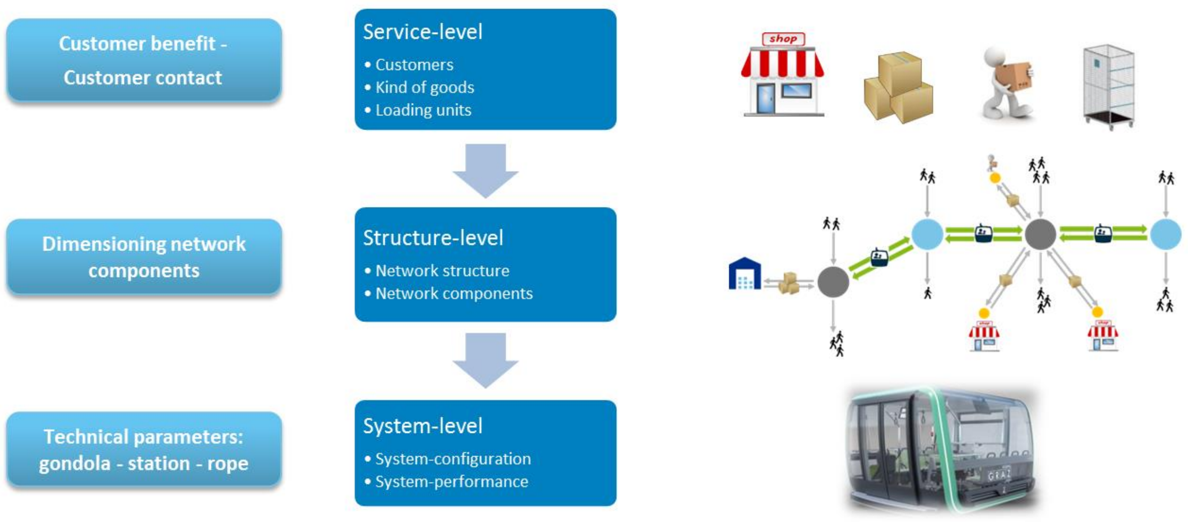


Figure 22: List of requirements: Service-Structure-System levels

The three different levels are:

- Service: Defines the customers of the system, the customer benefits and how the benefits are achieved, specification of the kind of transported goods.
- Structure: Deals with the network architecture and its components.
- System: Specifies all the technical parameters of gondolas, stations and the rope system itself.

Each level has the same structure. On the left hand the parameter number is stated followed by the identified parameter to the right (parameter groups and parameter sub groups). Moreover in the next columns the parameters are described, the requirements to each parameter listed and the values for the conceptual model defined. This arrangement of the list of requirements is displayed in Figure 23 on the following page.

No.	Parameter	Description	Requirements	Concept
1.	**Parameter group**	...	...	...
1.1.	**Sub group A**	... ...	...	...
1.2.	**Sub group B**	... ...	...	...
1.3.	**Sub group C**	... ...	...	...

Figure 23: Structure list of requirements

The filled version of the list of requirements is attached in chapter 9 Appendix.

By defining the list of requirements, the system specification process is completed. As a next step the required input data of the identified parameters have to be acquired and network structures as well as station layouts worked out.

4.1.4 Data acquisition

Various different parameters in the requirements table lead to a comprehensive data acquisition. Only with a qualitative research of the missing input data a simulation can be successful and can deliver accurate results. The data acquisition phase comprises the input data of persons and goods. Therefore a closer look to the data model of chapter 4.1.2 System specification – data model is helpful. Here the classes' entrance, city hub and customer are declared as sources of objects where a Start-Target-Quantity distribution is needed and necessary input data has to be specified.

Figure 24 demonstrates the overall view on the sourcing process. The procedure is split up into data acquisition of persons in grey and data acquisition of goods in yellow.

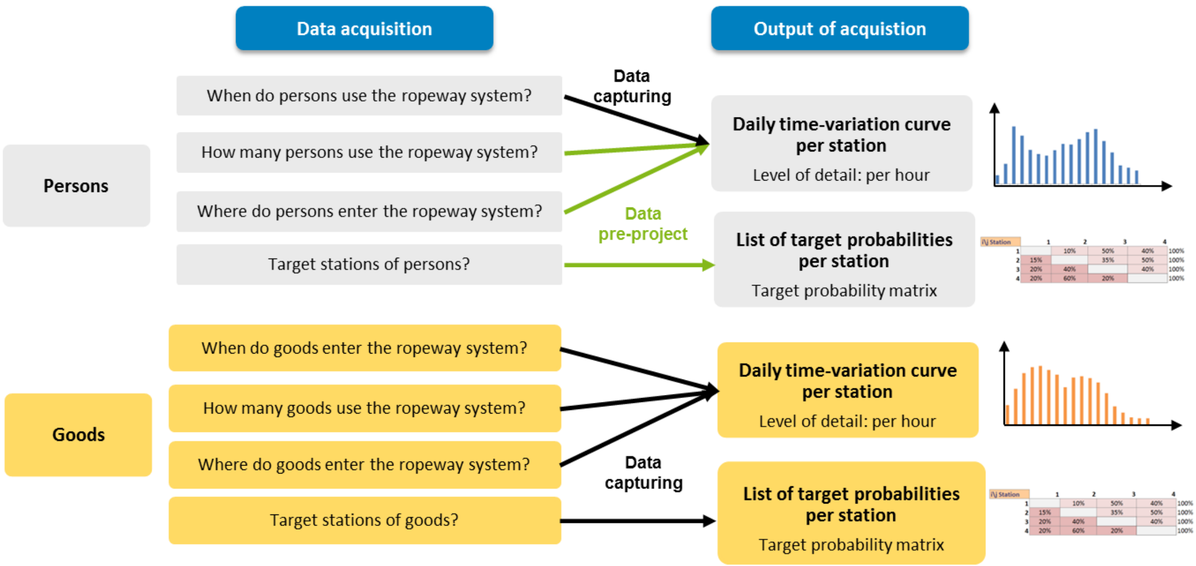


Figure 24: Overview data acquisition person and goods

The inputs referring time, amount, location and target of persons and goods are listed on the left hand. Black arrows signalize that additional data has to be captured the green ones that the data is already available from the pre-project "ROPEWAY_POT". Outputs from the acquisition process are daily time-variation curves, when people enter the station and daily time-variation curves, when goods are loaded into the gondola system. Furthermore the probabilities of the target stations are defined.

4.1.4.1 Data acquisition – persons

To gain the daily time-variation curve of persons per station the missing data is, when people use the ropeway system. Therefore points in time persons go with public transport system are further analysed.

In addition to the times two different daily time-variation curves have to be specified, because of different customer groups. Stations where most of the time commuters are entering (three P&R stations) have another curve than stations where citizens frequently board. The distinction is:

- Time-variation curve at standard stations
- Time-variation curve at P&R stations

Time-variation curve at standard stations

Customer groups of standard stations:

- Work citizens
- Shopping citizens
- Spare time activities citizens
- Adventure tour citizens
- Tourist overnight stay
- Tourist on a day trip

According to this customer groups data for the usage of public transportation was acquired and a resulting time-variation curve at standard stations specified. Three different sources deliver the necessary inputs for the resulting graph:

- Time-variation curve public transport in Steiermark (red)
- Time-variation curve public transport in Zürich (green)
- Time-variation curve public transport in Berlin (purple)

Figure 25 illustrates the three different input curves (in red, green and purple) as well as the resulting one (blue). The time-variation curves are equally weighted for the resulting time-variation graph of standard stations.

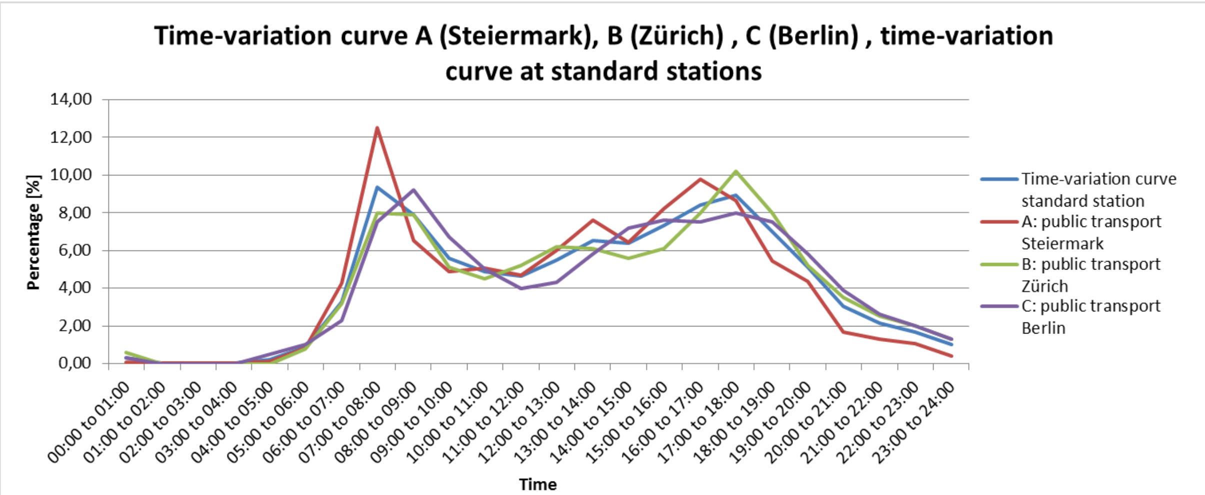


Figure 25: Time variation curves standard station, Steiermark, Zürich, Berlin, graph Steiermark [ISV18], graph Zürich [Rob12], graph Berlin [Mar16], own representation

All three time-variation graphs A, B and C of Figure 25 have common characteristics, a peak at the morning from 07:00 to 09:00 o'clock, low passenger numbers during midday and then a broad distribution in the afternoon and evening hours.

With the consideration of the operating hours from 05:00-23:00 o'clock the final time-variation curve at standard stations looks as Figure 26 demonstrates on the next page. According to this graph (blue) the persons enter the ropeway stations for the defined customer groups (tourists and citizens).

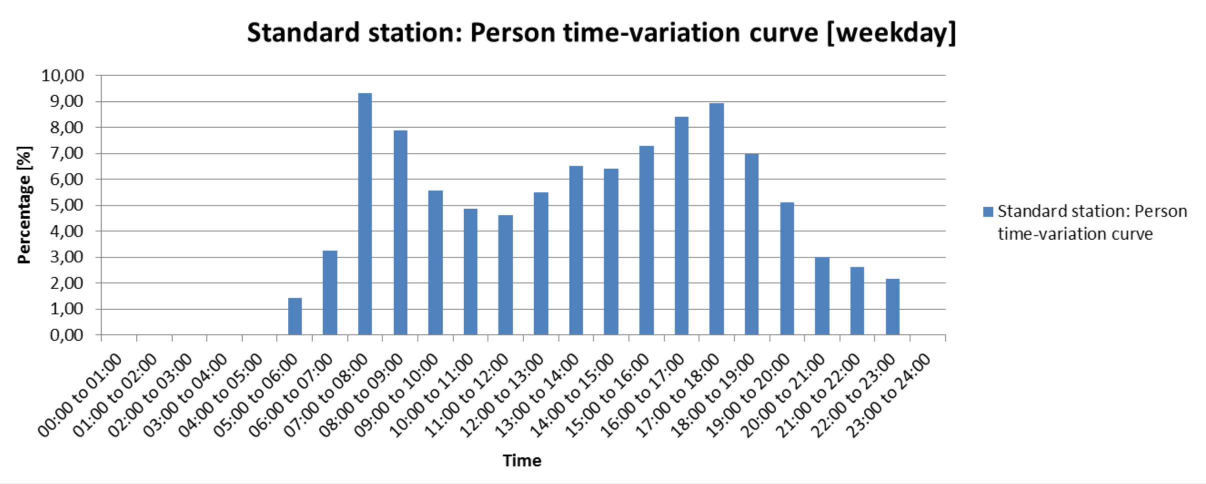


Figure 26: Standard station: person time-variation curve per weekday

Time-variation curve at P&R stations:

All seven customer groups may use P&R stations:

- Commuters using P&R facilities
- Work citizens
- Shopping citizens
- Spare time activities citizens
- Adventure tour citizens
- Tourist overnight stay
- Tourist on a day trip

The distribution curve at P&R stations is formed out of the time-variation curve at standard stations and the time-variation curve when people driving into P&R facilities. The EAR 91 norm (norm for creation process of static traffic) describes among other things the probabilities parking facilities are used for working purpose over one weekday. Figure 27 illustrates in blue the EAR 91 time-variation curve.

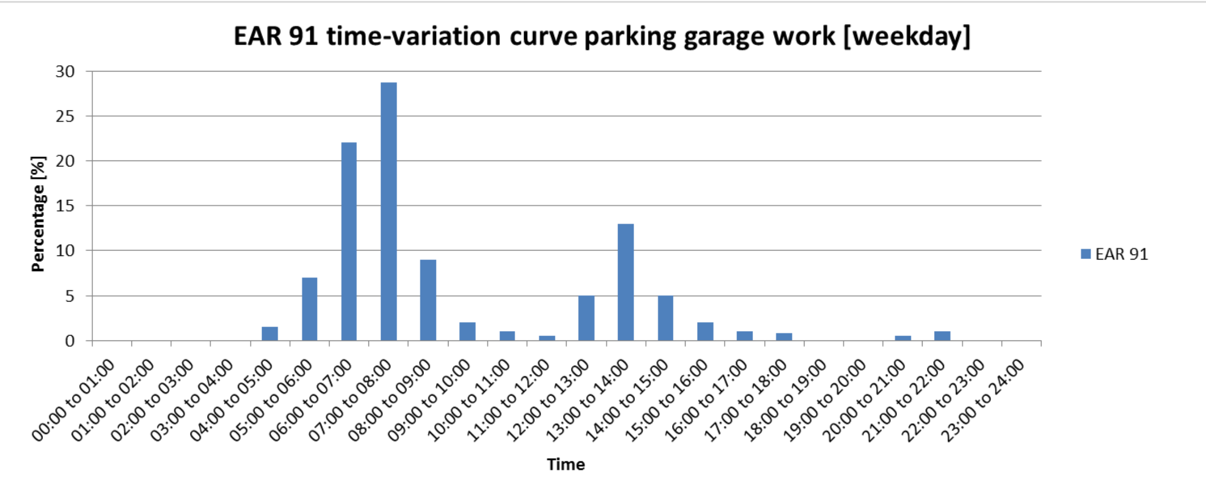


Figure 27: EAR 91 daily time-variation curve [Ros10], own representation

In order to factor into when other user groups (tourists, citizens) beside the main users of P&R stations (commuters) enter the gondolas at those stations a weightage has to be defined. This ratio is specified by the total potential of commuters per day and the total potential of other users per day and the corresponding possible entrance stations which results in the numbers of Table 5.

Table 5: User groups per station type

User group	Amount of persons	Possible entrance stations	Entrance per stations	Weightage
Commuters using P&R facilities	~11500	3	~3833	0,7
Work citizens	~19000	11	~1727	0,3
Shopping citizens				
Spare time activities citizens				
Adventure tour citizens				
Tourist overnight stay				
Tourist on a day trip				
			~5560	

The weightage of 0,7 for the time-variation curve of EAR 91 (Figure 27) and 0,3 for the time-variation curve of standard stations (Figure 26) results in the distribution curve for the entrance behaviour of people at P&R ropeway stations over a weekday. With inclusion of the defined operation hours from 05:00-23:00 o'clock it leads to the graph of Figure 28.

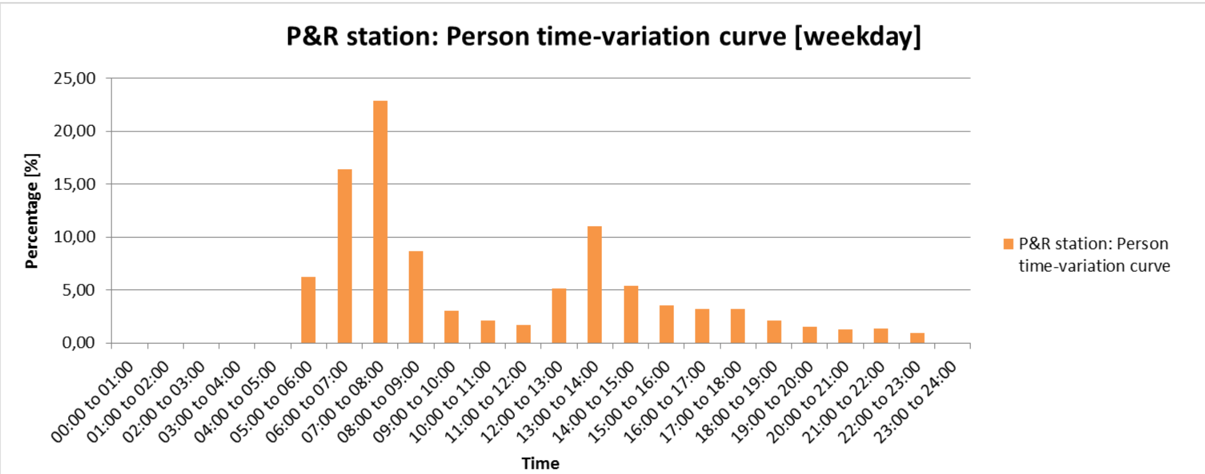


Figure 28: P&R station: person time-variation curve per weekday

In comparison to the time-variation curve at standard stations (Figure 26), at P&R station a higher peak occur in the morning hours and P&R stations are less frequented in the evening hours.

With the time-variation curves and the numbers of persons per station per weekday the workload per station can be calculated and transferred into the simulation model.

Target probability matrix – persons

The target probability matrix provides the necessary information about the target station. It indicates the probabilities (FROM – TO relation) when a person enters the system at a specific ropeway station to which station the person may travel. Figure 29 illustrates the resulting matrix with high target probabilities into the inner city of Graz (Andreas-Hofer Platz and Gebietskrankenkasse).

			To										
			1	2	3	4	5	6	7	8	9	10	11	
		i\j Station	P&R Weinzödlbrücke	Arlandgrund	Grabengürtel	Keplerbrücke	Andreas-Hofer Platz	Gebietskranken kasse	Bertha-von-Suttner Brücke	P&R Puntigamer Brücke	NVK Puntigam	SCW	P&R Webling	
From	1	P&R Weinzödlbrücke		2,64%	6,99%	17,40%	40,17%	20,68%	10,02%	0,81%	0,60%	0,38%	0,30%	100%
	2	Arlandgrund	6,71%		8,57%	18,01%	30,56%	18,01%	11,43%	3,48%	1,24%	0,75%	1,24%	100%
	3	Grabengürtel	6,60%	3,04%		12,02%	33,98%	20,88%	13,45%	4,73%	1,91%	1,26%	2,13%	100%
	4	Keplerbrücke	12,29%	4,86%	9,28%		18,39%	14,64%	14,67%	13,20%	3,89%	2,24%	6,53%	100%
	5	Andreas-Hofer Platz	17,42%	4,89%	15,59%	10,64%		4,39%	9,86%	20,22%	4,13%	2,00%	10,84%	100%
	6	Gebietskrankenkasse	12,47%	4,01%	13,44%	12,08%	6,15%		7,26%	23,82%	5,09%	2,50%	13,19%	100%
	7	Bertha-von-Suttner Brücke	8,61%	3,44%	11,83%	16,51%	18,38%	9,85%		15,46%	4,49%	2,62%	8,80%	100%
	8	P&R Puntigamer Brücke	0,60%	0,82%	3,60%	13,55%	33,61%	28,87%	13,96%		2,65%	1,17%	1,17%	100%
	9	NVK Puntigam	1,78%	1,19%	5,47%	13,56%	23,54%	20,81%	14,03%	9,04%		1,31%	9,27%	100%
	10	SCW	2,68%	1,46%	7,54%	15,82%	21,90%	19,71%	16,30%	8,52%	2,68%		3,41%	100%
	11	P&R Webling	13,43%	0,41%	2,59%	10,84%	28,16%	24,84%	12,45%	1,87%	4,62%	0,78%		100%

Figure 29: Target probability matrix persons (FROM-TO)

4.1.4.2 Data acquisition – goods

As demonstrated in Figure 24 the data acquisition process give answers belonging to the amount of goods and the time when goods are loaded into the gondolas. The definitions at which station the goods enter the system as well as the target probabilities are dependent on the network structure of the ropeway system and not further described in this chapter.

The kind of transported goods is set to big and small parcels, which are commonly delivered by CEP services like DHL, DPD, Post etc. In order to clarify the amount of goods two different acquisitions were executed. First a survey to evaluate the total quantity of parcels delivered in Austria over the last few years 2014-2017 and second an inquiry of the CEP amounts in bigger Cities (Berlin, Hamburg, Munich) in 2017 [BOG17].

With the number of inhabitants in Austria and in those German cities the quantity is based to parcels per person per weekday (Monday till Friday). This leads to the results displayed in Table 6.

Table 6: CEP quantities Austria and Berlin, Hamburg, Munich

Study of Austria				
	2014	2015	2016	2017
Delivered parcels per year [Mio. pieces]	151,1	157,3	181,9	208,9
Parcels per person per weekday [pieces]	0,071	0,073	0,083	0,095
Study of Berlin, Hamburg, Munich				
Delivered parcels per weekday [Mio. pieces]				0,7458
Parcels per person per weekday [pieces]				0,111
Average value of parcels per person per weekday [pieces]				0,103

Both investigations indicate quite the same amount of parcel per person on a weekday; 0,095 in Austria and 0,111 in German cities. Therefore the average of the calculated numbers in 2017 of both studies is further used, in Table 6 average value of parcels per person per weekday 0,103 pieces.

With the number of inhabitants in Graz in the year of 2017 (~320500 [Prä17]) the total amount of parcels being delivered in the city is estimated. Furthermore growing rates of the CEP sector are analysed to be able to make calculations for the future, Table 7 on the next page.

Table 7: CEP growing rate and CEP amount Graz [BIE17]

CEP market growing rate			
Growing rate parcel delivery [% p.a.]	**6,50**	**%**	
Estimated CEP amount Graz			
	2017	**2018**	**2019**
Total number of delivered parcels in Graz per weekday [pieces]	33115	35268	37560

In order to estimate the CEP amount of the ropeway system a corridor of five kilometres alongside the ropeway route is defined. Figure 30 illustrates in purple these five kilometres circles. Also in Figure 30 the route of the ropeway network in red and the outline of Graz with its districts in green.

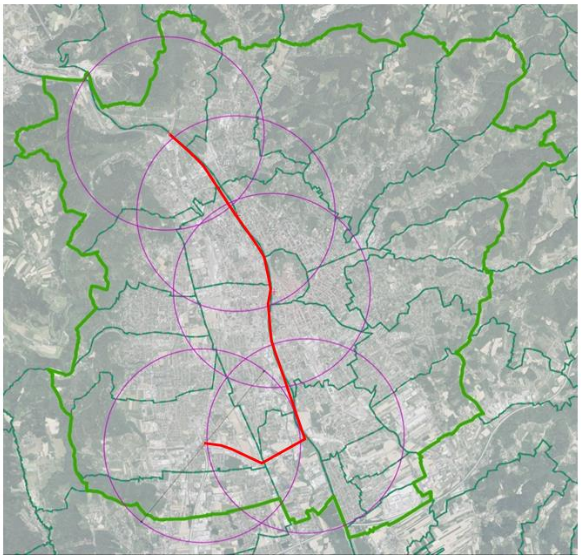


Figure 30: Corridor CEP amount alongside the ropeway system [GIS18], own representation

With the analysis of the number of persons living in this area and the same CEP growing rates, as in Table 7, the value of CEP deliveries is calculated for the years 2017, 2018 and 2019 alongside the ropeway system. The results are in Table 8.

Table 8: CEP amount ropeway system

Estimated CEP amount at the ropeway system			
	2017	**2018**	**2019**
Total number of delivered parcels at ropeway system per weekday [pieces]	26866	28612	30472

So in the year of 2018 a theoretical potential of CEP deliveries of about 28000 parcels per weekday is estimated. This calculation gives first reference points about the necessary capacity of the ropeway system to transport goods beside the function as a public transport mode, but with the certainty that not all CEP deliveries are done by the urban cable car. This yields to a lower capacity need for transporting goods in case of an urban ropeway system.

Time-variation curve of goods

For the specification of time-variation curve of goods the delivery times are evaluated. For this purpose three different sources deliver input data for the resulting graph:

- Time-variation curve X: Bachelor thesis TU Graz Mizera number of entrepreneurs delivering to the inner city of Graz (red)
- Time-variation curve Y: Evaluation of delivering vehicles (Vans) at roads in Switzerland (green)
- Time-variation curve Z: SVI Norm SN 640 005b graph of local traffic of goods transportation

In Figure 31 the input curves (in red, green and purple) as well as the resulting one (blue) are demonstrated. The time-variation curves are equally weighted for the resulting time-variation graph of goods delivery.

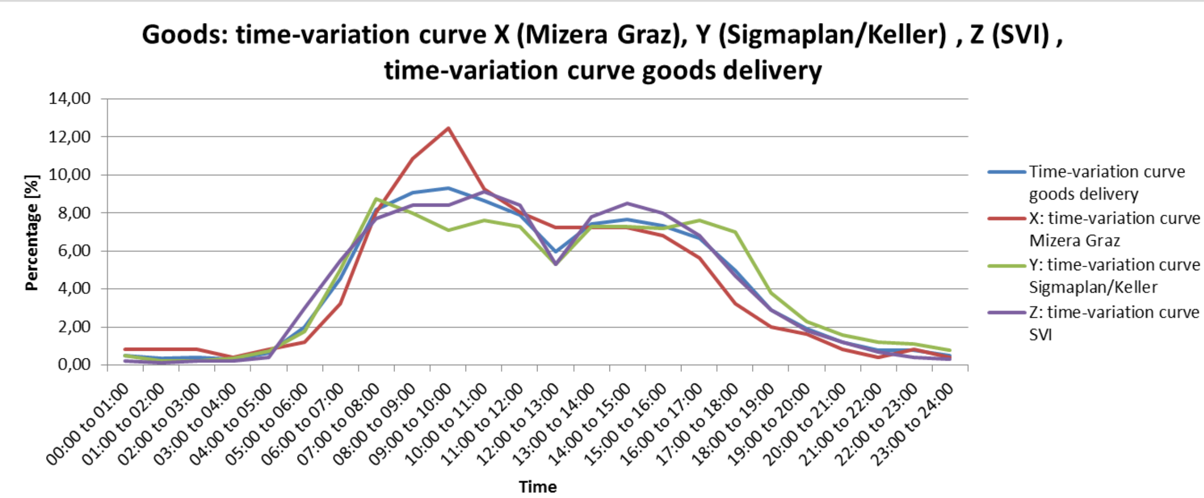


Figure 31: Goods time-variation curves X – Graz, Y – Sigmaplan/Keller, Z – SVI and resulting delivery graph of goods, own representation

All input graphs (red, green, purple) indicate a peak at the morning hours between 07:00-10:00 o'clock. In this period of time also the most goods are delivered in contrast to other daytimes. So the ropeway system has to ensure that the customers get their wanted goods in the morning hours as well.

Due to the quite high difference of the three input curves in the morning hours from 07:00-10:00 o'clock, the resulting time-variation curve for the delivery of goods is only a reference point and not an exact graph.

With consideration of the operating hours of the ropeway system from 05:00-23:00 o'clock, the resulting time-variation curve of the delivery process of goods is displayed in Figure 32.

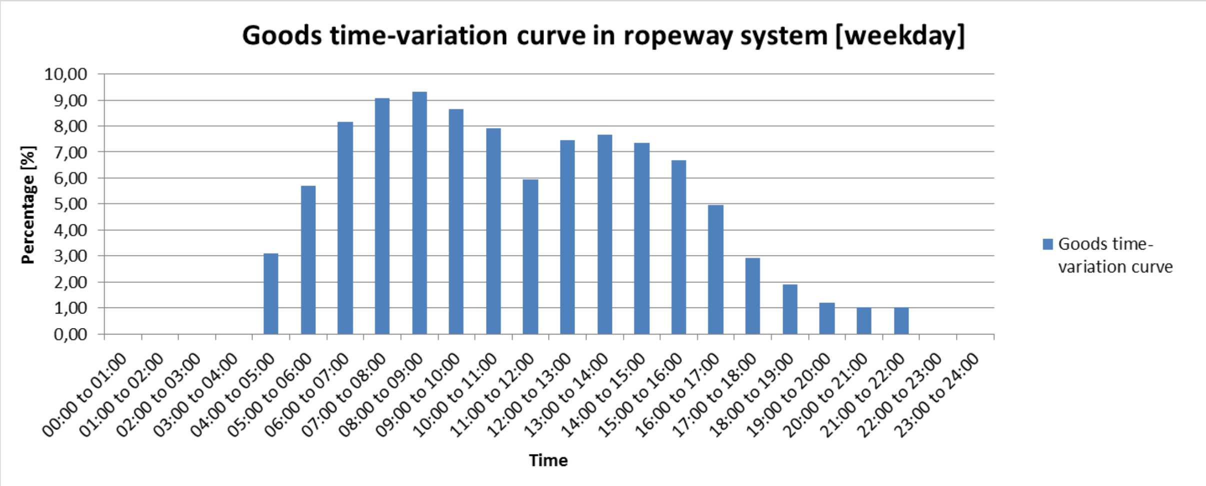


Figure 32: Time-variation curve of goods in ropeway system

By the amount of goods and the delivery times the workload of each station can be analysed and transferred into the simulation model.

All other input data like technical parameters or station layouts were acquired by expert interviews with IBV-Fallast, ISV-TU Graz, Leitner ropeways and the ITL institute of TU Graz, as well as by defining different concepts. The documentation of the acquiring process is written down in frequent protocols and by the requirements list.

4.1.5 Concept

The definition of concepts is the last part of the second project phase. It includes the identification and evaluation of different concept solutions belonging to network structure and station layout of the ropeway system. In a permanent iteration with the list of requirements as well as project meetings the concepts were developed and further improved. The results are demonstrated and explained on the following pages.

4.1.5.1 Concept – network structure

The network structure defines the positions of city hubs and distribution units plus pick-up stations along the route of the ropeway system. Therefore the structure has direct influence on the costs of the system, as well on the maximum material flow capacity (how much goods are possible to be transported). Furthermore it influences the travel time of the gondolas and the system as a public transport mode. Beside to these remarks the requirements to the geographical position of city hubs and distribution units were set as Figure 33 demonstrates:

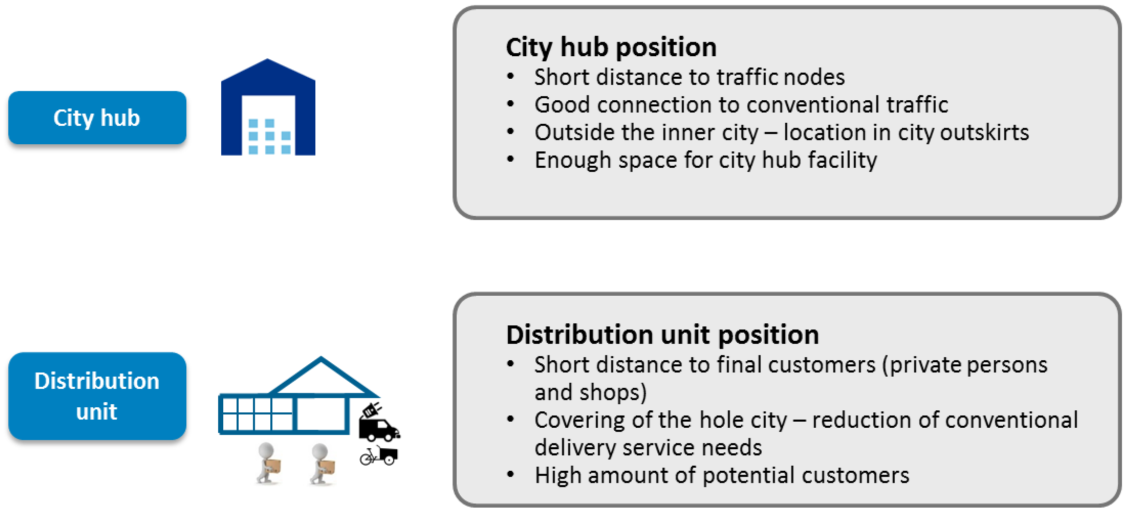


Figure 33: Location requirements city hub and distribution unit

- City hub:
  For the geographical position of the city hub it is essential that the facility is located nearby traffic nodes. This enables a good incorporation of a new delivery system in an existing infrastructure, which is predominantly designed of road traffic. Moreover city hubs need space for the facility and the vehicles which deliver the goods to the hubs. As stated at the beginning of the document the endeavour of legislators is to ban conventionally driven vehicles from cities to improve the air quality. Therefore the city hubs should be located outside the inner town.

- Distribution unit:
  The position of the distribution units have to be close to customers e.g. private person or companies/shops, which results in very short ways from the ropeway system to the consumers. Furthermore the units should cover almost the whole city to reduce the need of conventional delivery services.

To identify different concepts of network structures the route of the ropeway framework has to be analysed according the listed requirements before. Figure 34 shows the segmentation of the ropeway route in Graz regarding the location criteria of city hubs and distribution facilities.

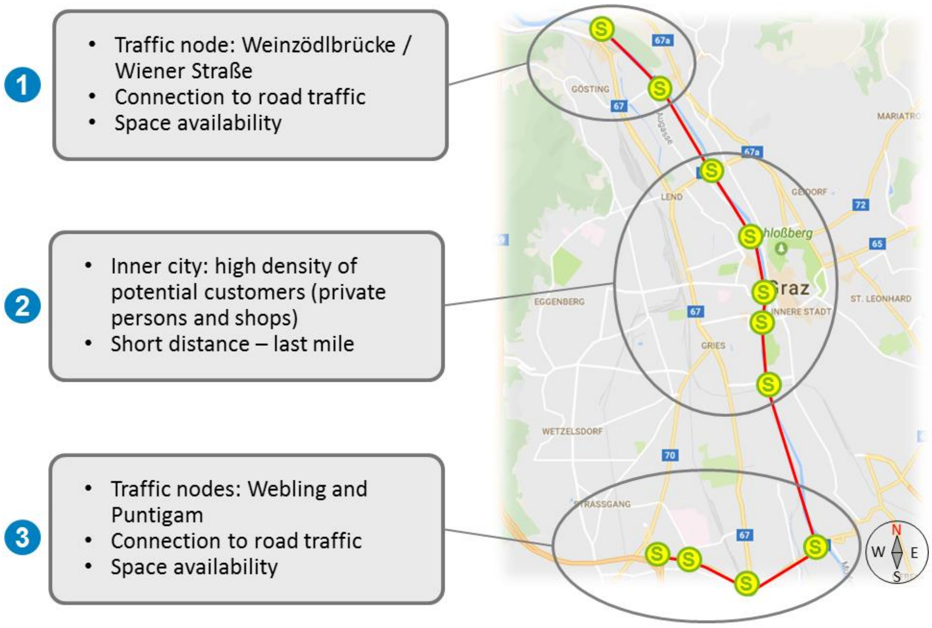


Figure 34: Segmentation ropeway route location criteria city hub, distribution unit

- (1) Marked area one has tendency for a city hub because of the traffic node Wiener Straße, which enables a close connection to the highway A9. Further the region provides more space than in the inner city.
- (2) Many citizens live and work (shops, stores) in this part of the town. Here the ropeway stations can fulfil the function as a distribution unit to conduct the last mile delivery service close to potential customers.
- (3) The stations at the south part of the cable car system have attributes for the implementation of city hubs. Traffic nodes Webling and Puntigam ensure a close linkage with the highway A9 and also a looser built-up area.

The route segmentation leads to six different network structures of the ropeway system which are further described by illustrations and their characteristics on the next pages, Table 9. The symbols of the graphics are explained in Figure 35 below.

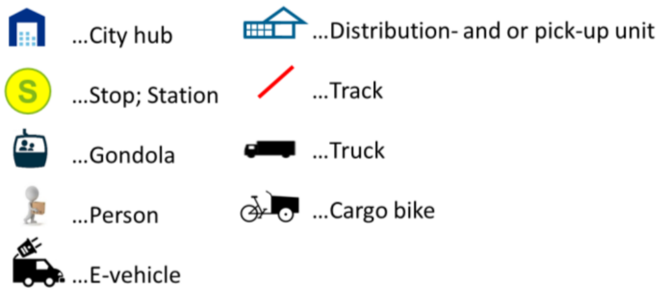
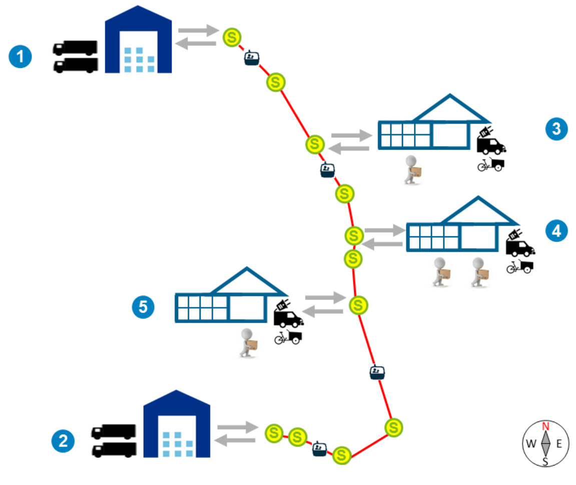
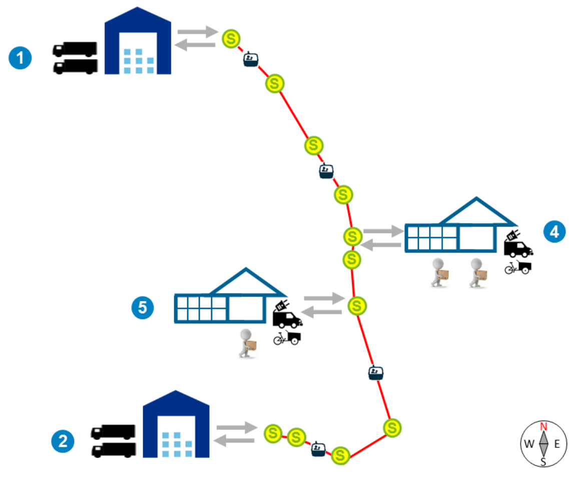
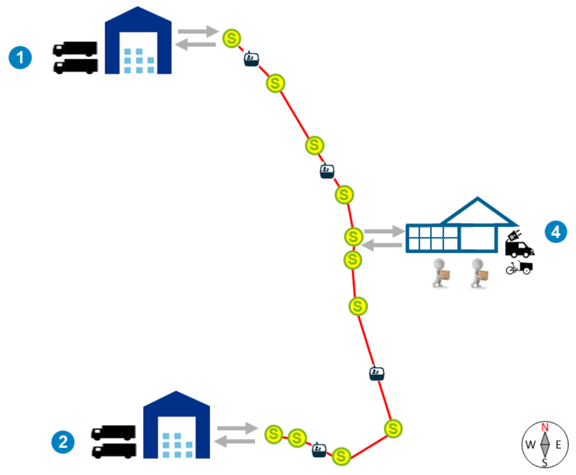


Figure 35: Symbols network structures

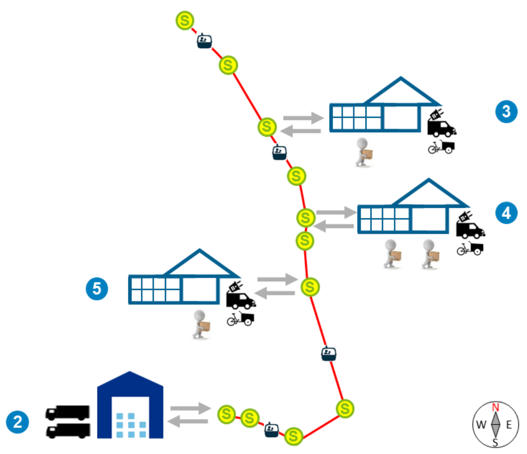
Table 9: Concepts network structures ropeway system

Network structure 1	
Illustration	**Characteristics**
	▪ City hubs: (1) City hub North P&R Weinzödlbrücke (2) City hub South P&R Webling ▪ Distribution units: (3) Grabengürtel (4) Andreas-Hofer Platz (5) Bertha-von-Suttner Brücke ▪ Pros: ○ High coverage of potential customers ○ Short delivery ways ○ High theoretical transportation capacity of goods (two city hubs) ▪ Cons: ○ High infrastructure costs ○ High need of staff

Network structure 2	
Illustration	**Characteristics**
	▪ City hubs: (1) City hub North P&R Weinzödlbrücke (2) City hub South P&R Webling ▪ Distribution units: (4) Andreas-Hofer Platz (5) Bertha-von-Suttner Brücke ▪ Pros: ○ Middle coverage of potential customers ○ Short delivery ways ○ High theoretical transportation capacity of goods (two city hubs) ▪ Cons: ○ High infrastructure costs ○ High need of staff

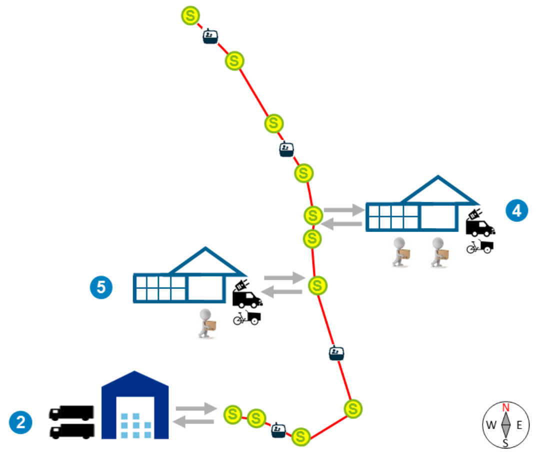
<table>
<tr><th colspan="2">Network structure 3</th></tr>
<tr><th>Illustration</th><th>Characteristics</th></tr>
<tr><td>
</td><td>

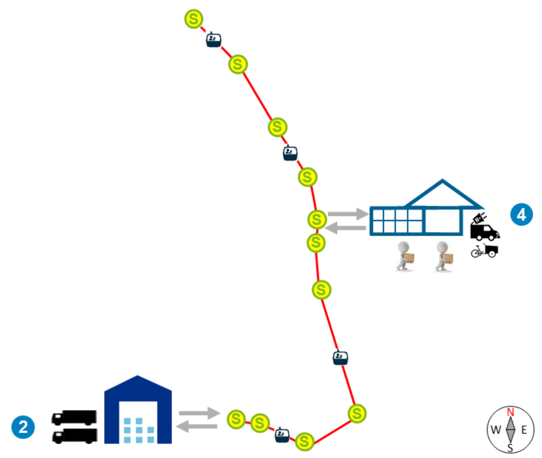
- City hubs:
(1) City hub North P&R Weinzödlbrücke
(2) City hub South P&R Webling
- Distribution unit:
(4) Andreas-Hofer Platz
- Pros:
  - High theoretical transportation capacity of goods (two City hubs)
- Cons:
  - Infrastructure costs (two city hubs)
  - Low coverage of potential customers, longer delivery ways

</td></tr>
<tr><td colspan="2"></td></tr>
<tr><th colspan="2">Network structure 4</th></tr>
<tr><th>Illustration</th><th>Characteristics</th></tr>
<tr><td>
</td><td>

- City hub:
(2) City hub South P&R Webling
- Distribution units:
(3) Grabengürtel
(4) Andreas-Hofer Platz
(5) Bertha-von-Suttner Brücke
- Pros:
  - High coverage of potential customers
  - Short delivery ways
- Cons:
  - Middle infrastructure costs (three distribution units)
  - Need of staff
  - Half of the theoretical transportation capacity of goods compared to structures 1,2,3

</td></tr>
<tr><td colspan="2"></td></tr>
</table>

Network structure 5	
Illustration	**Characteristics**
	▪ City hub: (2) City hub South P&R Webling ▪ Distribution units: (4) Andreas-Hofer Platz (5) Bertha-von-Suttner Brücke ▪ Pros: o Middle coverage of potential customers o Short delivery ways ▪ Cons: o Middle infrastructure costs (two distribution units) o Half of the theoretical transportation capacity of goods compared to structures 1,2,3

Network structure 6	
Illustration	**Characteristics**
	▪ City hub: (2) City hub South P&R Webling ▪ Distribution units: (4) Andreas-Hofer Platz ▪ Pros: o Lowest infrastructure costs o Low staff need ▪ Cons: o Half of the theoretical transportation capacity of goods compared to structures 1,2,3 o Low coverage of potential customers o Long delivery ways

4.1.5.2 Concept – station layout

The different ropeway structures indicate that some stations along the ropeway system are only used for the transportation of persons and others for the transfer of persons and goods. In order to enable the combining usage of the stations, it is necessary to define where the persons can enter or leave the gondolas and where the handling of goods takes place. Therefore the station layouts specify the arrangement of the exit and entrance areas of persons, as well as the handling areas of goods. The layouts are more or less the schedules for persons or goods in the stations. Out of this the arrangements have direct influence on the lead times of the gondolas through the station and the dimensions (length/width) of the stations. To ensure smooth exit and entrance of persons or goods and under consideration of technical feasibility, seven different layouts for the combining transfer of goods and persons were identified. These station arrangements are detailed described in Table 11. The symbols of the station layout illustrations have the meaning as Figure 36 displays.

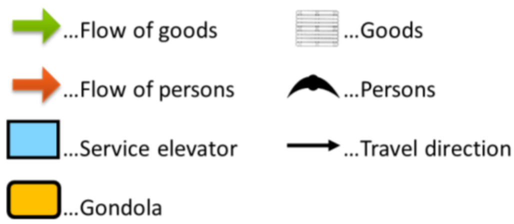
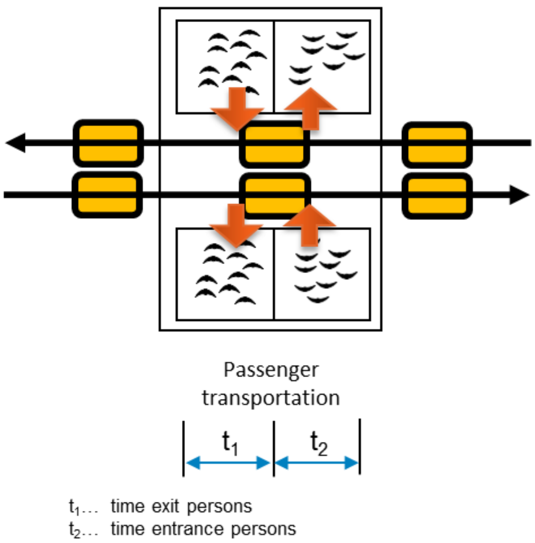


Figure 36: Symbols station layouts

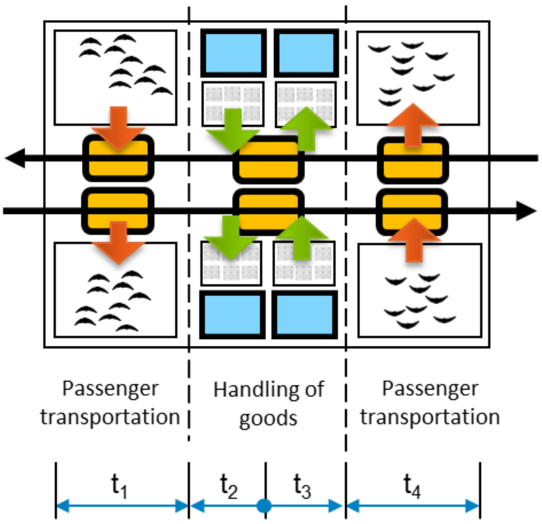
In the case of ropeway stations, where only persons are transported, the station layout is described in the following Table 10.

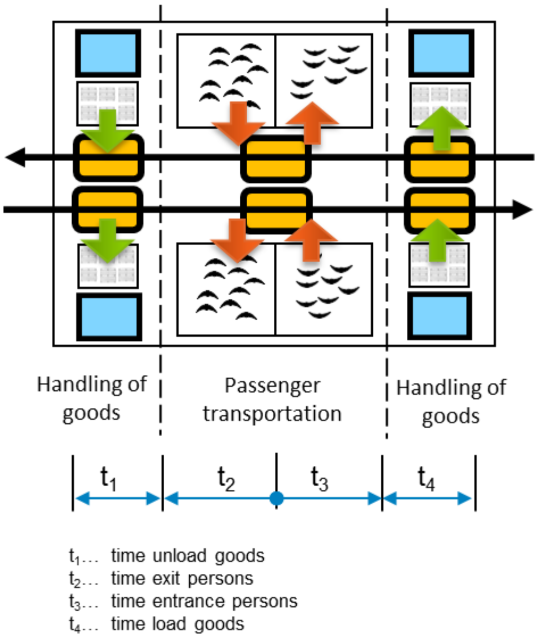
Table 10: Station layout passenger transportation

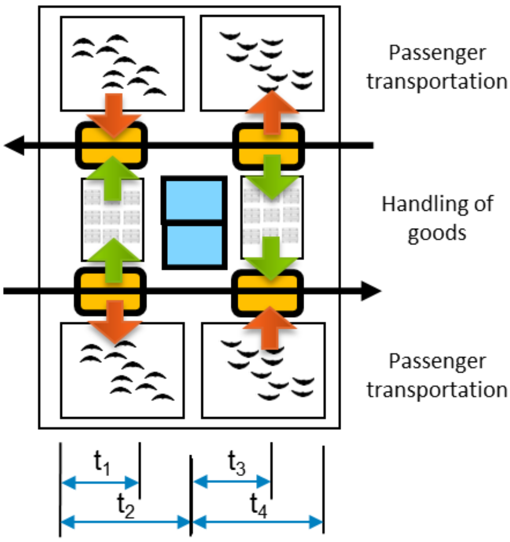
<table>
<tr><th colspan="2">Station layout passenger transportation</th></tr>
<tr><th>Layout</th><th>Characteristics</th></tr>
<tr><td>
</td><td>
- Arrangement:
Passenger transportation outside the ropeway lanes
- Procedure: serial
Exit of persons – Entrance of persons
- Lead time
  - $t_1 + t_2$
  - Lead time for passenger transport in the station is the sum of exit time and entrance time of persons
</td></tr>
</table>

The subsequent Table 11 lists the different station layout concepts for the combining transfer of persons and goods. Furthermore those layouts are described by an abstraction of the station and by its specific characteristics. The illustrations show middle stations (two travel direction), but are also valid for final stops. Station layouts 1&2, layouts 3&4&4b and layouts 5&6 have similar transfer procedures and can be more accurately compared to each other.

Table 11: Concepts station layouts ropeway system

Station layout 1	
Layout	**Characteristics**
	▪ Arrangement: Passenger transportation → Handling of goods → Passenger transportation ▪ Procedure: serial Exit of persons – Unload goods – Load goods – Entrance of persons ▪ Lead time ○ $t_1 + t_2 + t_3 + t_4$ ○ Lead time for passenger transport and handling of goods is the sum of exit time and entrance time of persons plus unloading time and loading time of goods ▪ Pros: ○ Conventional gondola design (one door) ○ Slim station dimensions perpendicular to travel direction ○ Clear arrangement of entrance and exit area for passenger transportation ○ One common area for the handling of goods per direction ▪ Cons: ○ Longer station lead times due to serial procedure

Station layout 2	
Layout	**Characteristics**
	▪ Arrangement: In contrast to station layout 1 the area arrangement is different Handling of goods → Passenger transportation → Handling of goods ▪ Procedure: serial Unload goods – Exit of persons – Entrance of persons – Load goods ▪ Lead time ○ $t_1 + t_2 + t_3 + t_4$ ○ Lead time for passenger transport and handling of goods is the sum of exit time and entrance time of persons plus unloading time and loading time of goods ▪ Pros: ○ Conventional gondola design (one door) ○ Slim station dimensions perpendicular to travel direction ▪ Cons: ○ Longer station lead times due to serial procedure ○ Area separation of goods handling (need of staff) ○ In case of service elevators each area for the handling of goods will need one elevator

<table>
<tr><th colspan="2">Station layout 3</th></tr>
<tr><th>Layout</th><th>Characteristics</th></tr>
<tr><td>


t_1… time unload goods
t_2… time exit persons
t_3… time entrance persons
t_4… time load goods
</td><td>

Arrangement:
Passenger transportation outside the ropeway lane
Handling of goods inside the ropeway lane
Procedure: Transport dependent
Goods: Inner gondola door opens
Unload goods – Load goods
Persons: Outer gondola door opens
Exit of persons – Entrance of persons
Lead time

Lead time goods: $t_2 + t_4$
Lead time persons: $t_1 + t_3$
Resulting lead time is the bigger effective transit time (goods or persons)

Pros:

Shorter station lead times (no serial summation)
Slim station dimensions in travel direction
Passenger transport areas and goods handling areas are clearly separated due to lane
One common area for the handling of goods

Cons:

More complex gondola design (two doors per gondola, inner and outer door)
Wider station dimensions perpendicular to travel direction
Wider track width (redirection of gondolas)

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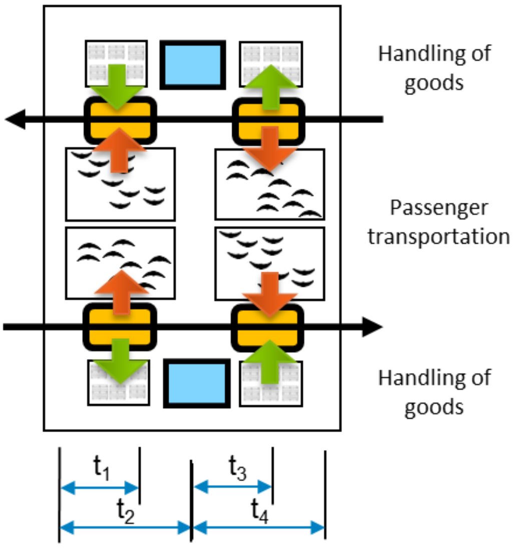
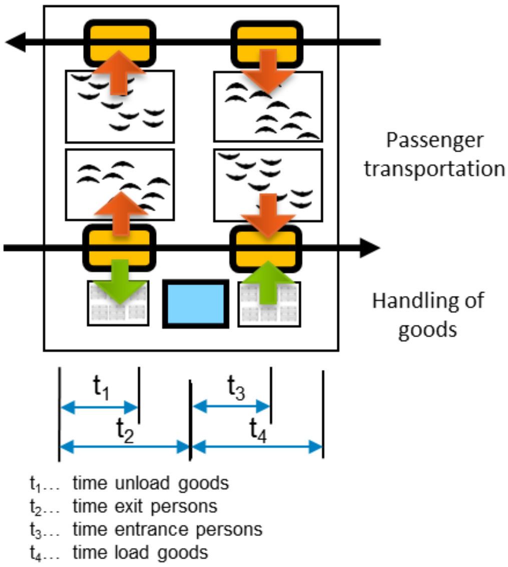
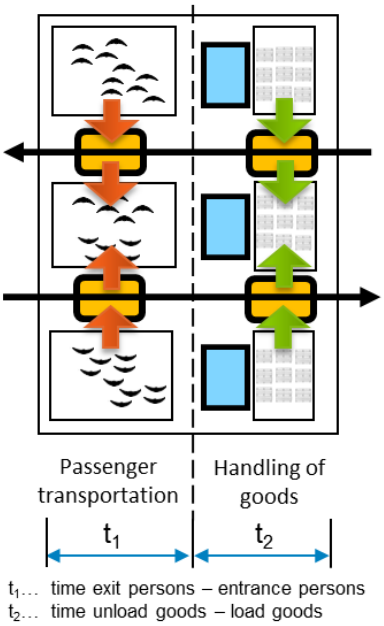
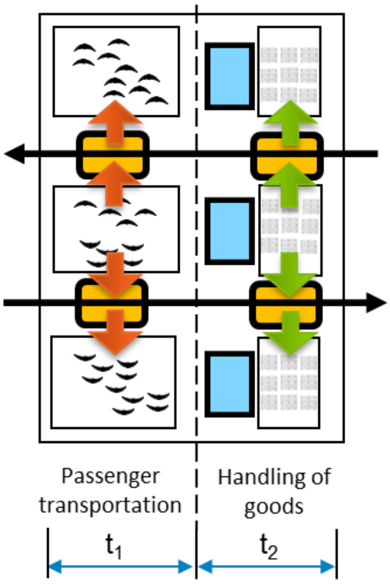
<tr><td colspan="2"></td></tr>
</table>

Station layout 4	
Layout	**Characteristics**
 t_1… time unload goods t_2… time exit persons t_3… time entrance persons t_4… time load goods	▪ Arrangement: In contrast to station layout 3 Passenger transportation inside the ropeway lane Handling of goods outside the ropeway lane ▪ Procedure: Transport dependent Goods: Outer gondola door opens Unload goods – Load goods Persons: Inner gondola door opens Exit of persons – Entrance of persons ▪ Lead time o Lead time goods: t_2 + t_4 o Lead time persons: t_1 + t_3 o Resulting lead time is the bigger effective transit time (goods or persons) ▪ Pros: o Shorter station lead times (no serial summation) o Slim station dimensions in travel direction o Passenger transport areas and goods handling areas are clearly separated due to lane ▪ Cons: o More complex gondola design (two doors per gondola, inner and outer door) o Area separation of goods handling (need of staff) o Wider station dimensions perpendicular to travel direction o Wider track width (redirection of gondolas)

Station layout 4b	
Layout	**Characteristics**
	▪ Arrangement: In contrast to station layout 4 at one travel direction no area for the handling of goods is set (network structures with one city hub) ▪ Procedure: Transport dependent Goods: Outer gondola door opens Unload goods – Load goods Persons: Inner gondola door opens Exit of persons – Entrance of persons ▪ Lead time ○ Lead time goods: $t_2 + t_4$ ○ Lead time persons: $t_1 + t_3$ ○ Resulting lead time is the bigger effective transit time (goods or persons) ▪ Pros: ○ Shorter station lead times (no serial summation) ○ Slim station dimensions in travel direction ○ Passenger transport areas and goods handling areas are clearly separated due to lane ○ Reduced station costs in contrast with station layout 4 due to only one handling of goods area per station ▪ Cons: ○ More complex gondola design (two doors per gondola, inner and outer door) ○ Area separation of goods handling (need of staff) ○ Wider station dimensions perpendicular to travel direction ○ Wider track width (redirection of gondolas)

Station layout 5	
Layout	**Characteristics**
	▪ Arrangement: Passenger transportation outside and inside the ropeway lane Handling of goods outside and inside the ropeway lane ➔ Exit area inside the ropeway lane ▪ Procedure: Serial with parallel passenger or goods transfer Goods: Parallel outer and inner gondola door opens to unload goods – load goods Persons: Parallel outer and inner gondola door opens to enable exit of persons – entrance of persons ▪ Lead time o Lead time goods: $t_1 + t_2$ o Lead time for passenger transport and handling of goods is the sum of exit time and entrance time of persons plus unloading time and loading time of goods ▪ Pros: o Shorter station lead times (no serial summation), parallel transfer of gondola content o Slim station dimensions in travel direction ▪ Cons: o More complex gondola design (two doors per gondola, inner and outer door) o Area separation of goods handling (need of staff) o Wider station dimensions perpendicular to travel direction o Wider track width (redirection of gondolas)

<table>
<tr><th colspan="2">Station layout 6</th></tr>
<tr><th>Layout</th><th>Characteristics</th></tr>
<tr><td>


t_1… time exit persons – entrance persons
t_2… time unload goods – load goods
</td><td>

- Arrangement:
Passenger transportation outside and inside the ropeway lane
Handling of goods outside and inside the ropeway lane
➔ Exit area outside the ropeway lane in contrast to station layout 5
- Procedure: Serial with parallel passenger or goods transfer
Goods: Parallel outer and inner gondola door opens to unload goods – load goods
Persons: Parallel outer and inner gondola door opens to enable exit of persons – entrance of persons
- Lead time
  - Lead time goods: $t_1 + t_2$
  - Lead time for passenger transport and handling of goods is the sum of exit time and entrance time of persons plus unloading time and loading time of goods
- Pros:
  - Shorter station lead times (no serial summation), parallel transfer of gondola content
  - Slim station dimensions in travel direction
- Cons:
  - More complex gondola design (two doors per gondola, inner and outer door)
  - Area separation of goods handling (need of staff)
  - Wider station dimensions perpendicular to travel direction
  - Wider track width (redirection of gondolas)
  - Areas of passenger transport for entrance and areas for loading of goods aren't separated, no clear entrance / loading

</td></tr>
</table>

4.2 Modelling & simulation

During the third project phase the specified system is transferred into the simulation environment. So the conceptual model based on project phase 2 data model, requirements list and concepts is implemented into a software model, which delivers the wanted output data.

The schematic implementation process is demonstrated in Figure 37. All data from the conceptual model is transferred into a software model in Plant Simulation.

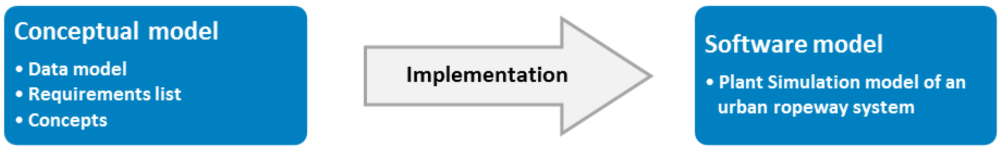


Figure 37: Modelling & simulation implementation process [Küh06], own representation

This process includes the building process of the virtual model, as well as the parameterisation of the used elements. Moreover the defined elements have to be programmed or modified in order to simulate the required behaviours.

The simulation model of the urban ropeway system has to fulfil various requirements due to the early stage in the development process. These targets are:

- Flexibility of input data, later or additional changes of input data have to be easily modifiable
- Variability of the model, simulation of different concept solutions regarding station layouts and network structures
- Calculation of required output data: throughputs, times, workloads etc.
- Easy operation of the model: click & run
- Simple and comprehensible model of the ropeway system, fast modifications of the model (hierarchical structure)
- Possibility to extend the model with further elements

According to these aspects the conceptual model has to be implemented into a software model of an urban ropeway system.

In order to build up a simulation model with an appropriate level of detail one further constraint was set:

- The stations are the drains of the transported goods, which results in a simulation model where the elements of the data model pick-up station and distribution unit are not implemented. This constraint is caused one the one hand by the early developing stage of the whole project (avoiding too detailed modelling) and on the other hand by the lack of input data to model these elements. Instead of inserting a buffer the workload of each station due to the transportation of goods can be recorded. At a later stage in the project the distribution unit and pick-up station can be easily implemented in the model due to the open and variable structure of the pattern.

To use the advantage of inheritance in the simulation software, as described in chapter 2.3.3 Siemens Plant Simulation, two different station types were identified and modelled:

- Main stations, final stops at the network edges, Figure 40
- Sub stations, stations between the final stops, Figure 41

The principal difference of these station types in the model is that main stations only have one travel direction and sub stations two travel lanes. This results from the working principle of a circulating ropeway system as described in chapter 2.2.1 Construction types. An abstraction of the main stop is illustrated in Figure 38.

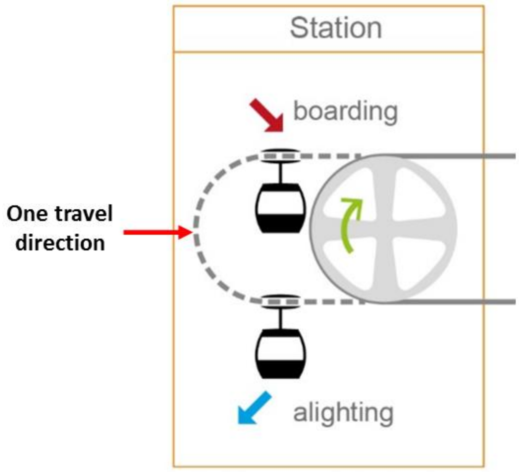


Figure 38: Main station – travel direction [Dop18], own representation

In contrast to the main station the sub stop is displayed in Figure 39.

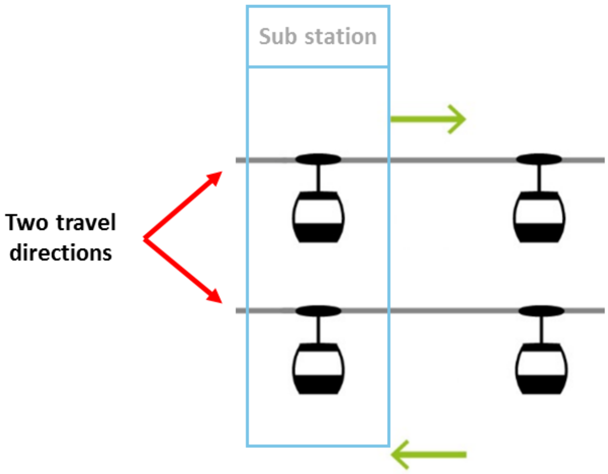


Figure 39: Sub station – travel direction [Dop18], own representation

Due to this difference of lane arrangement some methods and elements in the virtual model are adopted to the specific station type. To get an idea about the pattern of the stations, the following two pages demonstrate the main station and sub station modelled in Plant Simulation, Figure 40 and Figure 41.

- **Model: main station**

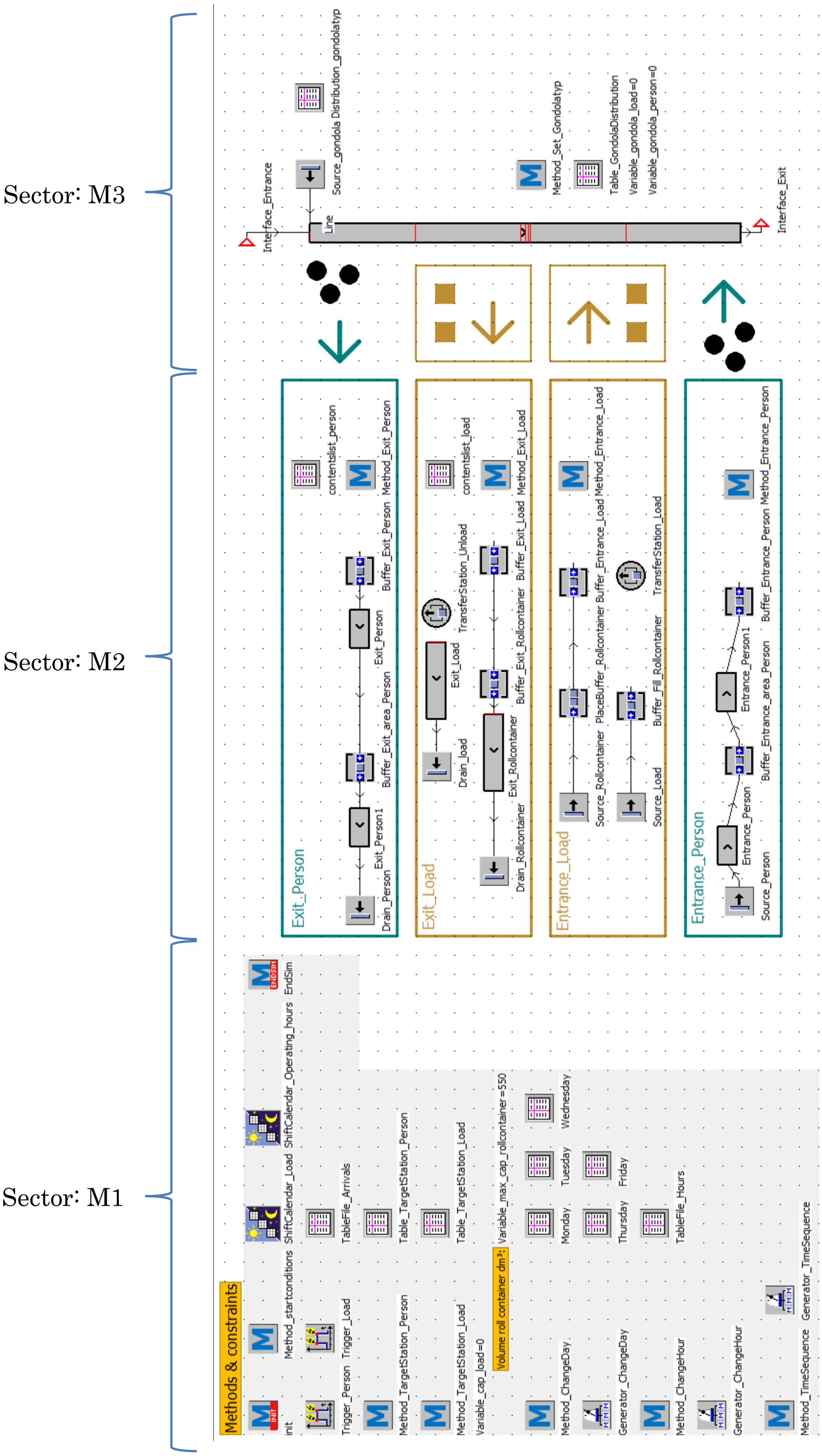


Figure 40: Simulation model: main station

- **Model: sub station**

Sector: S3

Sector: S2

Sector: S1

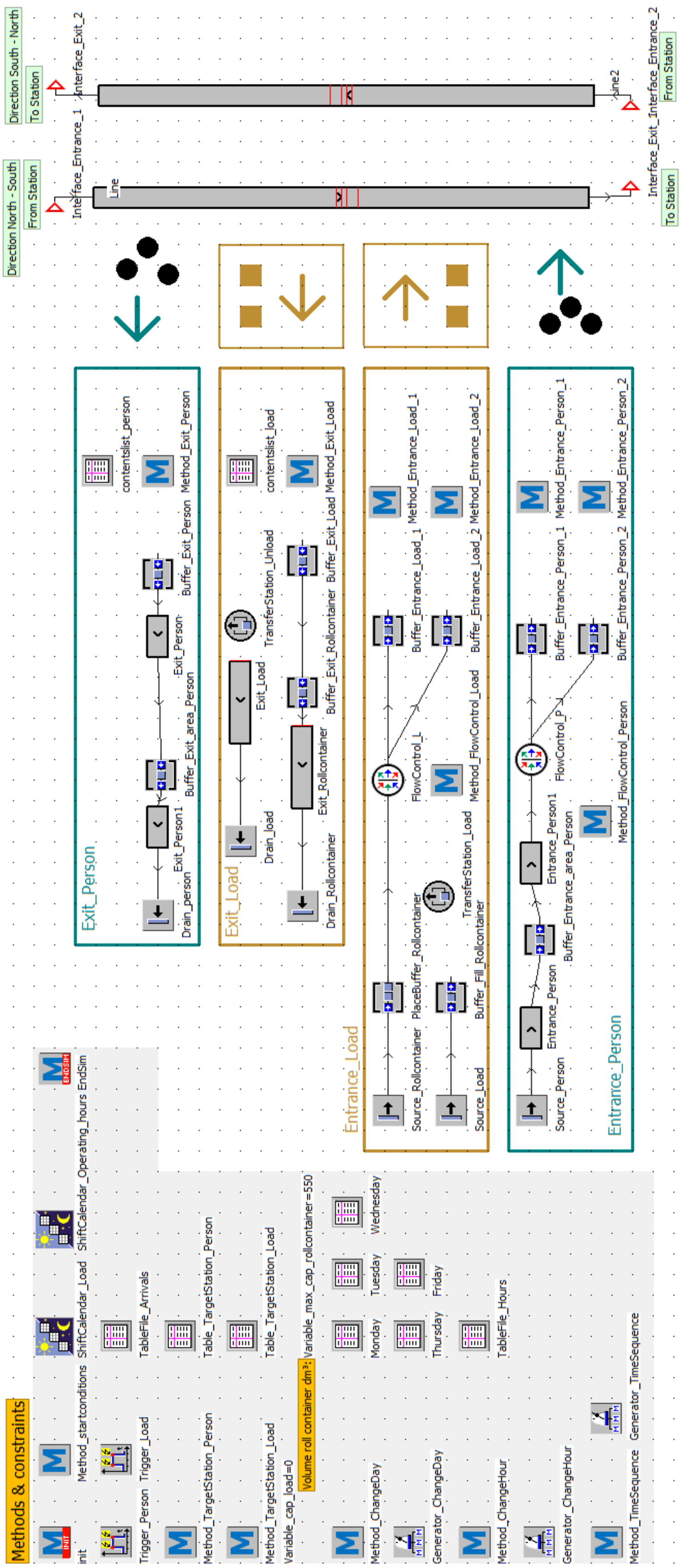


Figure 41: Simulation model: sub station

Both modelled station types are divided into three sectors, as displayed in Figure 40 and Figure 41, to enable a comprehensible and simple description of the urban ropeway simulation model. In the following documentation these sectors are further subdivided and explained.

4.2.1 Description main station

The first sector M1, illustrated in Figure 42, of the main station includes all methods and constraints, which are necessary to initiate the simulation model. These elements of the simulation software are more or less required to feed the model with input data.

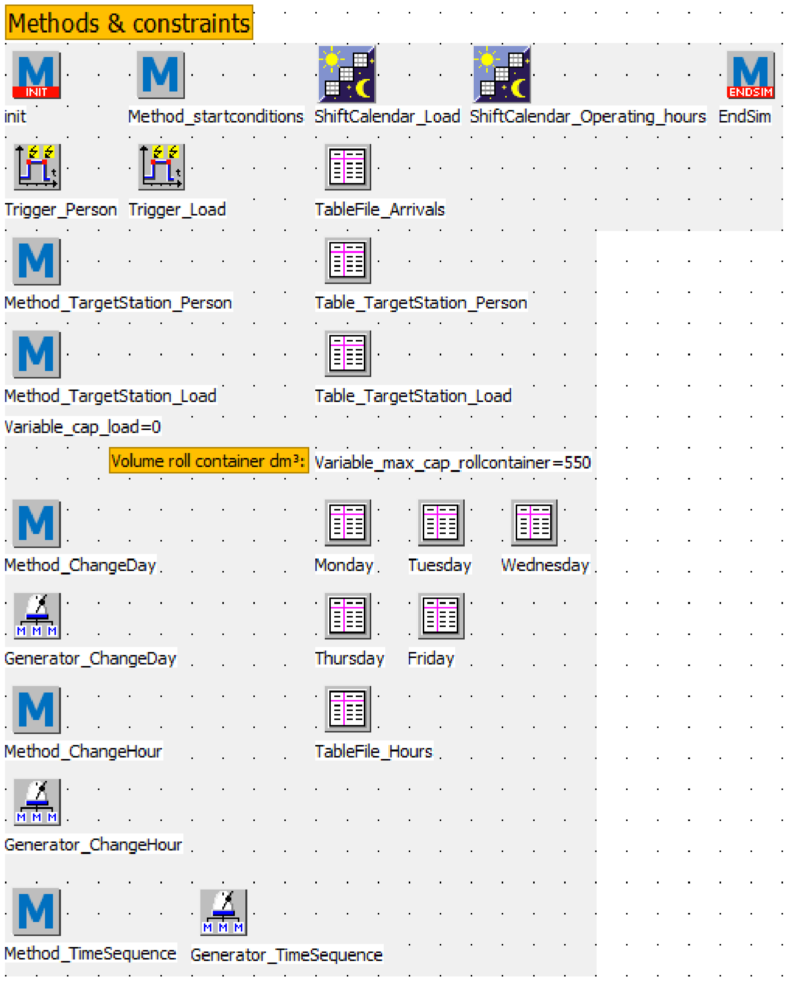


Figure 42: Main station sector M1

The element groups of the first sector of the main station M1 are:

- Method init and Method start conditions
- Shift calendars
- Method endsim
- Trigger person, trigger Load, Table file arrivals
- Method target station persons/goods – Table files targets – Variable roll container
- Method change day – Generator change day – Table files days
- Method change hour – Generator change hour – Table file hour
- Method time sequence – Generator time sequence

The detailed description of each method group or element group by its functions and tasks of sectors M1, M2 and M3 are attached in the appendix. There the element or method groups are displayed by its symbols and described by its characteristics and functions. The programming codes of methods are accessible in Plant Simulation and described and commented there.

The second sector M2 of the main station, illustrated in Figure 43, contains the material flow modules from entrance (source) and exit (drain) of MUs (moving units) to the transfer process in and out the gondolas. Here the system border is modelled.

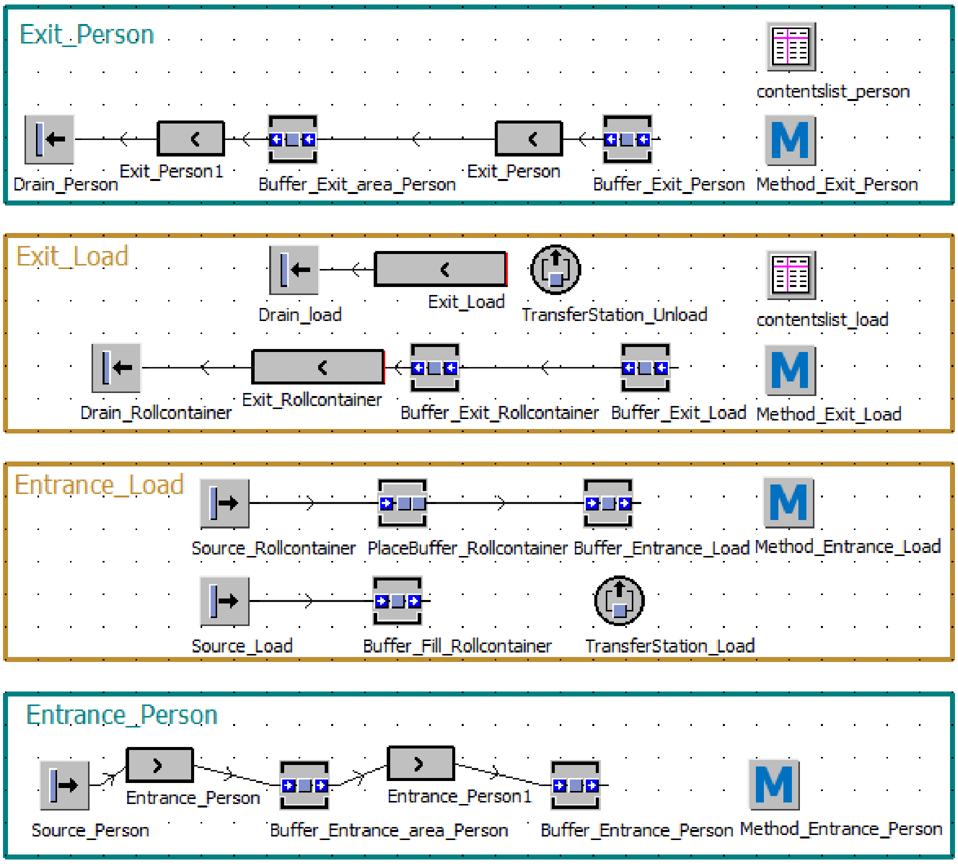


Figure 43: Main station sector M2

The element groups of sector M2 are:

- Exit person
- Exit load
- Entrance load
- Entrance person

These clusters are also described the same way as before sector M1 and are attached at the end of the thesis.

The last sector of the main station is M3, as Figure 44 displays. This section represents the interface between the entrance and exit areas and the gondolas, as well as the interface among the static stations itself inside the ropeway network.

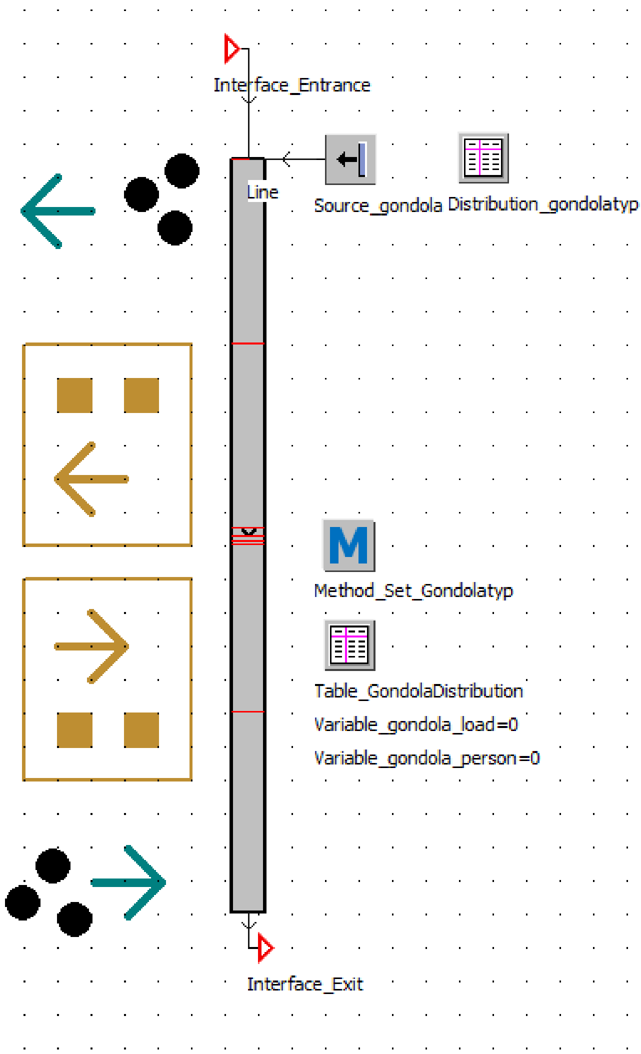


Figure 44: Main station sector M3

The main elements of section M3 are:

- Source gondola – Table file gondola type
- Method set gondola type – Table file gondola distribution
- Interfaces – Gondola lane

These element groups are fully explained in the appendix as well.

4.2.2 Description sub station

The sub stations, stations between the main ones in the ropeway network, have a quite similar structure as the final stops and fulfil nearly the same functions. For the explanation of methods and elements of the sub stations, the simulation model is subdivided in three sectors too, Figure 41. The first sector S1, as Figure 45 displays, has completely the same layout as the first sector of the main station M1 and accomplishes therefore equal tasks.

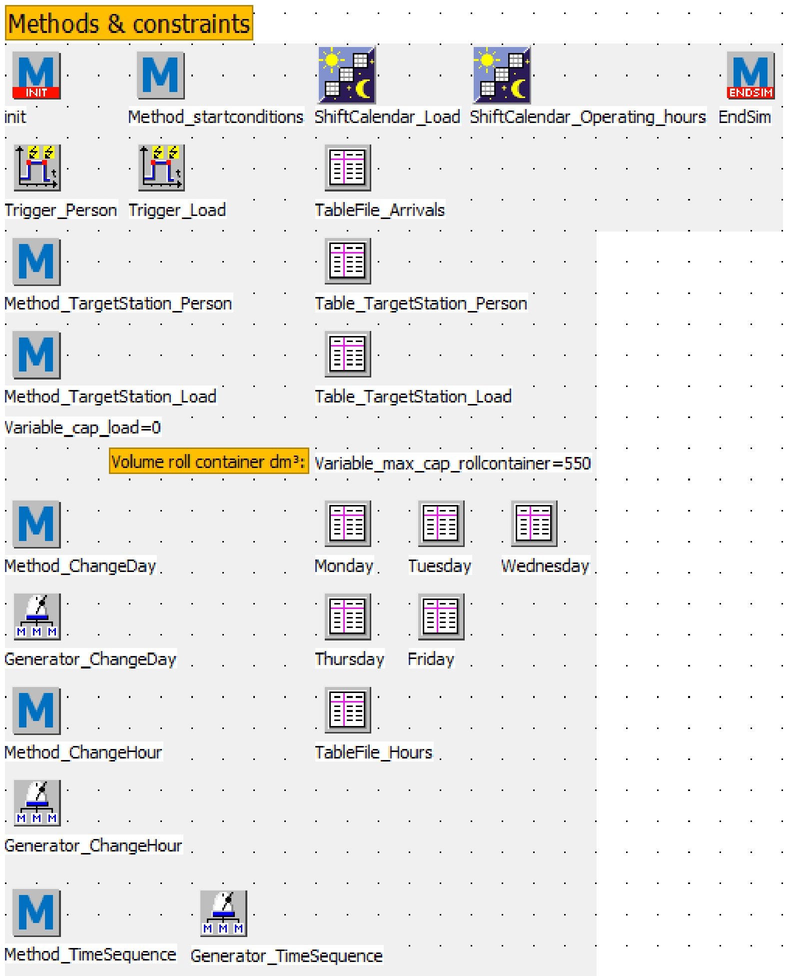


Figure 45: Sub station sector S1

Hence the description of sector M1 in 4.2.1 Description main station is also valid for the first sector of the sub station S1. The key element groups are:

- Method init and Method start conditions
- Shift calendars
- Method endsim
- Trigger person, trigger Load, Table file arrivals
- Method target station persons/goods – Table files targets – Variable roll container
- Method change day – Generator change day – Table files days
- Method change hour – Generator change hour – Table file hour
- Method time sequence – Generator time sequence

The second sector S2, illustrated in Figure 46, is responsible for the entrance and exit process of people and goods till the transfer process inside the gondolas and from the gondolas. In contrast to the main station a flow control is necessary in order to enable the distinction between the two travel directions of sub stations.

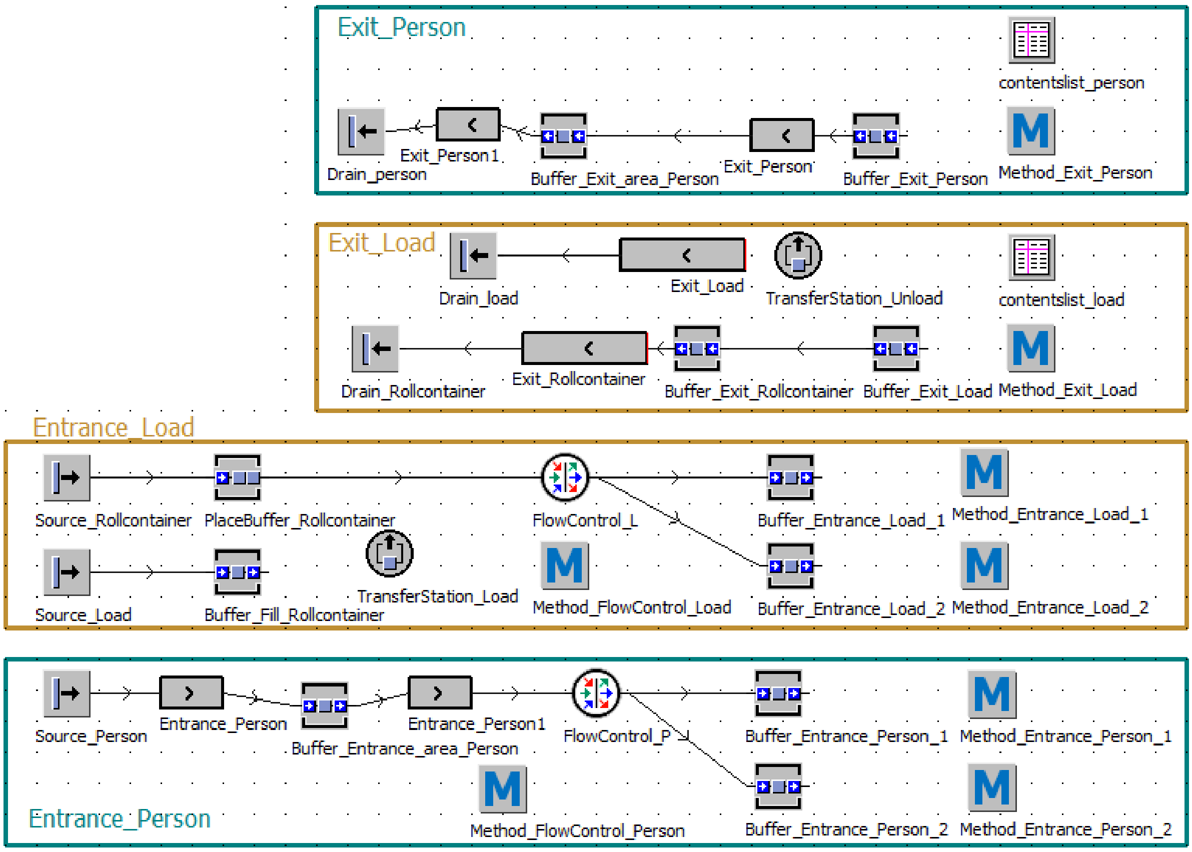


Figure 46: Sub station sector S2

As before in main station category M2 the element groups of sector S2 are:

- Exit person
- Exit load
- Entrance load
- Entrance person

The third sector S3 of the sub station is demonstrated in Figure 47 and consists of one element group.

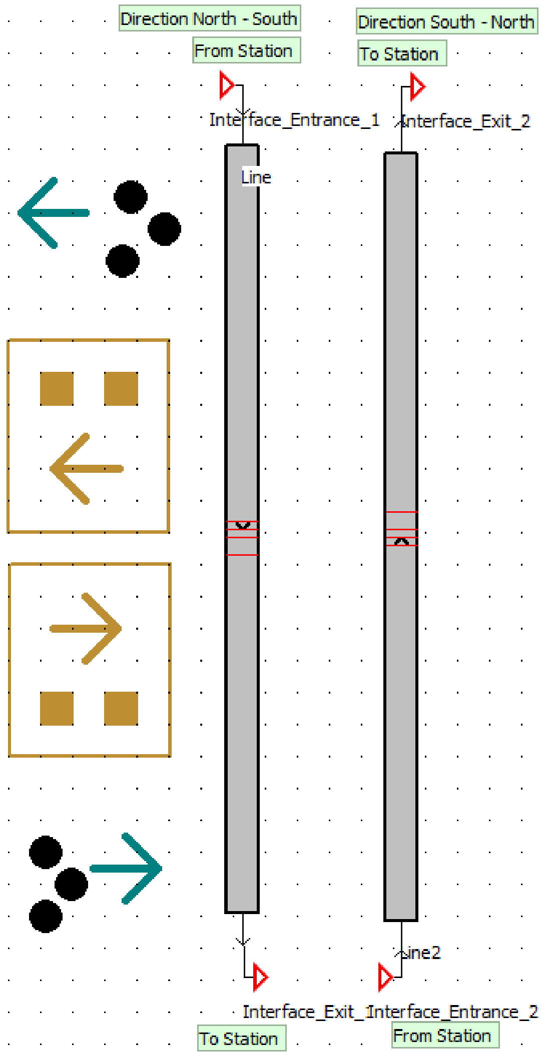


Figure 47: Sub station sector S3

This cluster contains both travel directions (lanes) with sensors triggering the methods to transfer people and goods as well as their interfaces with the ropeway network. The methods activated by the sensors are:

- "Method_Exit_Person"
- "Method_Exit_Load"
- "Method_Entrance_Load_1"
- "Method_Entrance_Load_2"
- "Method_Entrance_Person_1"
- "Method_Entrance_Person_2"

Regarding the network structure with eleven ropeway stations in the simulation model two main stations (S1 and S11) are inserted on the final stops and nine sub stations (S2-S10) between them. This leads to the simulation model frame of the urban ropeway system in Figure 48.

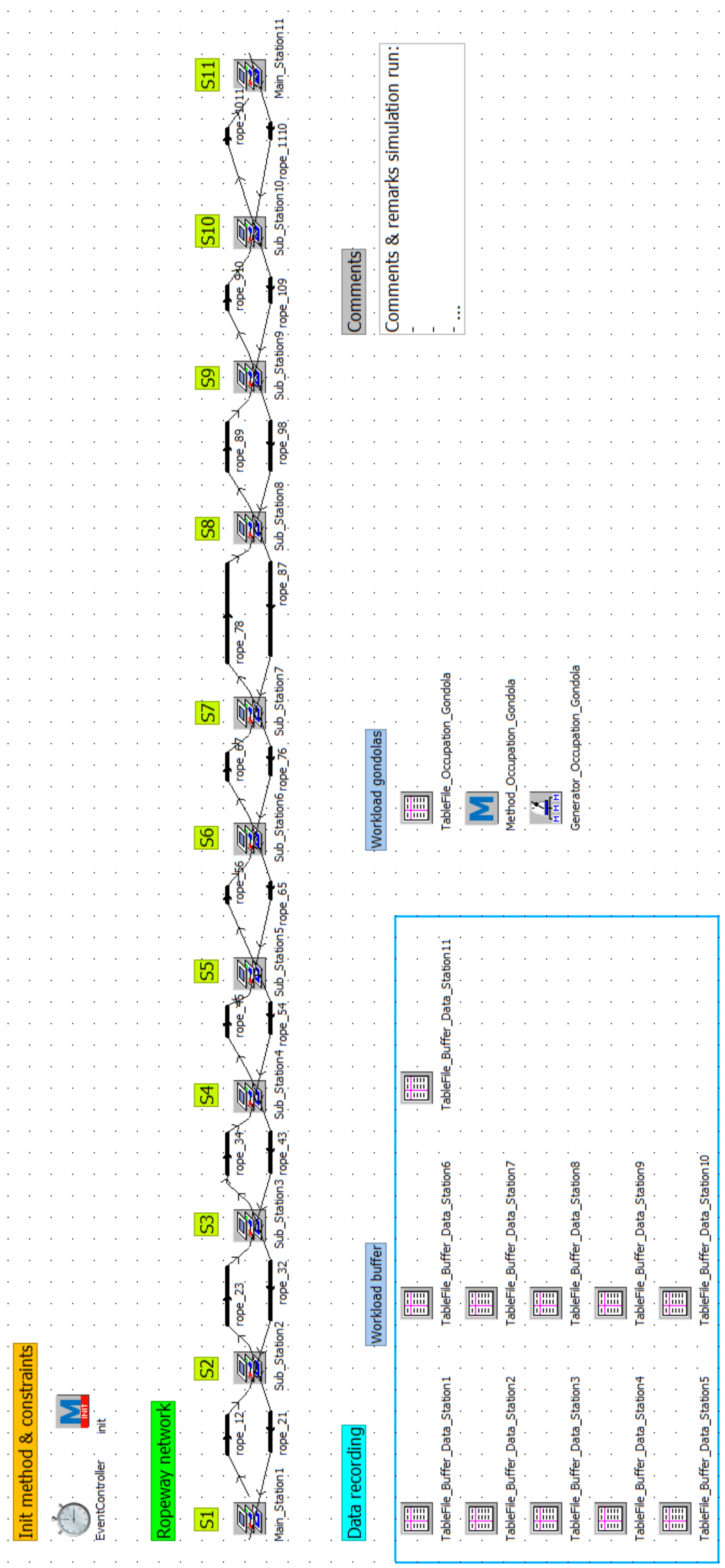


Figure 48: Simulation model: frame – network structure

The simulation model frame with the inserted stations can be subdivided into four sections. These are: "Init method and constraints" (orange), "Ropeway structure" (green), "Data recording" (cyan) and "Comments" (grey), which are described in detail in the appendix.

4.3 Model verification

The fourth project phase is dealing with the model verification, which plays a very important role in every simulation. In order to get correct output data the verification of the urban ropeway model is obligatory and was done parallel to the model built up process in Plant Simulation.

According to Wolfgang Kühn "Digitale Fabrik" the verification is defined and structured as follows:

Verification is the check whether the characteristics of the software model equal the characteristics of the conceptual model. Outcome of the verification is a simulation model, which has a correct logic regarding to the conceptual one [Küh06]. So the verification is a permanent iterative procedure, as Figure 49 illustrates.

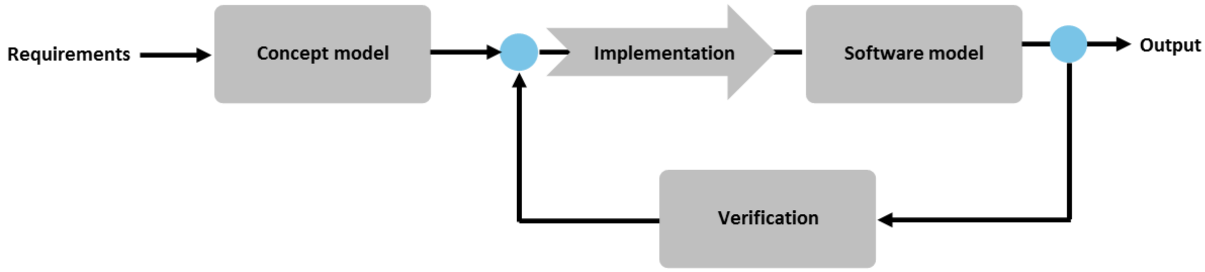


Figure 49: Model verification process [Küh06]

With consideration of the guidance by Kühn the subsequent verification methods were used to check the simulation model of the urban ropeway system: [Küh06]

- Plant Simulation debugger to identify errors in programming
- Animation to detect obvious logic errors
- Variation of system parameters – input parameters
- Data recording, analysis of statistics and assessment whether outcomes are plausible

Remark: All results during the verification process are just examples and are not applicable for answering the material flow potential of goods of the urban ropeway system.

4.3.1 Debugger

By debugging the programming code of the various written methods a permanent control of the feasibility of inserted method elements is achieved. The debugger starts manually to check the source code of a method or starts automatically before every simulation run. If no errors are detected in the programming code the simulation is ready to execute and deliver outcomes.

As mentioned before the verification is a permanent process beside the building procedure of the simulation model. Therefore the debugger function observed from the beginning of modelling till the final urban ropeway model the programming code, whereas the final model has no errors any more.

4.3.2 Animation

By the animation function of Plant Simulation, moving units in the ropeway system like persons, goods, roll container or gondolas can be visually displayed and therefore observed during simulation runs, Figure 50.

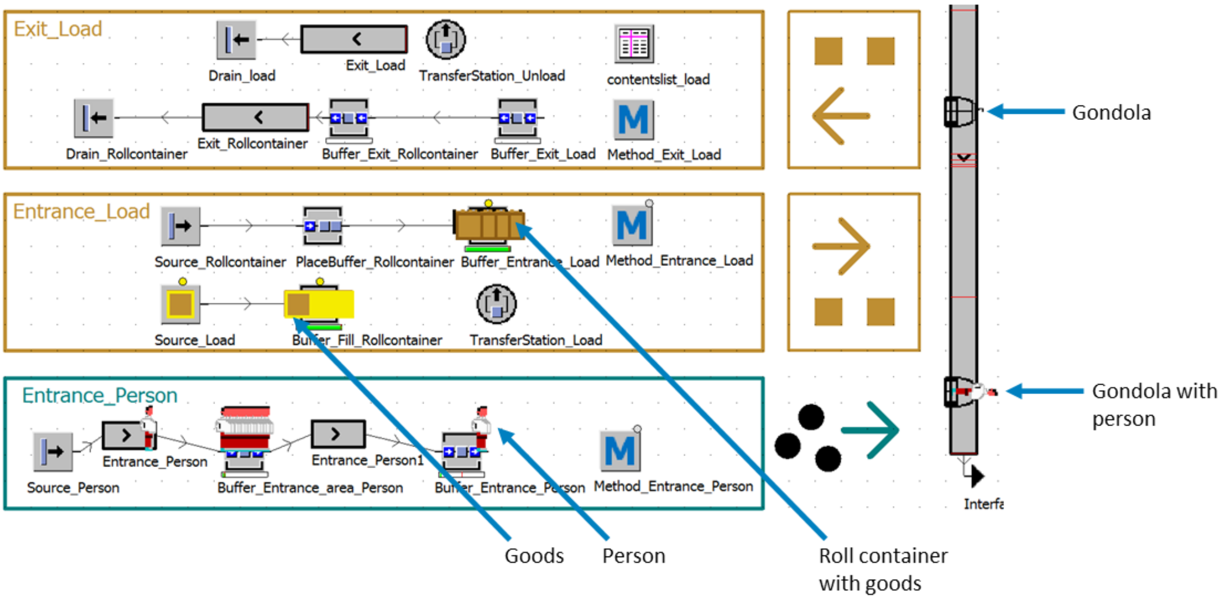


Figure 50: Animation moving units (MUs) ropeway model

This enables a very quick control of specified sequences in the conceptual model e.g. whether gondolas move in the right direction or persons/goods may enter or leave the gondolas at the stations.

4.3.3 Variation of parameters

The variation of parameters checks whether the simulation model is able to run with different input data and delivers output data. As a fully documented example a variation of the number of entering goods at different stations is selected. In simulation run 1 the following input constraints for goods/roll containers are set:

Table 12: Constraints for simulation run 1

Variation of parameters: simulation run 1	
	Station
Sources of goods/ roll containers	City hubs: S1, S11 – Distribution units: S3, S5, S7
Drains of goods/ roll containers	City hubs: S1, S11 – Distribution units: S3, S5, S7

At simulation run 1 the output data of MUs sources and MUs drains of goods and roll containers have the values of Table 13 and Table 14.

Table 13: Simulation run 1: Goods MUs source and drain

Goods		
Station no.	MUs Source	MUs Drain
1	24852	4505
2	0	0
3	3235	15052
4	0	0
5	4090	19121
6	0	0
7	1884	14093
8	0	0
9	0	0
10	0	0
11	23474	4657
Sum	57535	57428

Table 14: Simulation run 1: Roll containers MUs source and drain

Roll containers		
Station no.	MUs Source	MUs Drain
1	1025	189
2	1	0
3	136	623
4	1	0
5	170	791
6	1	0
7	79	583
8	1	0
9	1	0
10	1	0
11	972	196
Sum	2388	2382

Both tables Table 13 and Table 14 indicate the same. At the stations S1, S3, S5, S7 and S11 goods are entering and leaving the system as the constraints of Table 12 set. At the other stations no transfer of roll containers takes place. The difference of goods entering the system (MUs source) and leaving the system (MUs drain) result from the fact that the operating hours for the transportation of goods is restricted and no gondolas to transport that difference are travelling at this day any more.

For the second simulation no loads arrive at any station as Table 15 indicates. All other input parameters and system parameters are equally in simulation run 1 and simulation run 2.

Table 15: Constraints for simulation run 2

Variation of parameters: simulation run 2	
	Station
Sources of goods/ roll containers	City hubs: no source – Distribution units: no source
Sources of goods/ roll containers	City hubs: no drain – Distribution units: no drain

Simulation run 2 generates the output data of MUs sources and MUs drains of goods and roll containers of Table 16 and Table 17.

Table 16: Simulation run 2: Goods MUs source and drain

Goods		
Station no.	MUs Source	MUs Drain
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
Sum	0	0

Table 17: Simulation run 2: Roll containers MUs source and drain

Roll containers		
Station no.	MUs Source	MUs Drain
1	1	0
2	1	0
3	1	0
4	1	0
5	1	0
6	1	0
7	1	0
8	1	0
9	1	0
10	1	0
11	1	0
Sum	11	0

At simulation run 2 with no sources of goods no roll containers leave their stations. All other processes (e.g. transportation of people) work the same way as at simulation 1.

So many other system parameter variations can be simulated whereas the simulation model of the urban ropeway system operates according to these input parameters and delivers comprehensible output data.

4.3.4 Data recording and analysis

With the verification method of data recording and analysis many different statistical data can be observed and evaluated. During the model implementation phase this method was permanently used in order to detect errors of the model. Fully documented verification types are:

- Cycle time records of gondolas
- Target stations of persons
- Comparison of analytical results and simulation results

The cycle time of gondolas defines the time span between two consecutive gondolas on the ropeway system. Two different simulation runs are documented; simulation run “cycle42” with the constraints of Table 18 and simulation run “cycle30” with the constraints of Table 19.

Table 18: Constraints “cycle42”

Verification cycle time		
	Parameters	
Gondola cycle time	42	sec
Distribution person to load gondolas	1	Person gondola
	1	Load gondola

In Figure 51 the distribution function of person to load gondolas regarding the constraints of “cycle42” are illustrated; gondolas in yellow transport persons and gondolas in blue transport goods. So the distribution function defines the cyclic sequence of the type of transportation.

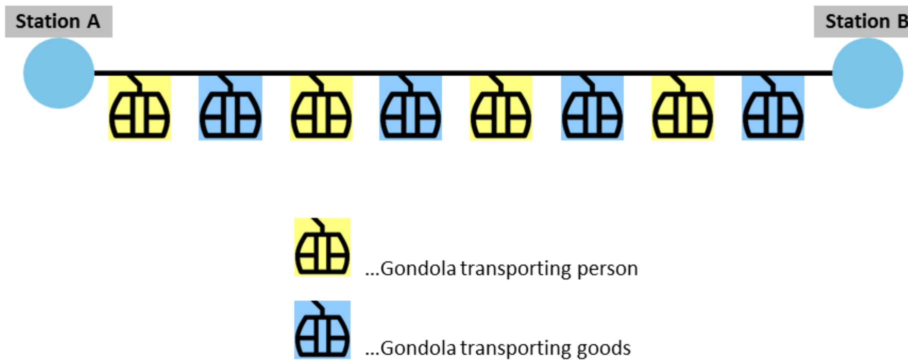


Figure 51: Illustration gondola distribution function 1 person gondola 1 load gondola

Table 19: Constraints “cycle30”

Verification cycle time		
	Parameters	
Gondola cycle time	30	sec
Distribution person to load gondolas	3	Person gondola
	1	Load gondola

Reffering the constraints of “cycle30” with a distribution of person to load gondolas of three person gondolas followed by one load gondola Figure 52 displays the function.

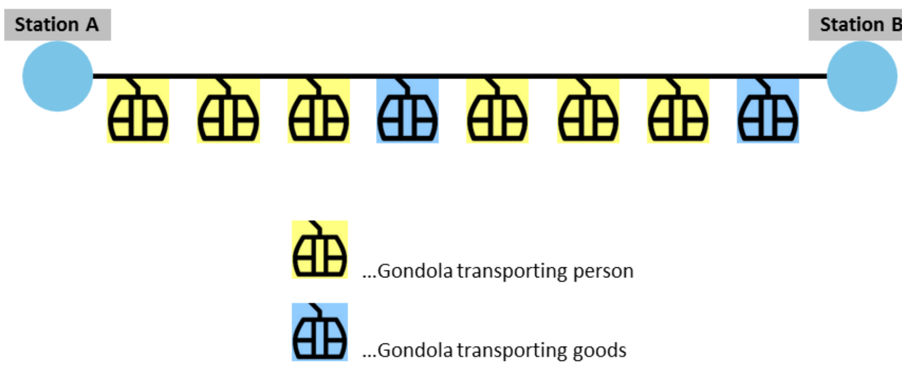


Figure 52: Illustration gondola distribution function 3 person gondola 1 load gondola

The records of both simulation runs “cycle42” and “cycle30” are displayed in Table 20 and Table 21 with data records of: Simulation time, gondola type and time span between gondolas.

Both tables show that the time span between the gondolas as well as the distributions between the transportation types of person and load are according to the constraints. In both simulation runs the output tables indicate the right values for a whole day.

- Simulation run "cycle42" data records: Simulation time, gondola type and time span between gondolas:

Table 20: Data records simulation run „cycle42"

Time	Gondola type	Time span [sec]
05:01:28	load	
05:02:10	person	00:00:42
05:02:52	load	00:00:42
05:03:34	person	00:00:42
05:04:16	load	00:00:42
05:04:58	person	00:00:42
05:05:40	load	00:00:42
05:06:22	person	00:00:42
05:07:04	load	00:00:42
05:07:46	person	00:00:42
05:08:28	load	00:00:42
05:09:10	person	00:00:42
…	…	…

- Simulation run "cycle30" data records: Simulation time, gondola type and time span between gondolas:

Table 21: Data records simulation run „cycle30"

Time	Gondola type	Time span [sec]
05:01:28	load	
05:01:58	person	00:00:30
05:02:28	person	00:00:30
05:02:58	person	00:00:30
05:03:28	load	00:00:30
05:03:58	person	00:00:30
05:04:28	person	00:00:30
05:04:58	person	00:00:30
05:05:28	load	00:00:30
05:05:58	person	00:00:30
05:06:28	person	00:00:30
05:06:58	person	00:00:30
…	…	…

- Target station:

As described in chapter 4.2 every person and roll container has a specific target station, which is set at the source of the MU. Therefore each person or roll container has to leave at its target station the gondola. By observing and recording the persons or roll containers at the drains of the system it can be checked whether the persons and roll containers travel to the right station. The target number equal the number of the station; target number 1 = S1, target number 2 = S2 and so on. An extract from the overall records are shown in Table 22 and Table 23 for station 2 and station 4. So Persons leave at the right stations their cabins, same results for the transport of roll containers over the whole simulation period.

Table 22: Drain person target number records station 2

MU	Target number	Time
Person	2	05:21:19
Person	2	05:37:09
Person	2	05:37:10
Person	2	05:41:21
Person	2	05:53:13
Person	2	05:56:45
Person	2	05:56:46
Person	2	05:59:33
Person	2	05:59:34
Person	2	06:00:57
Person	2	06:05:09
…	…	…

Table 23: Drain person target number records station 4

MU	Target number	Time
Person	4	05:17:47
Person	4	05:19:11
Person	4	05:20:35
Person	4	05:20:36
Person	4	05:20:36
Person	4	05:23:23
Person	4	05:24:47
Person	4	05:26:11
Person	4	05:27:35
Person	4	05:27:36
Person	4	05:28:05
…	…	…

- Analytical vs. simulation results

The comparison of analytical calculations of the urban ropeway system and the results out of the simulation is used as a further verification method. As an example the throughput of roll containers in the morning hours between 05:00 and 11:00 o'clock is examined. This sample has a network structure of two city hubs at stations S1 and S11 and distribution units at stations S3, S5 and S7. In the observed time period goods are transported from stations S1 and S11 to S3, S5 and S7. Further important constraints and input parameters are presented in Table 24.

Table 24: Constraints and input parameters of throughput rate of roll containers

Constraints and input parameters			
		Parameters	
Gondola cycle time of gondolas		42	sec
Capacity of roll containers per gondola		4	per gondola
Travel direction 1			
	Time	Person gondola	Load gondola
Distribution gondolas Direction 1 North – South	05:00 – 06:00	1	1
	06:00 – 07:00	1	1
	07:00 – 08:00	1	1
	08:00 – 09:00	2	1
	09:00 – 10:00	2	1
	10:00 – 11:00	2	1
Travel direction 2			
	Time	Person gondola	Load gondola
Distribution gondolas Direction 2 South – North	05:00 - 06:00	2	1
	06:00 - 07:00	2	1
	07:00 - 08:00	2	1
	08:00 - 09:00	1	1
	09:00 - 10:00	1	1
	10:00 – 11:00	1	1

The results from the analytical calculation are documented in Table 25 and conclude a total throughput rate of roll containers from stations S1 and S11 to stations S3, S5 and S7 between 05:00 to 11:00 o'clock of 1710 roll containers.

Table 25: Analytical results – roll container throughput

Analytical results roll containers throughput			
Travel direction 1			
	Time	Throughput roll container	
Distribution gondolas Direction 1 North – South	05:00 – 06:00	171	per h
	06:00 – 07:00	171	per h
	07:00 – 08:00	171	per h
	08:00 – 09:00	114	per h
	09:00 – 10:00	114	per h
	10:00 – 11:00	114	per h

Travel direction 2			
	Time	Throughput roll container	
Distribution gondolas Direction 2 South – North	05:00 – 06:00	114	per h
	06:00 – 07:00	114	per h
	07:00 – 08:00	114	per h
	08:00 – 09:00	171	per h
	09:00 – 10:00	171	per h
	10:00 – 11:00	171	per h
Total number of roll containers		**1710**	

In contrast to the analytical calculation the simulation run examined a throughput of 1718 roll containers at the same time period, as the following Table 26 shows.

Table 26: Simulation results: roll container throughput

Simulation run		
Station 3	Roll container	520
Station 5	Roll container	689
Station 7	Roll container	509
Total number of roll containers		**1718**

To conclude the verification process all methods recorded in the thesis and additional ones executed during the modelling indicate that the conceptual model is successfully implemented into the software environment of Plant Simulation. All errors detected during the verification have been solved. Therefore the urban ropeway model is ready to analyse different scenarios to identify the material flow potential of goods beside the predicted passenger volume.

4.4 Analysis

In this subchapter one scenario, called “2CH_3DU_Layout_1_max“, of the urban ropeway system is analysed and described by its simulation results. The outcomes refer to this one state, whereby the potential of goods transportation due to material flow properties is examined. For a complete evaluation of the ropeway system further simulation studies have to be conducted and their outputs analysed. The parameters for the analysed scenario are listed in Table 27.

Table 27: Parameter list simulation run ²2CH_3DU_Layout_1_max“

Input data and constraints: simulation “2CH_3DU_Layout_1_max”		
Network structure		
City hubs	2	Station S1 Station S11
Distribution units	3	Station S3 Station S5 Station S7
Station layout		
Station layout 1	Serial arrangement: Person exit – goods exit – goods entrance – person entrance	
Station lead time with goods handling (without gondola acceleration and deceleration)	88	sec
Station lead time without goods handling (without gondola acceleration and deceleration)	44	sec
System parameters		
Operating hours person transport	start 05:00 end 23:00	
Operating hours load transport	start 05:00 end 12:00	From 05:00 to 11:00 o’clock into the city (distribution units); from 11:00-12:00 o’clock outwards (to city hubs).
Cycle time gondola	42	sec
Rope speed	7,5	m/s
Acceleration gondola	1	m/s²
Deceleration gondola	1	m/s²
Transport capacity persons	35	per gondola
Transport capacity roll containers	4	per gondola
Transport volume roll container	550	dm³
Gondolas on the system	108	gondolas
Accumulated travel time	37 min 56 sec	one travel direction

This analysis of simulation “2CH_3DU_Layout_1_max” identifies its maximum capacity for the transportation of goods beside the predicted person volume at a weekday. Therefore it can be seen as a marginal analysis or benchmark without considerations of economic resources like staff for the handling of roll containers. The results are useful to define the maximum performance of the urban ropeway system.

The distribution (cycle times) of gondolas which transport persons and gondolas which transport goods is guided by an analytical workload matrix. Out of this analysis and the limitation of a maximum waiting time for persons of 3 minutes and 30 seconds (distribution of 1 person gondola followed by 4 load gondolas) the following tables, Table 28 and Table 29, are examined for the setting of the gondola type.

Table 28: Gondola distribution station S1 simulation “2CH_3DU_Layout_1_max”

Station S1		
Time	Person gondola	Load gondola
05:00-06:00	1	4
06:00-07:00	1	3
07:00-08:00	1	1
08:00-09:00	1	2
09:00-10:00	1	3
10:00-11:00	1	4
11:00-12:00	1	4
12:00-13:00	no load gondolas	
13:00-23:00	…	…

Table 29: Gondola distribution station S11 simulation “2CH_3DU_Layout_1_max”

Station S11		
Time	Person gondola	Load gondola
05:00-06:00	1	4
06:00-07:00	1	1
07:00-08:00	2	1
08:00-09:00	1	1
09:00-10:00	1	2
10:00-11:00	1	4
11:00-12:00	1	4
12:00-13:00	no load gondolas	
13:00-23:00	…	…

The operating time of carrying goods is set from 05:00 to 12:00 o’clock because of the results from the data acquisition 4.1.4.2. There it is outlined that most of the goods are delivered in the morning hours to the customers. In order to establish an equivalent delivery service the goods have to be at the same time at customers. According to these gondola distributions over a weekday, the input parameters of Table 27 and the network described at the beginning in 3.1 Start and initial conditions the ropeway system is simulated.

4.4.1 Analysis: statistical report

The first analysis part contains the statistical report of MUs (person, load and roll container), which have entered the system at the sources and have leaved at the drains. So it displays more or less all parts processed by the ropeway system. The report of simulation run "2CH_3DU_Layout_1_max" of the moving unit type person has the values of Table 30.

Table 30: Statistical report simulation "2CH_3DU_Layout_1_max" combining transport - person

Station no.	MU type	Average throughput time	Throughput
Station 1	Person	00:20:52	2779
Station 2	Person	00:14:55	892
Station 3	Person	00:12:04	2592
Station 4	Person	00:13:19	3655
Station 5	Person	00:14:11	6111
Station 6	Person	00:14:31	4512
Station 7	Person	00:12:50	3119
Station 8	Person	00:14:35	3286
Station 9	Person	00:16:21	1041
Station 10	Person	00:20:30	502
Station 11	Person	00:21:52	1826

The column station no. lists all drains at which MUs left the urban ropeway system. To the right the type of moving unit is recorded persons, loads or roll containers. Next column contains the average throughput time, which is the average time of all moving units need to be transported to the specific drain. The throughput time of persons includes two minutes, which people need to come to the entrance area and to go from the exit area of gondolas to leave the stations. Fourth column records the total number of persons, loads or roll containers which enter the specific drain.

The average throughput times of persons per station of scenario "2CH_3DU_Layout_1_max" are illustrated in the yellow graph of Figure 53.

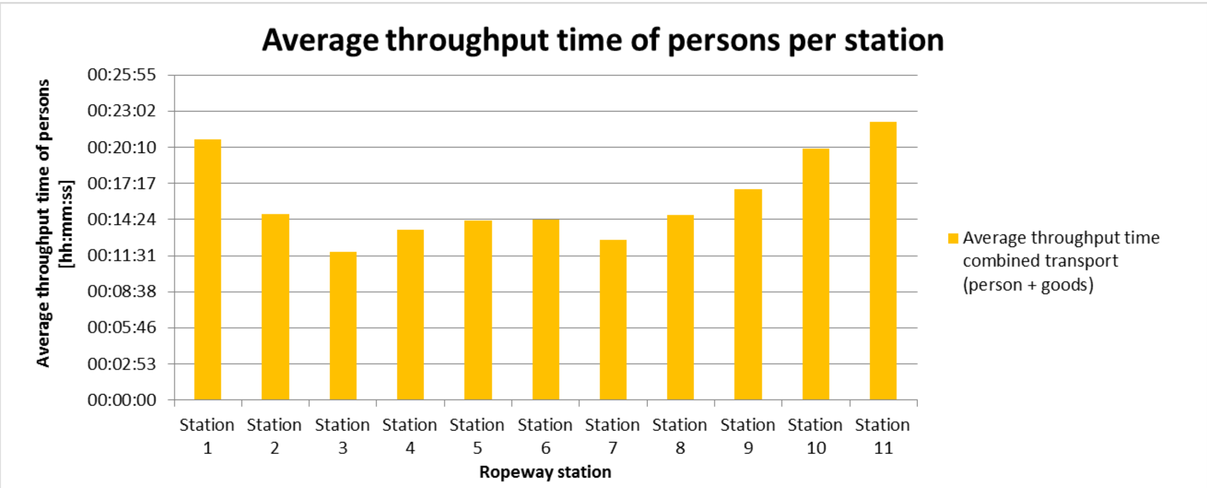


Figure 53: Average throughput time of persons per station combining transport

This diagram indicate lower throughput times of persons at stations in the inner city than at stations to the edges of the system.

The report of simulation run “2CH_3DU_Layout_1_max” of the moving unit type loads and transport unit roll container has the results of Table 31.

Table 31: Statistical report simulation “2CH_3DU_Layout_1_max” combining transport - goods

Station no.	MU type	Average throughput time	Throughput
Station 1	Load	00:17:32	6626
	Roll container	00:17:25	277
Station 3	Load	00:19:34	19727
	Roll container	00:19:22	820
Station 5	Load	00:20:15	25730
	Roll container	00:20:08	1062
Station 7	Load	00:20:39	19938
	Roll container	00:20:31	825
Station 11	Load	00:27:26	7370
	Roll container	00:27:12	304

According to this simulation output a total throughput of 2708 roll containers with a load content of 65479 goods into the city is achieved. Table 32 summarizes these values.

Table 32: Throughputs roll container and goods into city

Transport of goods from city hubs to distribution units	
05:00 - 11:00	
Total throughput roll containers	2708
Total throughput loads	65479

Outwards the city centre 616 roll containers with 14826 goods are transported in the time period of one hour between 11:00 and 12:00 o’clock.

Table 33: Throughputs roll container and goods to city hubs

Transport of goods from distribution units to city hubs	
11:00 - 12:00	
Total throughput roll containers	616
Total throughput loads	14826

The first analysis of the material flow throughputs outlines that the urban ropeway system with two city hubs and three distribution units has a marginal total throughput of about 3320 roll containers or approximately 80000 pieces of goods.

The total throughput analysis yields to the conclusion that the network structure with two city hubs fulfil the maximum estimated theoretical CEP amount on the ropeway system of around 28000 goods in 2018 (4.1.4.2 Data acquisition – goods). As a consequence the operating times of goods transportation may be shortened or the distribution of gondola type is switched to a higher passenger transportation ratio. Another possibility is to change the network structure of two city hubs to one city hub, which halves the number transported goods.

Due to the combining usage of transporting people and goods the travel times of people rise compared to a ropeway system used only for passenger transportation. To analyse the prolongation the ropeway system for person transfer is simulated as well. This simulation results in the values of Table 34.

Table 34: Statistical report simulation person transport

Station no.	MU type	Average throughput time	Throughput
Station 1	Person	00:19:23	2878
Station 2	Person	00:13:34	1792
Station 3	Person	00:11:16	928
Station 4	Person	00:12:13	2656
Station 5	Person	00:13:12	3577
Station 6	Person	00:13:14	6138
Station 7	Person	00:11:50	4435
Station 8	Person	00:13:30	3077
Station 9	Person	00:15:38	3408
Station 10	Person	00:18:41	993
Station 11	Person	00:20:46	461

The average throughput times of persons per station, when only transporting persons with the ropeway system are illustrated in the blue graph of Figure 54.

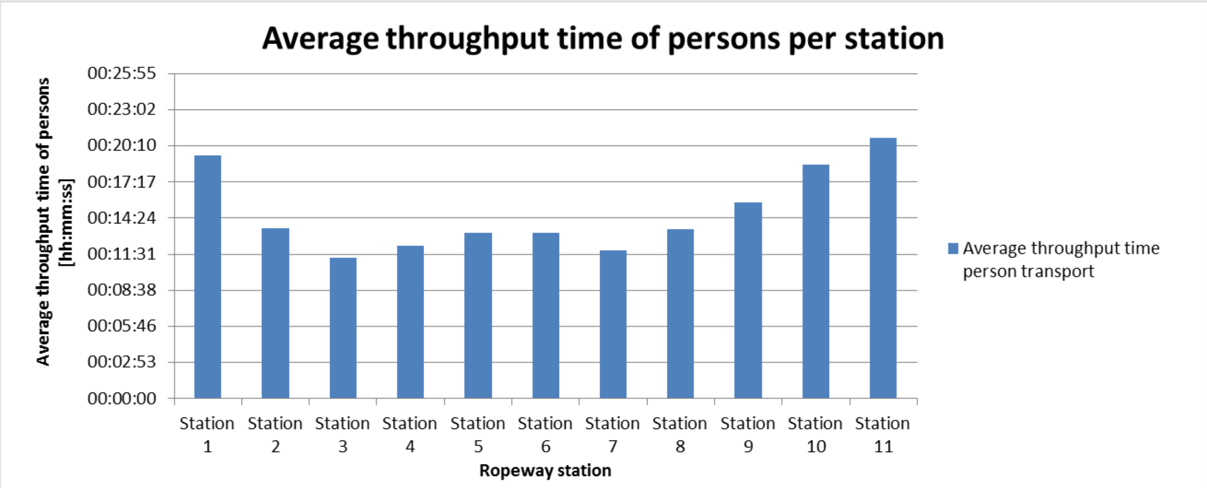


Figure 54: Average throughput time of persons per station person transport

By comparing both simulations the benchmark scenario "2CH_3DU_Layout_1_max" and the scenario with only transporting passengers the following chart, Figure 55, results.

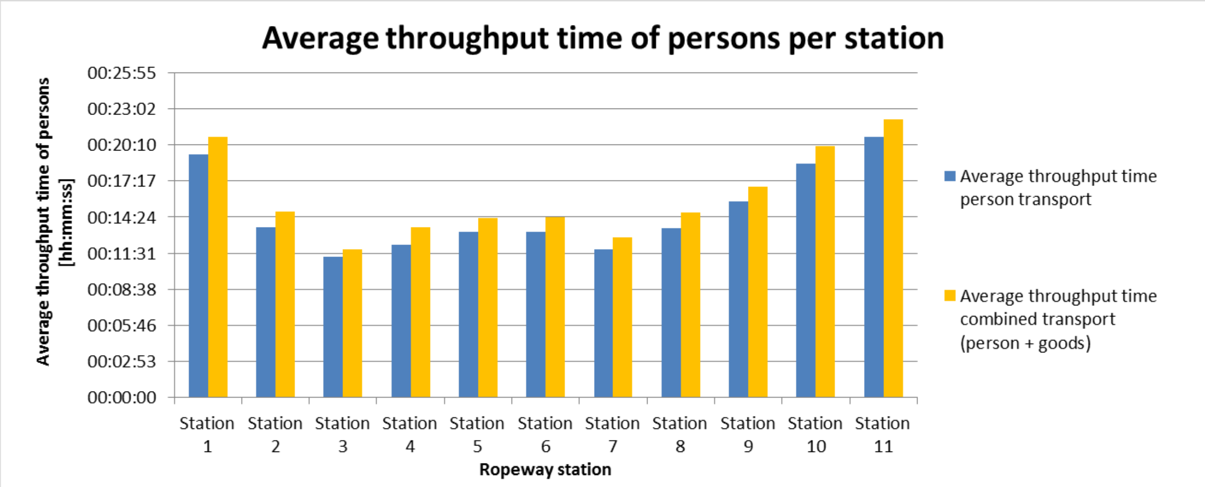


Figure 55: Comparison average throughput time of persons per station

The graph in Figure 55 displays that a combining transport of people and goods results in a prolongation of travel time to every ropeway station in the network. This may influence the attractiveness of the overall ropeway system. In numbers the differences of the average throughput time of persons per station are as follows, Table 35.

Table 35: Prolongation average throughput time

Station no.	Prolongation average throughput time
Station 1	00:01:26
Station 2	00:01:14
Station 3	00:00:34
Station 4	00:01:21
Station 5	00:01:06
Station 6	00:01:11
Station 7	00:00:56
Station 8	00:01:15
Station 9	00:01:14
Station 10	00:01:21
Station 11	00:01:26

The increase of throughput times of persons vary from a minimum of 34 seconds up to 1 minute and 26 seconds, which yields over all station to an average prolongation of 1 min and 11 seconds in case of a combining transport system.

4.4.2 Analysis: gondola utilization

Second part of the simulation run analysis is the utilization of gondolas during the operating hours of goods transportation (05:00-12:00). In order to evaluate the material flow potential of a combining ropeway system for people and goods the gondola utilization with and without carrying goods is analysed.

- Combining system - people and goods

Figure 56 illustrates in yellow the utilization of each gondola at the ropeway system during the time period of 05:00 to 12:00 o'clock.

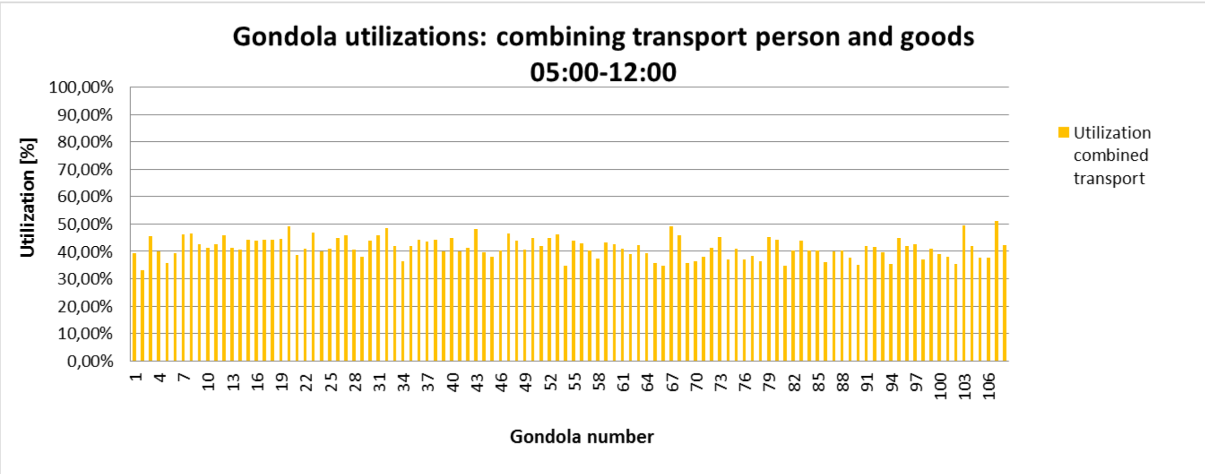


Figure 56: Gondola utilizations combining transport "2CH_3DU_Layout_1_max"

With a total number of 108 gondolas the gondola utilization fluctuates between a minimum level of 33,24% and a maximum level of 51,08%, which results over all gondolas to a gondola utilization of 41,45%.

- Person transport system

If the urban ropeway system only transports person the utilization of gondolas decrease, as Figure 57 displays in blue.

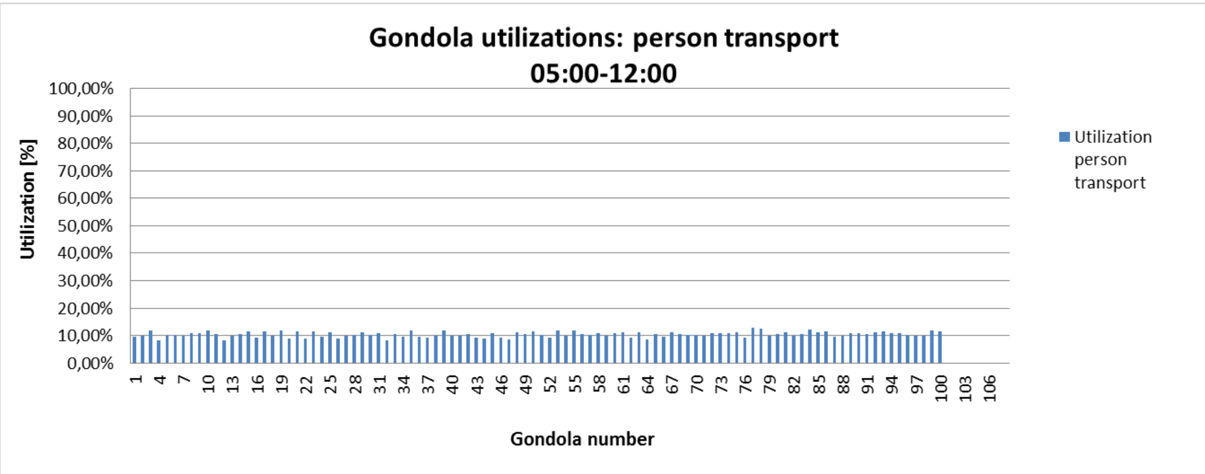


Figure 57: Gondola utilizations person transport

Here the utilization is in a corridor of 8,27% to 12,81% among all gondolas (100 gondolas). In total the mean value of gondola utilization is about 10,42% in the observed period from 05:00 to 12:00 o'clock.

The comparison of gondola utilization of both strategies, combining transport and person transport, of the simulated scenario results in the diagram in Figure 58.

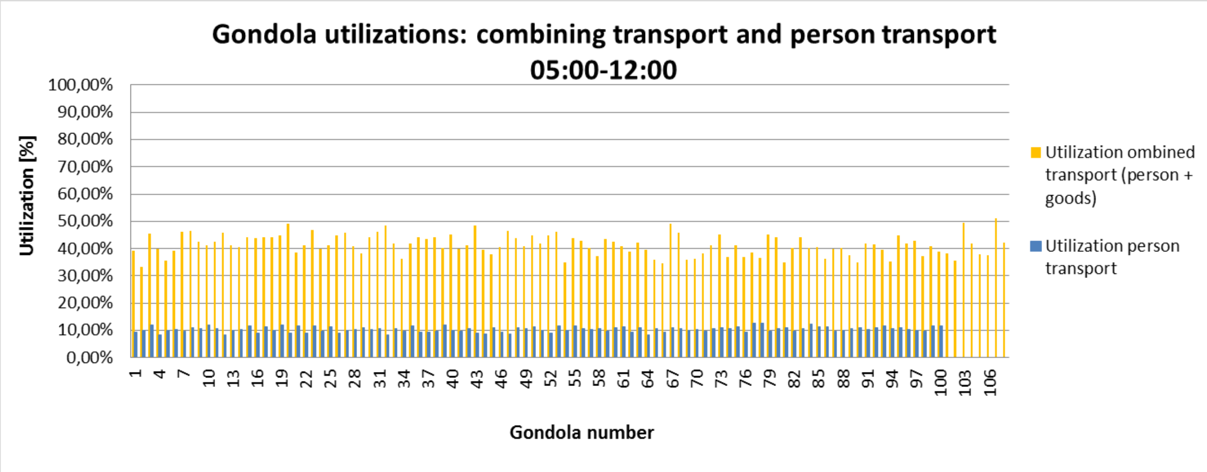


Figure 58: Comparison gondola utilizations combined transport and person transport

In the subsequent Figure 59 the average gondola utilization of both transportation strategies are compared, in yellow the combined one with 41,45% gondola utilization and in blue transporting only persons with 10,42% gondola utilization in the observed time period from 05:00-12:00 o'clock. This leads to the result that the combining transport with two city hubs and three distribution units operating at its maximum performance has a four times higher gondola utilization than when only transporting persons with the system.

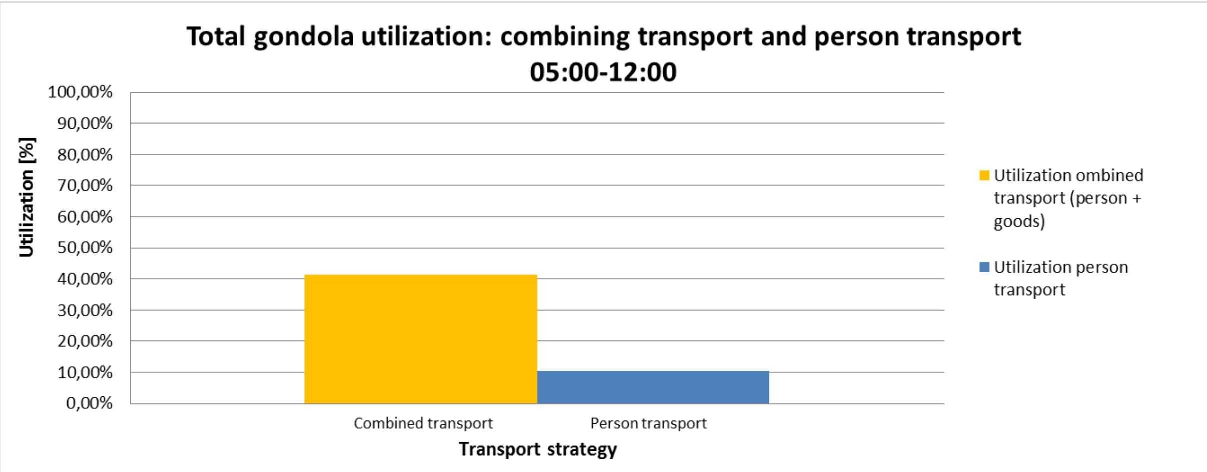


Figure 59: Total gondola utilization combined transport vs. person transport

When only transporting persons with the ropeway system the gondola utilization decreases. Beside that the number of gondolas on the system decreases from 108 to 100, so fewer resources are needed. The reason of the reduced gondola amount is the shorter lead time in ropeway station S1, S3, S5, S7 and S11.

4.4.3 Analysis: buffer workload

This subchapter is dealing with the occupancy analysis of the entrance areas of each station. The workload recording is done by identifying the amount of persons on the entrance buffers every minute over the whole operating hours (05:00 – 23:00).

Main reason of this investigation is to dimension the entrance areas of the stations properly. Furthermore the occupancy evaluation immediately outlines the daytimes where a change of the ratio between person and load gondolas is needed (high peaks of person amount) or is possible.

Two chosen station workloads are further described here, main station S1 and sub station S5. The other ones are attached in appendix chapter 9.4. In addition to the workload over the day of the combined transport strategy with two city hubs and three distribution units (yellow) also the workload curves of transporting only persons are displayed (blue).

- Station S1:

The accumulated amount of persons in the entrance area of station S1 over one weekday shows the yellow graph in Figure 60. On the abscissa the daytime and on the ordinate the number of persons are displayed.

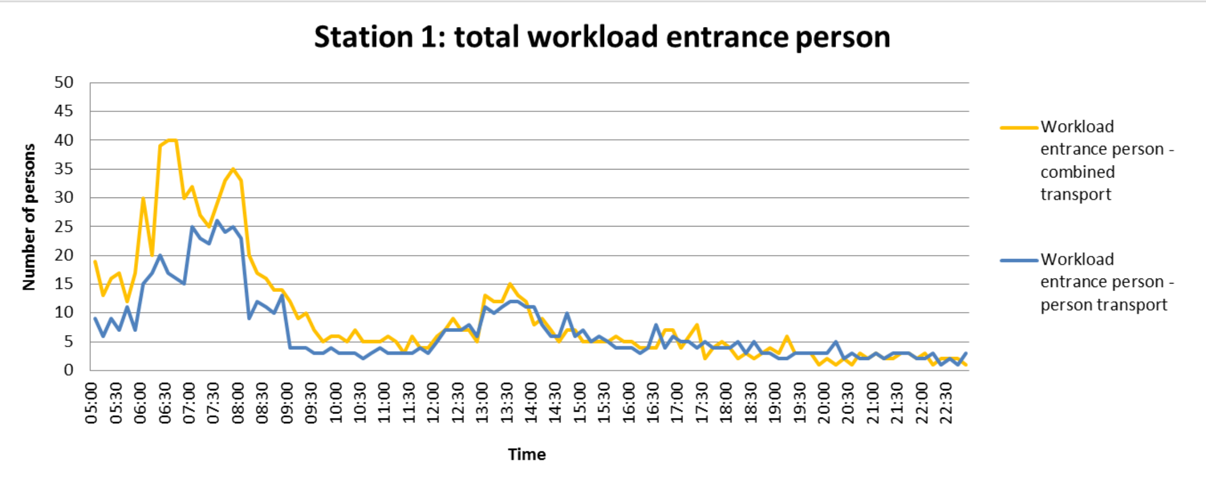


Figure 60: Station 1 total workload in entrance area combined transport and person transport

Till 08:30 the entrance area at station 1 has a workload up to 40 persons. Then the curve drops and the values fluctuate around five to ten people in the entrance area. The low number of persons from 08:30 to 12:00 o'clock supposes to increase the number of load gondolas during this time period, but when looking at the total workloads in other stations it results in too high person amounts. Therefore the permanent regard to the other workload lines of stations is essential.

During the operating hours of goods transportation (05:00-12:00) station S1 has a higher workload than when only transporting persons (gap between yellow and blue lines). The increase of people in stations has an influence on the structural design of each single station and directly affects the building costs of the ropeway system.

- Station S5:

The subsequent Figure 61 illustrates the chart of workload of station 5. At this station the maximum number of persons in the entrance area is lower than at station 1, but the line has a more constant course over the whole day.

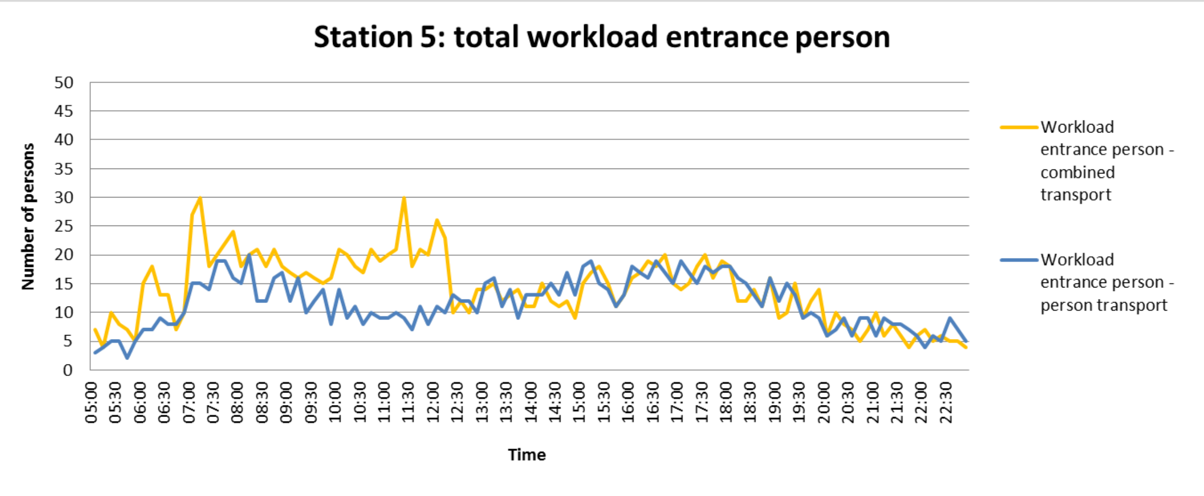


Figure 61: Station S5 total workload in entrance area “2CH_3DU_Layout_1_max”

Referring to station S1, where a shift to more load gondolas between 08:30 and 12:00 may be possible, would lead to a higher entrance capacity need in station S5. Furthermore the average throughput times will rise because people have to wait longer at the entrance areas. Out of this explanation it is obvious that a closer look on the buffer workloads of every station is necessary. In station S5 the workload of persons in the entrance area is also higher when transporting people and goods than by transporting only people.

All other workload graphs of stations S2-S4 and S6-S11 are attached at the end in the appendix chapter.

4.4.4 Analysis: passenger transport

As mentioned in the previous analysis chapters the ropeway system was also simulated by transporting passengers only. This analysis indicates low gondola utilization and low workloads of persons in the entrance areas of the stations. Therefore the ropeway system is overdesigned when transporting only persons and leads to the following conclusions for this scenario:

- The ropeway system can transfer more people than the predicted amount of about 30500 per weekday.
- The gondola cycle times can be increased, fewer gondolas per hour and fewer gondolas on the system are needed.

5 Summary and conclusion

Due to the actual emission situation in Graz and further legislative restrictions concerning road traffic and city logistics alternatives in mobility have to be found and evaluated. One innovative solution might be the use of city cable cars. In the present thesis the main aim was to fully describe and specify an urban ropeway system for the combining transport of people and goods in Graz. The study contains information about most important elements of such ropeway systems. In addition a simulation model was developed which helps to evaluate material flow parameters of urban cable cars.

In a first step a fundamental literature research was conducted to get basic knowledge on material flow studies as well as on urban ropeway systems. This includes getting familiar with the simulation software Plant Simulation, which is commonly used to simulate material flow networks of production systems. The main results out of the first phase are:

- Elementary calculation forms of material flow studies
- Overview of urban ropeway systems, especially the construction types, fields of applications and their specific characteristics
- Introduction into simulation processes

Out of the first insights in material flow systems and city cable cars the specific problem of an urban ropeway system in Graz was analysed. During this phase the start and initial conditions out of a pre-project were extracted and the most important outputs listed. The problem examination delivered a concrete project structure, which considers the aims and tasks of this master thesis. Furthermore the steps give guidance for a systematic project approach. The project phases have been set as follows:

- System specification, data acquisition and concepts
- Modelling and simulation
- Model verification
- Analysis

The system specification delivered a clear set of the system boundary as well as a specification of the key indicators of an urban ropeway system for the combining transport of people and goods. Outputs of this phase are a data model which illustrates the elements and their relations among each other and a list of requirements which describes the influencing factors on such a system.

In order to determine the values and characteristics of attributes and parameters a data acquisition was necessary. This investigation provides time-variation curves for persons and time-variation curves for goods using the ropeway system on a weekday. Subsequently the amount of goods (parcels) which are delivered in the catchment area of the ropeway system was identified.

The first project part concluded with the identification of possible network structures and station layouts. By the set of six different network structures and their advantages and disadvantages a comprehensive view on positions of city hubs and distribution units alongside the network route is provided. Second part of the concept stage was the definition of seven station layouts, which result in longer or shorter station lead times.

By modelling the ropeway system the conceptual model was transferred into the virtual form of a simulation model. Here all the functions and elements described in the project phase before have to be properly implemented. The simulation model has three basic sections: main station, which represents the station form of a final stop; a sub station, which defines the stations between the main stations and the models frame into which the stations are inserted and the distances between those stations are defined. In the simulation model four moving unit types are set:

- Persons, who enter the system at a specific station and leave the system at their target station
- Loads (goods), which enter the system either at city hubs or distribution units and are transported in roll containers
- Roll containers, which represent the transport units of loads and be carried to their target station
- Gondolas, which move either persons or goods and circulate on the ropeway system from station to station

Every simulation model has to be verified to check the qualitative implementation of the conceptual model into the virtual one. This verification process was permanently conducted during the building phase of the model and iteratively improved the model. During the verification four methods were used: debugger function of Plant Simulation, which identifies programming mistakes; animation of the system elements during simulation runs; variation of input parameters and subsequent check of outputs; recording of data and analysis.

Out of these various project steps a clear structure of an urban ropeway system for the combining transport of people and goods was identified. By the definition of the key elements of such a system it is easier to understand the limiting factors on material flow outputs. In addition to that the various specified concepts of network structures and station layouts can help to find the best solution.

With the consideration of the requirements on the simulation model it is possible to simulate several arrangements of the urban ropeway system. This flexibility allows a quick evaluation of different scenarios and also easy modifications of input factors.

The final part of the project was the simulation of one specific scenario of the urban ropeway system and the analysis of its results. This analysis includes the evaluation of the statistical report with its important material flow characteristics throughput and average throughput time, as well the examination of the gondolas utilizations and the identification of the workloads on the buffers in the system.

The first conducted analysis with two city hubs and three distribution units estimates the maximum performance of the ropeway system and can be seen as a benchmark for further investigations. The results indicate a maximum transport capacity of about 80000 goods per weekday, which is almost three times the amount of the theoretical parcel deliveries alongside the ropeway system (CEP amount of around 28000 pieces). In addition to this throughput result the workloads and throughput times of each single station were observed and analysed. The outcomes suggest higher workloads and throughput times than by transporting only passengers but on a negligible scale.

In addition to analysis results the predefined output forms and diagrams can be used as a template for further simulation runs and will simplify the comparison of diverse cable car scenarios.

6 Outlook

With the fundamental development and specification of the urban ropeway system for the combining transport of people and goods new insights in such a material flow network were gained. The various results e.g. list of requirements, different concepts, verified simulation model, templates for simulation output analysis; provide the basis for a detailed evaluation of a city cable car system in Graz.

As a next step the outcomes of the thesis can be used to define a complete design of experiment in order to get a systematic approach for the analysis of different simulation scenarios. This plan structures and fastens the finding process of the optimal solution of the urban ropeway system concerning to material flow aspects.

In addition to the design of experiment the analysis of output data may be automated. The current simulation model fulfils all requirements to evaluate the system but the preparation and documentation of data into adequate forms is time consuming. Depending on the number of simulation runs the complete output process could be automated in order to accelerate these steps. One possibility is programming an Excel master file for the data treatment as already done with the input of data. When the simulation run is finished the material flow software Plant Simulation writes the data into Excel files which are further processed by this master file. This leads to very short processing time for the simulation and evaluation of different ropeway scenarios.

Out of the simulation results the potential capacities for transporting goods beside the predicted passenger numbers are gained. In further analysis of the ropeway system additional evaluation criteria like economic, environmental or social factors have to be considered. This overall reflection leads to reasonable arguments to introduce or not an urban ropeway system for the combing transport of people and goods in the Austrian city Graz.

7 Lists

7.1 List of figures

7.2 List of tables

8 Bibliography

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9 Appendix

9.1 Data model

Table 36: Data model

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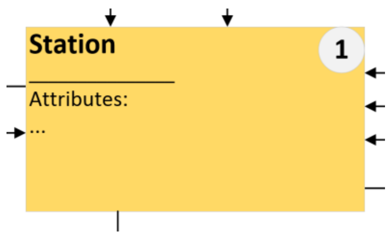
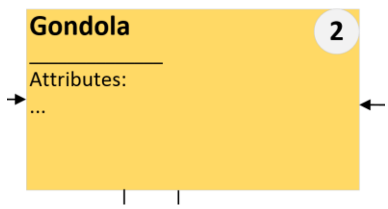
<tr><td colspan="2">
</td></tr>
<tr><td>

$: ID-station: string
Name: string
Position: string
Layout: string
Length of station: real
I: Capacity person entrance: integer
I: Capacity person exit: integer
I: Capacity goods entrance: integer
I: Capacity goods exit: integer
I: Lead time station person: time
I: Lead time station goods: time
O: Workload capacity person entrance: real
O: Workload capacity person exit: real
O: Workload capacity goods entrance: real
O: Workload capacity goods exit: real

</td><td>

Station – Exit:
From the Station persons leave the system via the Exit. Station supplies the Exit with persons.
Station – City hub:
From the Station goods leave the system via the city hub. Station supplies the city hub with goods.
Station – Pick-up station:
A Station may possess a Pick-up station depending on the network structure where people pick-up their goods.

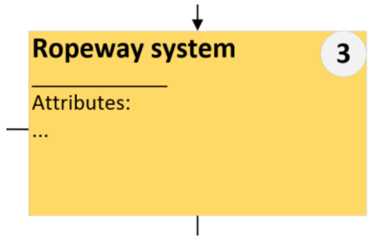
</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>

$: ID-gondola: string
Type: string
I: Capacity person: integer
I: Capacity goods – roll container: integer

</td><td>

Gondola – Station:
Gondolas pass through Station: enter or exit persons - load or unload goods.
Gondola – Persons:
Gondolas transport persons.
Gondola – Goods:
Gondolas transport goods.

</td></tr>
</table>

<table>
<tr><th colspan="2">Class</th></tr>
<tr><th>Attributes</th><th>Relations</th></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>

- $: ID-ropeway system: string

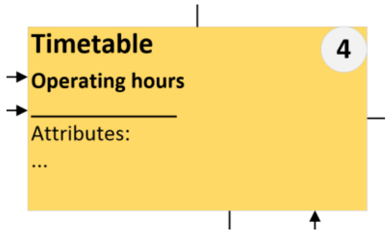
- Availability-maintenance: real
- Number of gondolas: integer
- Acceleration - deceleration real
- Conveying speed: real
- Cycle time: time

- O: Throughput person: real
- O: Throughput goods – roll container: real
- O: Lead time passenger transport: time
- O: Lead time goods transport: time
- O: Workload person gondola: real
- O: Workload goods gondola: real

</td><td>

- Ropeway system – Gondola:
The Ropeway system use gondolas as the transportation unit for people and goods.

- Ropeway system – Station:
The Ropeway system connects the Station according the network route together.

</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>

- $: ID-timetable: string

- Operating hours (start-end): time
- Date: date

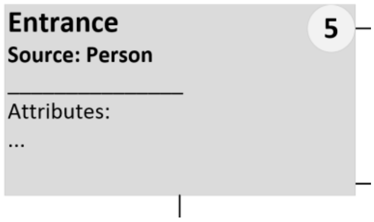
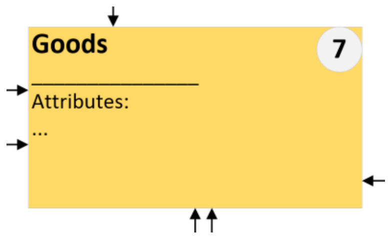
</td><td>

- Timetable – Ropeway system:
The Timetable operates the Ropeway system relating to operating hours.

- Timetable – Gondola:
The Timetable operates the Gondola relating to operating hours.

- Timetable – Station:
The Timetable operates the Station relating to operating hours.

</td></tr>
</table>

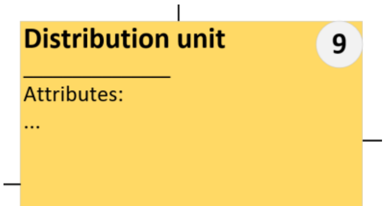
<table>
<tr><th colspan="2">Class</th></tr>
<tr><th>Attributes</th><th>Relations</th></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>$: ID-source person: string
SP: Start-Target-Quantity distribution: table</td><td>Entrance – Timetable:
The number of persons entering the system via the interface Entrance to the environment affects the Timetable (operating hours of the system).
Entrance – Station:
Via the Entrance persons come to the Station.
Entrance – Persons:
Entrance is the source of Persons. Entrance creates Persons.</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>$: ID-Person: string
Target station: integer</td><td></td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>$: ID-goods: string
Target station: integer</td><td></td></tr>
</table>

<table>
<tr><th colspan="2">Class</th></tr>
<tr><th>Attributes</th><th>Relations</th></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>

- $: ID-City hub: string
- Name: string
- Position: string
- Capacity input goods: integer
- Capacity output goods: integer
- SP: Start-Target-Quantity distribution: table

</td><td>

- City hub – Timetable:
The number of goods entering the system via the city hub affects the Timetable of the ropeway system.
- City hub – Station:
The city hub supplies the Station with goods.
- City hub –Goods:
City hub is the source of Goods.
- City hub – Warehouse:
A city hub possesses a Warehouse where the incoming/ outgoing goods are stored/ buffered.

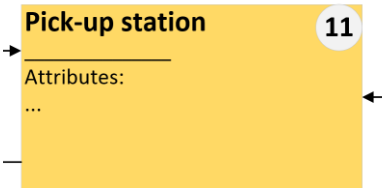
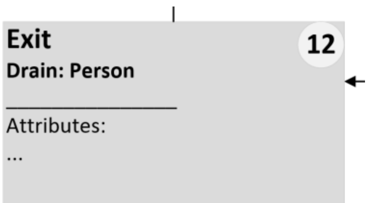
</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>

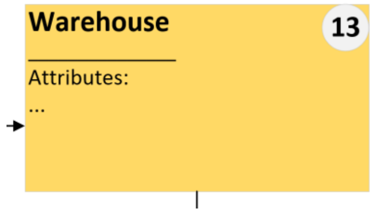
- $: ID-distribution unit: string
- Name: string
- Type: string
- Capacity-transport volume: real
- Time for distribution - availability: time
- I: Number of distribution vehicles: integer
- O: Workload vehicle fleet: real

</td><td>

- Distribution unit – Goods:
The Distribution unit transports goods to the final customers.
- Distribution unit – Customer:
Distribution unit delivers goods from Station to Customer (shops, private persons).
- Distribution unit – Station:
Distribution unit delivers goods form shops, private persons to Stations of the ropeway system (return deliveries, goods to destinations outside the city).

</td></tr>
</table>

Class	
Attributes	**Relations**
	
▪ $: ID-customer: string ▪ SP: Start-Target-Quantity distribution: table	▪ Customer – Timetable: The demand of goods affects the Timetable (operating hours) . ▪ Customer – Goods: Customer (shops, private person) have a need of Goods. ▪ Customer – Pick-up station: Customers may pick-up their goods at Pick-up stations located along the ropeway system, depending on network structure.
	
▪ $: ID-Pick-up station: string ▪ Name: string ▪ Stock - content: integer ▪ Time move in: time ▪ Time move out: time ▪ I: Capacity: integer ▪ O: Workload capacity: real	▪ Pick-up station – Goods: A Pick-up station stores Goods for Customers who want to pick-up their Goods directly from the ropeway system. Pick-up station is an additional service.
	
▪ $: ID-drain person: string ▪ O: Throughput station: integer	▪ Exit – Persons: Exit is the drain of Persons. Exit deletes Persons.

<table>
<tr><th colspan="2">Class</th></tr>
<tr><th>Attributes</th><th>Relations</th></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>

- $: ID-warehouse: string

- Stock - content: integer
- Time move in: time
- Time move out: time

- I: Capacity: integer
- O: Workload capacity: real

</td><td>

- Warehouse – Goods:
The Warehouse stores Goods in the city hub.

</td></tr>
</table>

9.2 List of requirements

9.2.1 Service level:

Table 37: List of requirements – service level

No.	Parameter	Description	Requirements	Concept
1.	**Organisation**	Target groups.		
1.1.	**Business activity / company / potential customers**	Identifying the groups (people, businesses, companies) who will use the ropeway system.	Person transportation: short transport time, attractive charge model. Goods transportation: transport goods to customer on schedule, attractive charge model.	Person: moving object Good: moving object Customer-company: drain
1.2.	**Business branches/ customers**	Active users of the system.	Identifying why persons, branches using the ropeway system.	Person: moving object Good: moving object Customer-company: drain
1.3.	**Structure of logistics - logistic network**			
1.3.1	**Number of receiving spots (shops/ customers)**	Receiving spots: Number of position where customers can pick up their goods (Pick-up station) and or customers receive their goods per service unit (distribution unit - cargo bike, e-vehicle). Receiving spots: City hub delivery returns.	Comprehensive supply of all potential customers Version 1: At all station it is possible to pick-up goods and distributes goods. Version 2: Receiving spots at chosen station (costs to benefit).	Version 2: Receiving spots at highly frequented stations, high number of potential customers in surrounding area 1. Grabengürtel 2. Andreas-Hofer Platz 3. Bertha von Suttner Brücke

1.3.2	**Number of goods sources**	Source of goods: Number of positions where goods enters the ropeway system (city hubs, distribution units)	City hubs outside the inner city to reduce the city traffic from delivery services, city hubs located near highways. Version 1: High number of city hubs, low transportation times, near end customer, high theoretical transportation capacity with system. Version 2: Low number of city hubs, lower traffic to city.	Version 2: Low number of city hubs Scenarios: 1. City Hub Nord Weinzödlbrücke 2. City Hub Süd Webling Good traffic connection (A9 - Wiener Straße)
2.	**Resources**	Infrastructure and vehicles		
2.1.	**Loading equipment**	To build transport units. Ease the loading and unloading process of goods.	Standardized products (costs, dimensions). Easy to handle.	Standardized roll container are used. Different sizes are available according need and available space in gondola.
3.	**Order volume**			
3.1.	**Transport unit**	Parcel/ roll container	Protect and facilitate ordered items.	Parcel will be generated at sources.
3.1.1	**Kind of goods**	Distribution of different kind of goods (parcels): Small parcel, big parcel, bulky goods, and pallets.	Version 1: Transportation of small and big parcels. Version 2: Transportation of small and big parcels and additionally bulky goods and pallets.	Version 1: only transportation of small and big parcels (big parcel can be carried without additional technical equipment.
3.1.2	**Dimension of freight**	Length, width and height of goods (parcel), influence the possible amount of items per transport unit.	Maximum dimension of freight according size of conveying means.	According to distribution function of de Volume of goods the maximum number of goods per conveying mean is calculated.

3.2.	**Loading unit**	Parcels/goods will be pooled into loading units with the same target station. Transportation in loading units from city hub to target station.	Standardized products (costs, dimensions). Easy to handle	Standardized roll container are used. Different sizes are available according need and available space in gondola.
3.3.	**Daily order volume**	Daily time variation curve: how many goods/ parcels are delivered per hour and day?	Calculation of number of goods per day, evaluation when goods will be delivered.	Time variation curve per weekday [MO-FR].

9.2.2 Structure level:

Table 38: List of requirements – structure level

No.	Parameter	Description	Requirements	Concept
1.	**Network structure**			
1.1.	**Network node**	Point in network where two or more network edges are intersecting each other. Shift of persons or goods.		
1.1.1	**Amount of nodes**	Number of nodes in the whole ropeway system.	Appropriate number of nodes to establish a system with satisfying amount of station for achieving low costs for infrastructure and resources but also low distances and high covering.	Person transportation: 11 stations Goods transportation: Depending on the defined network structure scenario up to 2 city hubs (Webling & Weinzödlbrücke) and up to 3 distribution/ pick-up stations (Bertha von Suttner Brücke, Andreas Hofer Platz, Grabengürtel)
1.1.2	**Position**	Position point of network node.	Network node at highly frequented spots.	According to "Planfall 1.1." (Ropeway POT project)
1.1.3	**Node throughput**	Amount of moving objects in one specific node.	Throughputs in defined nodes for documentation purposes.	Documentation with tables and diagrams.

1.1.4	**Node constraints**	Limitation factors at nodes		
1.1.4.1	**Constraint: amount**	Limitation of number of persons/ goods at one network node.	Limitation according to capacity and type of node.	Distribution of persons/ goods due to daily time variation curves.
1.1.4.2	**Constraint: time**	Operating hours of the nodes. Active or inactive node.	Limitation according to daytime.	Day control: shift calendar (operating hours of each day) set from 0500-2300 per weekday. Hour control: Trigger function, control to actual daytime.
1.2.	**Network edge**	Path for person and good transport.		
1.2.1	**Means of carriage**	Means of carriage are used to transport persons and goods (gondolas) between the different stations.	Definition of the maximum capacity for person and good transport.	Modelling means of carriage with moving objects, where persons or goods may enter. Person transport: Maximum Capacity 35 persons per gondola. Good transport: Maximum capacity according loading space (~3,2x3,2x2,5m) and maximum load 2500 kg; defined with maximum of 4 roll containers per gondola.
1.2.2	**Distance matrix**	Length between stations.	Define the position of each station.	Length according to "Planfall 1.1." (Ropeway POT project)
1.2.3	**Transportation time matrix**	Transport time between stations.	Defined by maximum rope speed, deceleration and acceleration.	Analytical calculation of transportation times. Node edge will be parameterized according analytical calculation.

1.2.4	**Workload matrix**	Workload between stations.	Defined by number of entrances per station and targets of objects (goods/ persons)	Person transport: Target probabilities according Ropeway Pot project (ISV TU Graz) Good transport: Definition of Target probabilities of goods according estimation (expert interviews) Target probabilities influence the workload between stations.
1.2.5	**Edge constraints**			
1.2.5.1	**Constraint: amount**	Number of gondolas on the ropeway system according cycle time.	Cycle time defines the amount of gondolas at the network edges.	Gondolas enter the system at the two outer stations (final stops). According the cycle time and the travel time between the two final stops the number of gondolas is generated.
1.2.5.2	**Constraint: time**	Operating hours.	Operating hours define when it is possible to use the ropeway system.	Operating hour's ropeway system with shift calendar: 05:00-23:00 o'clock. Last entrance at 23:00 o'clock.
2.	**Network components**			

2.1.	**City hub**	Ropeway station where goods enter and leave the system.	City hubs outside the inner city to reduce the city traffic from delivery services, city hubs located near highways. Version 1: High number of city hubs, low transportation times, near end customer, high theoretical transportation capacity with system. Version 2: Low number of city hubs, lower traffic to city.	Version 2: Low number of City hubs Scenarios: 1. City Hub Nord Weinzödlbrücke 2. City Hub Süd Webling Good traffic connection (A9 - Wiener Straße)
2.2.	**Pick-up station**	Customer can directly pick-up their goods/ parcels at ropeway stations. The goods/ parcels are stored in lock boxes. The customer will be informed electronically (email, sms) when the good/parcel is ready to pick-up.	Comprehensive supply of all potential customers Version 1: At all station it is possible to pick-up goods and distribute goods Version 2: Receiving spots at chosen station (costs to benefit)	Version 2: Receiving spots at highly frequented stations, high number of potential customers in surrounding area 1. Grabengürtel 2. Andreas-Hofer Platz 3. Bertha von Suttner Brücke
2.3.	**Distribution unit**	Distribution units for the delivery service to customers (private persons, companies, shops etc.) Use of economically friendly delivery vehicles e-vehicle, cargo bike, e-bike.	Comprehensive supply of all potential customers Version 1: At all stations distribution units, low delivery ways, high infrastructure costs. Version 2: Distribution units at chosen station (costs to benefit)	Version 2: Distribution units located at inner city, at highly frequented stations, high number of potential customers in surrounding area 1. Grabengürtel 2. Andreas-Hofer Platz 3. Bertha von Suttner Brücke
3.	**Network dimension**			
3.1.	**Resource requirement**	Requirements for attractive and satisfying transportation.		

3.1.1	**Need of gondolas**	Number of gondolas on the ropeway system according cycle time to achieve required throughput of persons and goods.	Cycle time defines the amount of gondolas at the network edges.	Gondolas enter the system at the two outer stations (final stops). According the cycle time and the travel time between the two final stops the number of gondolas is generated.
3.1.2	**Relation person to load gondolas**	Defines the relation between person and load gondolas.	Relation has to ensure to transport person and goods in a proper way regarding waiting times and throughput rates.	Analytical calculation of the person workload between all stations each hour. Setting the type of gondola to transport goods or persons with the relation each hour. Gondola types are set at the two outer stations (final stops).
3.1.3	**Need of logistic area**	Capacity needed to load and unload goods. Capacity needed for entrance and exit of persons.	Enough capacity to ensure smooth ropeway operation with low infrastructure costs.	Logistic areas will be dimensioned to ensure not to limit the system itself. Need of logistic areas will be defined with workload documentation during simulation of scenarios.
4.	**Network efficiency (analysis)**	Analysis - evaluation of simulation results		
4.1.	**Throughput rates**			
4.1.1	**Throughput goods**	Amount of goods which are transported with the ropeway system per time unit.	Recording and documentation of all goods.	Statistical analysis of recorded goods which were entering the system at sources and leaving the systems at drains per time unit.
4.1.2	**Throughput persons**	Amount of persons which are transported with the ropeway system per time unit.	Recording and documentation of all persons.	Statistical analysis of recorded persons who were entering the system at sources and leaving the systems at drains per time unit.

4.2.	**Lead Time**	Time span between the point of time entering the system and the point of time leaving the system. Output mean lead time.		
4.2.1	**Lead time goods**	Time span between the point of time the good is entering the system and the point of time leaving the system.	Recording and documentation of all lead times of goods.	Statistical analysis of the mean lead time of goods to the specific station.
4.2.2	**Lead time persons**	Time span between the point of time the person entering the system and the point of time leaving the system.	Recording and documentation of all lead times of persons.	Statistical analysis of the mean lead time of goods to the specific station.
4.3.	**Workload**	Relation of transported amount to the theoretical amount.		
4.3.1	**Workload gondolas**	Workload of each gondola per time unit.	Recording the workload during ropeway operating hours	Statistical analysis of the recorded workloads of each gondola per time unit.
4.3.2	**Workload gondolas**	Workload of each gondola per time unit.	Recording the workload during ropeway operating hours.	Statistical analysis of the recorded workloads of each gondola per time unit.
4.3.3	**Workload logistic areas**	Workload of the logistic area (capacity) to load and unload goods. Workload of the person entrance-exit area (capacity).	Recording the workload during ropeway operating hours.	Statistical analysis of the recorded workloads of each area per time unit.
4.3.4	**Workload optimum - workload limit**	Optimum of operation. Highest throughput rates, low lead times, lowest costs.	Highest throughput rates, low lead times, lowest costs.	Iterative simulation study by various simulation scenarios.

9.2.3 System level:

Table 39: List of requirements – system level

No.	Parameter	Description	Requirements	Concept
1.	**Type of gondola**			
1.1	**Standard gondola**			
1.1.1	**Standard gondola with/ without modification steps**	Standard gondola with modification steps: for transportation of goods a modification of the gondola is needed. Results in additional time. Standard gondola without modification steps: for transportation of goods no modification of the gondola is needed.	**Version 1:** with modification steps: design of gondola has to ensure quick and easy modification to use the gondola for transportation of goods. More space available for transporting goods. **Version 2:** without modification steps: no additional time needed lower capacity to transport goods.	Version 2: without modification steps. During operation gondola can be used either transporting goods or persons according relation person to load gondolas.
1.2.	**Technical parameters**	Dimensions of available space for transporting.		
1.2.1	**Gondola dimensions - available space for transport**	Gondola dimensions according rendering of gondola manufacturer. Length x width x height.	Standard 3S gondola. Gondola space according requirements for the public transportation.	Gondola dimensions: ~3,2x3,2x2,5 m. Person transportation: max. 35 persons. Transport of goods: max. 4 roll containers.
1.2.2	**Gondola weight restrictions**	Restrictions to the maximum weight per gondola.		
1.2.2.1	**Maximum total weight**	Total weight = weight of gondola + weight of transported objects (persons or goods).	Total weight <= maximum total weight	Weight of transported goods (roll containers) is limited by the maximum weight per roll container itself.
1.2.2.2	**Maximum transportation weight**	Maximum value including all transported objects.	Max. transported weight = 35 persons x 80kg = 2.800 kg. When transporting goods the footprint of loading units (roll containers) are not allowed to exceed the maximum weight per footprint of persons.	Weight of transported goods (roll containers) is limited by the maximum weight per roll container itself. Analytical calculation of the footprint per person and footprint per roll container.

2.	**Rope system**			
2.1.	**Types**			
2.1.1	**3R - TGD / 1R - MGD**	3R - TGD Tricable gondola detachable: 3 Ropes (2 support rope, 1 convey rope). 1R - MGD Monocable gondola detachable: 1 Rope (1 support rope additionally used for conveying).	3R - TGD due to higher gondola capacities, higher transportation speed, higher stability.	Consistent 3R - TGD gondola system.
2.2.	**Technical parameters**			
2.2.1	**Transportation speed - rope speed**	Speed of rope. Maximum speed of the gondola between stations.	Appropriate rope speed in urban areas ~ 7,5 m/s due to short distances between stations. (expert interviews Zatran, Leitner)	Rope speed 7,5 m/s 1 m/s gondola acceleration 1 m/s deceleration Analytical calculation of travel time between stations.
2.2.2	**Distance between gondolas**	Distance between two gondolas.	According to defined throughput rates, rope speed and persons per gondola.	Distance will be defined by the gondola cycle time.
2.2.3	**Gondola throughput**	Number of gondolas per time unit.	According to defined throughput rates, rope speed and persons per gondola.	~ 85 gondolas per hour. ~ 3000 persons per hour and direction.
3.	**Circulation system**			
3.1.	**Types**			
3.1.1	**Common / separate system**	**Common system:** Load and person gondolas use the same circulation system. **Separate system:** Load and person gondolas use the different circulation systems.	Low need of space (urban area), low lead times in stations.	Common system with different station layouts according concept solutions of stations.
3.2.	**Technical parameters**			
3.2.1	**Velocity of circulation**	Velocity of gondola in stations.	Appropriate velocity for handling of goods (load and unload of gondola) and for entrance and exit of persons.	Defined velocity of circulation 0,2 m/s (expert interviews)

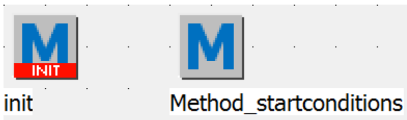
3.2.2	**Length of Station**	Length in stations.	According to velocity of circulation in stations and the needed times of handling goods and entrance/exit persons.	According different station layouts different length of stations will result. Length of station = velocity of circulation x time in station.
4.	**Station layout**			
4.1.	**Types**			
4.1.1	**Layout**			
4.1.1.1	**Common / separate circulation area**	**Common circulation area:** Entrance and exit of person in same area/ space as handling of goods. **Separate circulation area:** Separate entrance and exit area/ space for persons and for goods.	Separate circulation areas are required. Possibility to use areas for goods handling also for passenger entrance/ exit in times where no goods are transported --> flexible area management.	Separate areas, person use person areas (buffer, ways) and goods use good areas (buffer, ways).
4.1.1.2	**Common / separate level (floor)**	**Common level:** Entrance and exit area for persons are at the same level (floor) as the handling of goods. **Separate level:** Entrance and exit area for persons and the area for handling of goods are in different levels (floors).	No separation of levels necessary, separation of levels will increase costs and efforts of handling goods.	Common level: same level for entrance/ exit persons and handling of goods.
4.1.2	**Layout - position of areas**			
4.1.2.1	**Sequence plan person transport**	Plan to schedule the entrance and exit of persons.	Separate entrance and exit areas to ensure a smooth flow of persons.	Sequence plan according concept solutions of the station layout.
4.1.2.2	**Sequence plan transport of goods**	Plan to schedule the loading and unloading process of goods.	Separation of areas for persons and areas for goods.	Sequence plan according concept solutions of the station layout.
5.	**Loading-Unloading system**			
5.1.	**Technical parameters**			
5.1.1	**Handling time**			

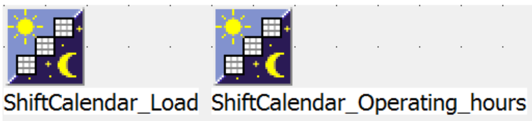
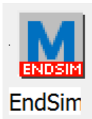
5.1.1.1	**Effective unloading and loading time per gondola (goods)**	Total time for the unloading and loading process of goods.	Quick and smooth unloading and loading processes are necessary to ensure short lead times in stations.	Lead time goods = 44 seconds.
5.1.1.2	**Effective exit and entrance time per gondola (person)**	Total time for the exit and entrance of persons.	Enough time to ensure smooth exit and entrance of people into gondolas.	Lead time persons = 44 seconds.
6.	**Loading equipment**			
6.1.	**Technical parameters**			
6.1.1	**Loading volume**	Available volume of loading equipment for transporting parcels/ goods.	Use of large loading equipment up to maximum of 4 per gondola. Footprint of loading equipment <= footprint of persons.	Use of roll containers (standardized products) up to maximum of 4 per gondola.
7.	**Circulation area for loading and unloading**			
7.1.	**Types**			
7.1.1	**Gondola decoupling/ not decoupling**	**Decoupling:** in stations gondola is separated from the ropeway system. **Not decoupling:** in stations gondola is not separated from the ropeway system.	Decoupling will reduce throughput rates due to less speed in stations and additional technical processes (changing of points).	Not decoupling. Gondola will move with constant speed in stations.
7.1.2	**Loading equipment decoupling/ not decoupling**	**Decoupling:** Loading equipment can be loaded and unloaded from gondola. **Not decoupling:** Loading equipment permanently in gondola.	Decoupling is necessary. Gondola is used for transportation of goods and persons.	Decoupling: loading equipment will be loaded and unloaded manually.

9.3 Description simulation model

9.3.1 Main station sector M1

Table 40: Method and element groups main station sector M1

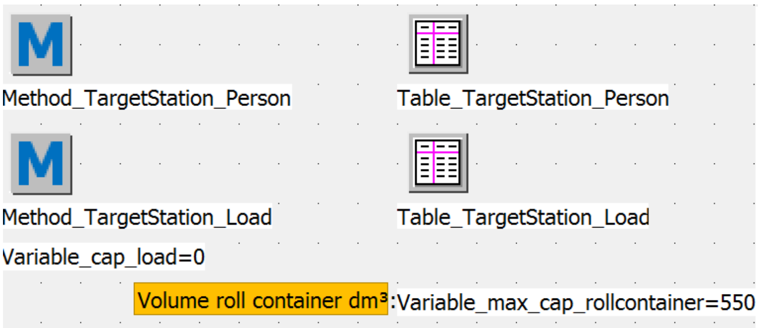
<table>
<tr><th colspan="2">Method init and Method start conditions</th></tr>
<tr><td colspan="2">
</td></tr>
<tr><th>Characteristics - functions</th><td></td></tr>
<tr><td colspan="2">Both methods are responsible to initialize the urban ropeway model. The method “init” has an individual programming code for each station whereas the method “Method_startconditions” is inherited. Functions are:

Import data from the excel sheets into the model (table file arrivals)
Load imported data into corresponding table files
Fill trigger tables with values
Delete recording tables, delete content from last simulation run
Set start conditions for time sequences (record workload of each buffer)
</td></tr>
<tr><th colspan="2">Shift calendar (operating hours): goods and passenger transport</th></tr>
<tr><td colspan="2">
</td></tr>
<tr><th>Characteristics - functions</th><td></td></tr>
<tr><td colspan="2">The shift calendars enable the set of operating hours for the whole urban ropeway model. On the one hand for the transportation of passengers and on the other hand for the transportation of goods.</td></tr>
<tr><th colspan="2">Method endsim (end of simulation)</th></tr>
<tr><td colspan="2">
</td></tr>
<tr><th>Characteristics - functions</th><td></td></tr>
<tr><td colspan="2">This method set the conditions when a simulation run is finished. The main function is to copy the recorded data into corresponding table files.</td></tr>
<tr><th colspan="2">Trigger person and Trigger Load – Table arrivals</th></tr>
<tr><td colspan="2">
</td></tr>
</table>

Characteristics - functions

The Trigger elements control the sources of persons and loads in each station. According to the changing amount of persons and goods entering a station the triggers set the values as wells as the distribution function for each hour.
In the table file “TableFile_Arrivals” the whole imported data is stored and can be further processed by the trigger elements.

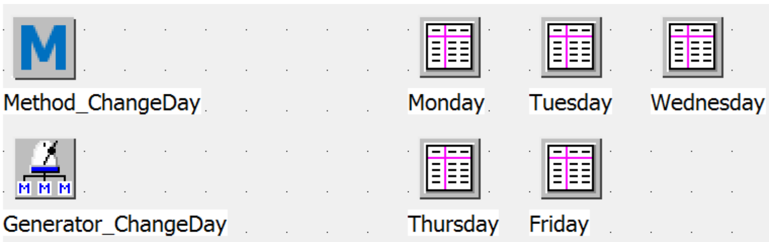
Method target station persons and goods – Table files targets – Variable roll container



Characteristics - functions

The methods “Method_TargetStation_Person” and “Method_TargetStation_Load” set the target station of each moving unit (person or load) when they leave their corresponding sources. The necessary target probabilities are written in the table files “Table_TargetStation_Person” and “Table_TargetStation_Load” with percentages for each station in the network.
In addition the method for the target station of loads specifies the capacity of each roll container generated according a defined function. This ensures a distribution of parcel sizes. The variable “Variable_max_cap_rollcontainer” defines the maximum capacity of a single roll container in dm^3. By defining the maximum volume of roll containers different design types of roll containers can be simulated and the potential of transported goods directly influenced.

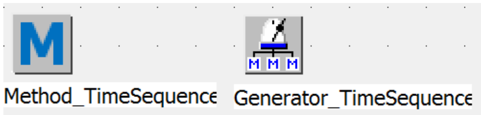
Method change day – Generator change day – Table files days



Characteristics - functions

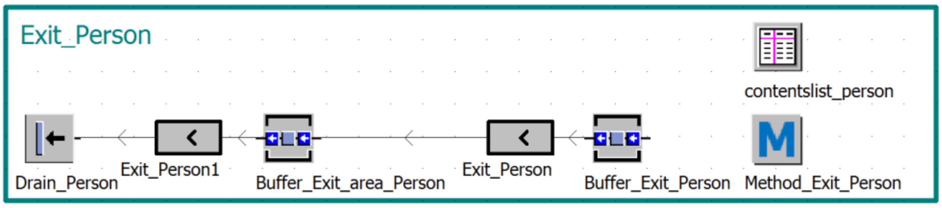
The method “Method_ChangeDay” and generator “Generator_ChangeDay” enable simulation runs over a whole week (Monday to Friday). For this the generator triggers the method when a day ends. Then the data from the respective table file (Monday, Tuesday, Wednesday, Thursday and Friday) is imported into the trigger tables of the sources.

Method change hour – Generator change hour – Table file hour

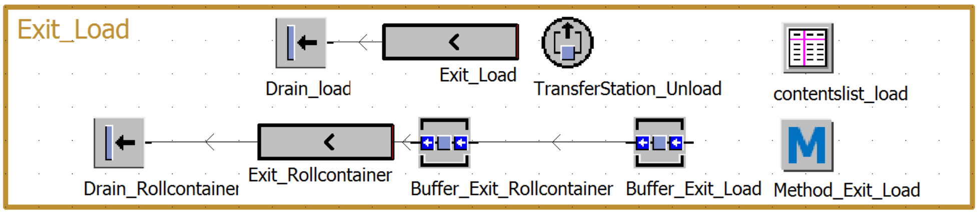
Characteristics - functions
The method "Method_ChangeHour" and generator "Generator_ChangeHour" have the function to change the target probabilities of the moving units (persons and loads) hourly. In the table file "TableFile_Hours" the full hours of one day are listed. The method is triggered by the generator and inserts the percentages into the table files for the target stations.
Method time sequence – Generator time sequence

Characteristics - functions
These elements are responsible for the triggering of data recording. The method "Method_TimeSequence" and generator "Generator_TimeSequence" activate the time sequence module to start their registration of workload values.

9.3.2 Main station sector M2

Table 41: Method and element groups main station sector M2

Exit person

Characteristics - functions
The elements of the exit person group control the leaving process of persons from to gondola into a station. Method "Method_Exit_Person" checks the target attribute of persons in the cabins entering the station. If persons inside the gondola have this station as the target then the method moves the persons to the Buffer "Buffer_Exit_Person" all other MUs stay in the cabin. In addition the method set by a seed value the willingness of people to enter the respective gondola to simulate that persons may not enter too crowded gondolas. The table file "contentslist_person" is used by the method to check the target attribute of the persons. Persons walk on the lanes "Exit_Person" and "Exit_Person1" to the drain "Drain_Person" where they leave the urban ropeway system. Between the lanes the buffer "Buffer_Exit_area_Person" models the time people need to leave the station.

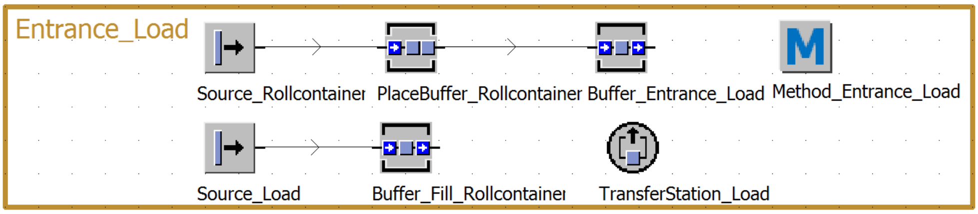
Exit load



Characteristics - functions

As described before in the element group Exit person the method “Method_Exit_Load”, the table file “contentslist_load” and the buffer “Buffer_Exit_Load” have the same tasks and fulfil the same functions regarding the exit process of roll containers (loads) from gondolas.
In contrast to the exit of persons a transfer station “TransferStation_Unload” unloads the goods from the roll containers placed in the buffer “Buffer_Exit_Rollcontainer”. Afterwards the goods and roll containers leave the urban ropeway system via the lanes “Exit_Load” and “Exit_Rollcontainer” into the drains “Drain_load” and “Drain_Rollcontainer”.

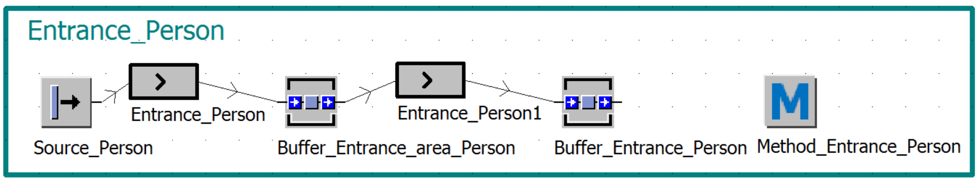
Entrance load



Characteristics - functions

The group Entrance load consists of two sources “Source_Rollcontainer” where roll container enter the stations and “Source_Load” where the goods are generated. With a transfer station “TransferStation_Load” the goods are loaded into the roll containers on the place buffer “PlaceBuffer_Rollcontainer”. Then the roll containers are buffered in “Buffer_Entrance_Load”. The method “Method_Entrance_Load” controls the loading process from the roll containers into the gondolas if a gondola travels through the station and if the gondola is defined to transport goods. In addition the method only load as much roll containers inside the cabins till the maximum capacity is reached and only if roll containers wait at the buffer “Buffer_Entrance_Load”.

Entrance person



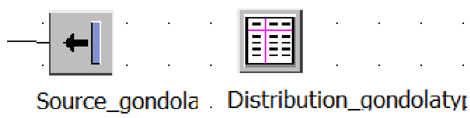
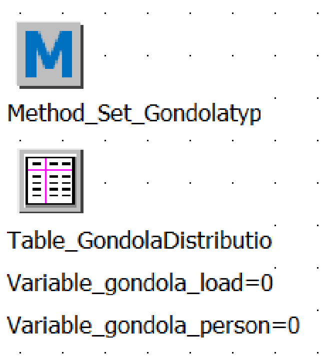
Characteristics - functions

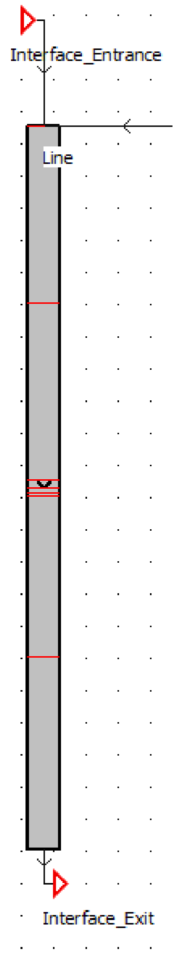
The entrance process of persons is almost the same as the entrance process of goods. Here the persons are generated by the source “Source_Person” and walk to the entrance buffer “Buffer_Entrance_Person” where they have to wait for gondolas to enter. If the method “Method_Entrance_Person” is triggered by a gondola the waiting persons are boarded into the cabin up to the maximum transportation capacity. Between the two lanes “Entrance_Person” and

"Entrance_Person1" a buffer "Buffer_Entrance_area_Person" models the time person need to pass through the stations. Due to workload recording of this buffer the entrance area of stations can be evaluated

9.3.3 Main station sector M3

Table 42: Method and element groups main station sector M3

Source gondola – Table file gondola type

Characteristics - functions
The source "Source_gondola" inserts gondolas into the ropeway system regarding operating hours and cycle times. So the cabins are attached on the travel lane as in reality. Gondolas only enter the ropeway system at the both main stations of the network. The Table file "Distribution_gondolatyp" predefines the type of MU which can be transported with the gondola.
Method set gondola type – Table file gondola distribution

Characteristics - functions
The method "Method_Set_Gondolatyp" fulfils the task to clarify the transportation type of each gondola. So the method either sets the gondola to transport persons or to transport goods. The distribution which kind of MU is defined is specified by the table file "Table_GondolaDistribution". Furthermore the table file enables the change of gondola distribution every hour to adjust the cycle times of each transportation type according to the workload. Variables "Variable_gondola_load" and "Variable_gondola_person" have the function to count the gondola types set.

<table>
<tr><th colspan="2">Interfaces – Gondola lane</th></tr>
<tr><td rowspan="2">
</td><th>Characteristics - functions</th></tr>
<tr><td>The gondola lane (Line in illustration on the right hand side) models the way where the gondola moves through the main station. Therefore the lane specifies the lead time a gondola needs to travel through the station. In addition the lane contains various sensors (red lines in the illustration). These sensors are triggered if a gondola is at the sensor positions and will activate different methods. As described before the methods enable a transfer process of MUs as well as the setting of the gondola transportation type. The methods triggered by the sensors are:
▪ “Method_Exit_Person”
▪ “Method_Exit_Load”
▪ “Method_Entrance_Load”
▪ “Method_Entrance_Person”
▪ “Method_Set_Gondolatyp”

Interfaces “Interface_Entrance” and “Interface_Exit” connect the different static stations. This enables that the gondolas can enter and leave the stations and builds a circulating ropeway system.</td></tr>
</table>

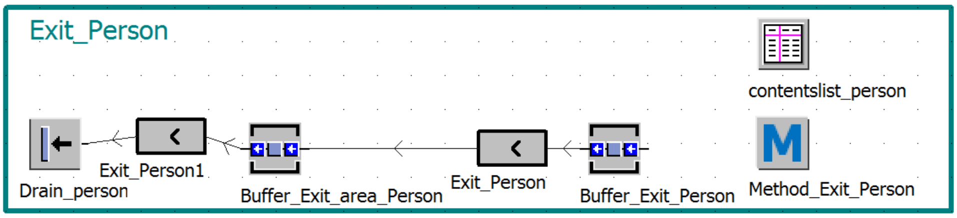
9.3.4 Sub station sector S1

Sector S1 consists of the same element and method groups as in main station M1 (9.3.1 Main station sector M1).

9.3.5 Sub station sector S2

Table 43: Method and element groups sub station sector S2

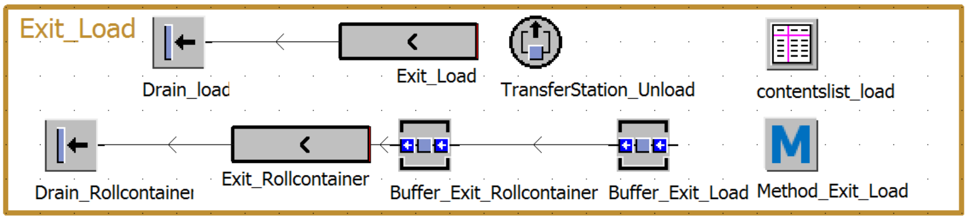
Exit person



Characteristics - functions

The elements of the exit person group steer the leaving process of persons from to gondola into a station and perform the same tasks as in M2.

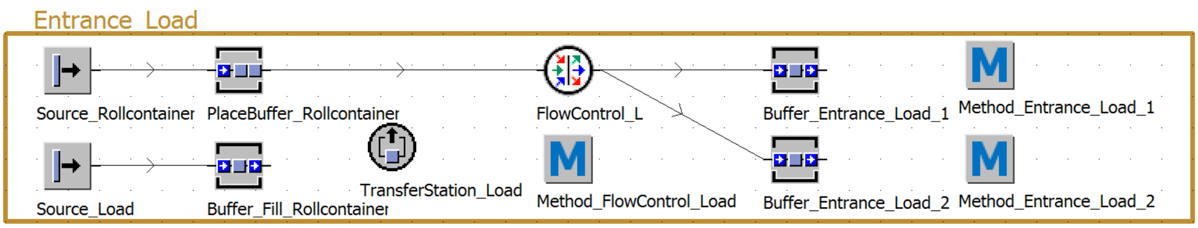
Exit load



Characteristics - functions

The exit load group of the sub station is working with the same principle as the exit load group of the main station.

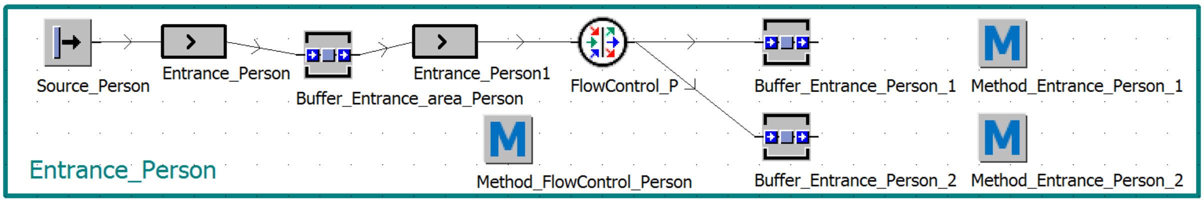
Entrance load



Characteristics - functions

The group Entrance load consists of two sources "Source_Rollcontainer" where roll container enter the stations and "Source_Load" where the goods are generated. With a transfer station "TransferStation_Load" the goods are loaded into the roll containers on the place buffer "PlaceBuffer_Rollcontainer". In contrast to the main station after the place buffer a flow control "FlowControl_L" is needed to transfer the roll containers to the right travel direction, either on lane 1 or lane 2. The method "Method_FlowControl_Load" operates as query function and transfer belonging to the target attribute of the roll container either the roll container to the buffer "Buffer_Entrance_Load_1" or to buffer "Buffer_Entrance_Load_2". In a next step the methods "Method_Entrance_Load_1" and "Method_Entrance_Load_2" control the loading process from the roll containers into the gondolas if a gondola travels through the station on the specific lane. In addition the gondola must be defined to transport goods. The methods only load as much roll containers inside the cabins till the maximum capacity is reached.

Entrance person



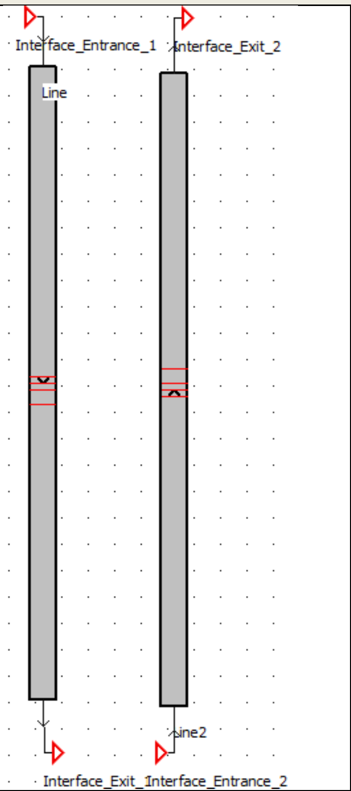
Characteristics - functions

The entrance process of persons is almost the same as the entrance process of goods. Here the persons are generated by the source “Source_Person” and walk to the entrance buffers “Buffer_Entrance_Person_1” or “Buffer_Entrance_Person_2” where they have to wait for gondolas to enter. As in the entrance process of roll containers a flow control “FlowControl_P” controls the way to the right travel direction lane. Here the method “Method_FlowControl_Person” is also triggered by the flow control element and transfers the persons either to buffer “Buffer_Entrance_Person_1” or buffer “Buffer_Entrance_Person_2” depending on the target attribute of each person. In a further step the methods “Method_Entrance_Person_1” or “Method_Entrance_Person_2” are triggered by gondolas passing through the stations. Persons waiting on the buffers are boarded into the cabin up to the maximum transportation capacity.
As before in the main station between the two lanes “Entrance_Person” and “Entrance_Person1” a buffer “Buffer_Entrance_area_Person” models the time person need to pass through the stations. Due to workload recording of this buffer the entrance area of stations can be evaluated

9.3.6 Sub station sector S3

Table 44: Method and element groups sub station sector S3

Interfaces – Gondola lane



Characteristics - functions

The gondola lanes (Lines in illustration on the right hand side) models the way where the gondolas moves through the sub stations. Therefore the lanes specify the lead times a gondola needs to travel through the station. In addition the lane contains various sensors (red lines in the illustration). These sensors are triggered if a gondola is at the sensor positions and will activate different methods. As described before the methods enable a transfer process of MUs The methods triggered by the sensors are:

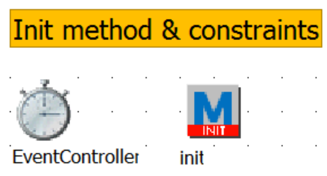
- “Method_Exit_Person”
- “Method_Exit_Load”
- “Method_Entrance_Load_1”
- “Method_Entrance_Load_2”
- “Method_Entrance_Person_1”
- “Method_Entrance_Person_2”

In sub stations Interfaces “Interface_Entrance_1”, “Interface_Entrance_2”, “Interface_Exit_1” and “Interface_Exit_2” connect the different static stations. This enables that the gondolas can enter and leave the stations and builds a circulating ropeway system.

9.3.7 Model frame

Table 45: Method and element groups model frame

Init method and constraints

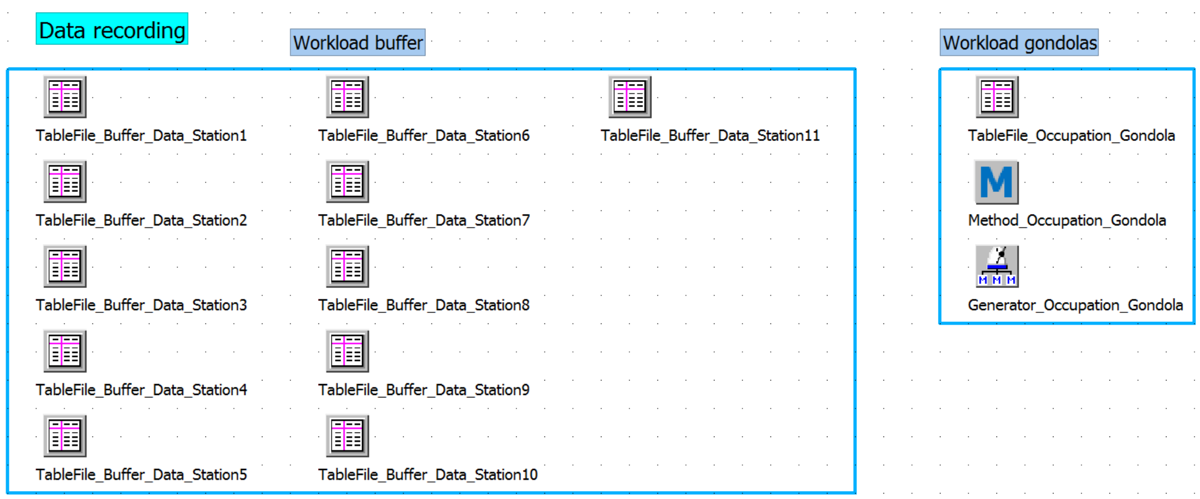


Characteristics - functions

In the init method and constraints sector the event controller "EventController" and the method "init" is located. The event controller plays a very important part in the simulation model because it manages and synchronizes the events taking place during a simulation run. Furthermore with the event controller the user can define the start and end points and so the length of a simulation action.

The method "init" sets two important parameters of the urban ropeway model. These are the lengths between the different ropeway stations and the travel times needed for this lengths. The travel times include the times for acceleration and deceleration of the gondolas and are calculated by a predefined excel input file.

Data recording

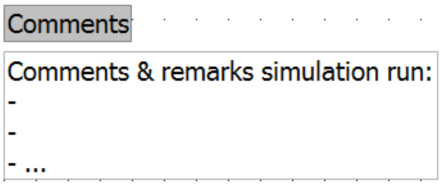


Characteristics - functions

The data recording part includes the tables for the workload recording of the buffers of each station, in the defined urban ropeway network eleven tables. For every minute a time sequence element records the number of persons or goods on the buffers and at the end of the simulation run the values are written into the tables.

In addition to the data recording of each buffer the workload of the singular gondolas is documented in the table "TableFile_Occupation_Gondola". The method "Method_Occupation_Gondola" is triggered by the generator "Generator_Occupation_Gondola" where the timescale is set at which the workload is analysed. In Plant Simulation the workload (occupation) is defined over the entire statistics collection period. Due to the generator it is possible to analyse the workload of the gondolas at different time spans e.g. analysis of the workload of the gondolas between 05:00 till 12:00 o'clock.

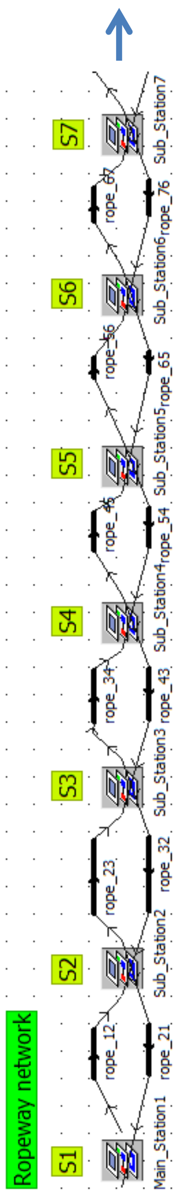
Comments

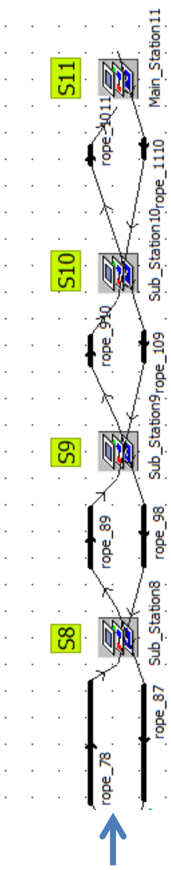


Characteristics - functions

At the comments section of the model frame important remarks regarding the simulation run can be made. This helps to get a quick overview about the simulated scenario and confusions can be minimized. The comments can be inserted just by a double click on the comments box.

Ropeway network





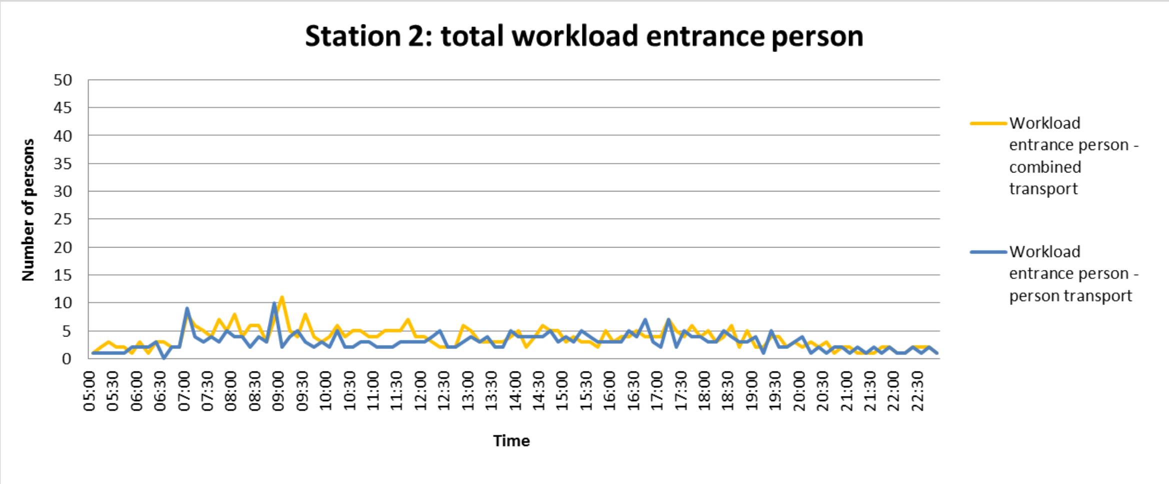
Characteristics - functions

The ropeway network is built up out of eleven stations networks (S1—S11) as the illustration on the left displays. Between these stations the ropes at which the gondolas are carried are modelled by lines. By parametrisation (init method) each line has a certain length and the gondolas need a certain time to travel this way. In order to establish a circulating ropeway system both travel directions have the same length and travel time.

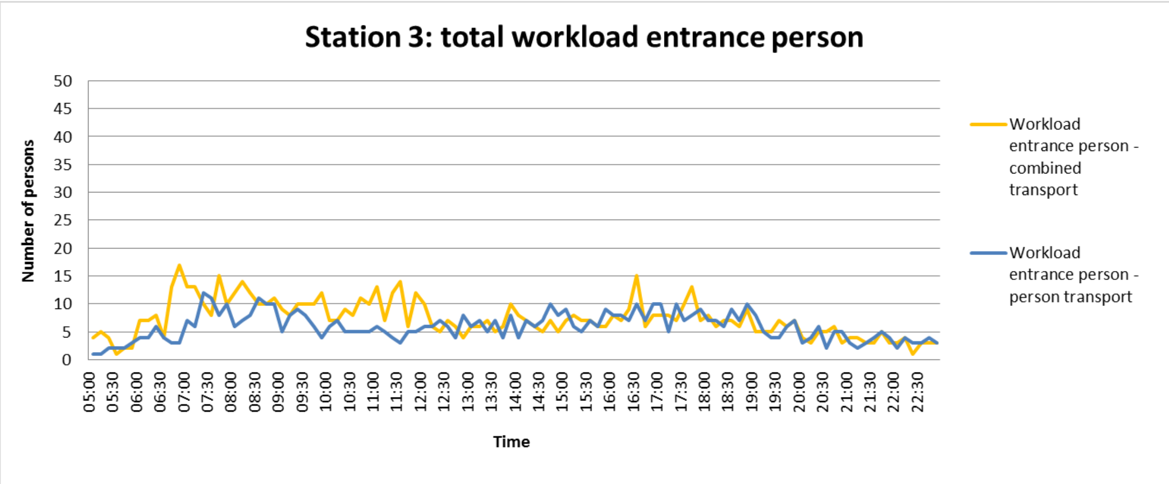
By a double click on a station network the simulation user can enter each station and can modify parameters if needed. Furthermore the user can easily extend the ropeway network by inserting stations in the frame, up to 15 stations. Also a reduction of stations is possible. So a variable and flexible simulation model of the urban ropeway system is achieved.

9.4 Analysis workload buffer

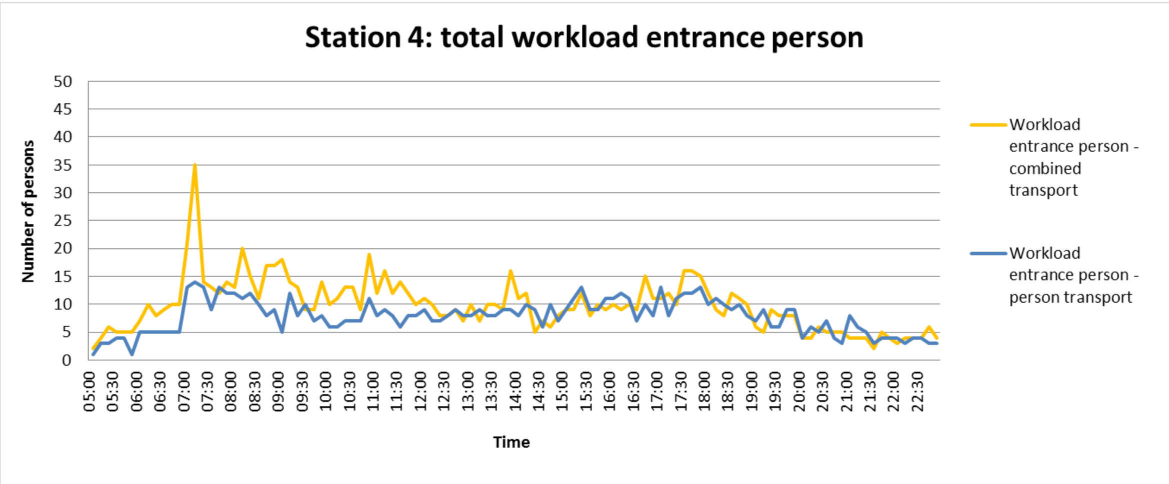
- Station S2:



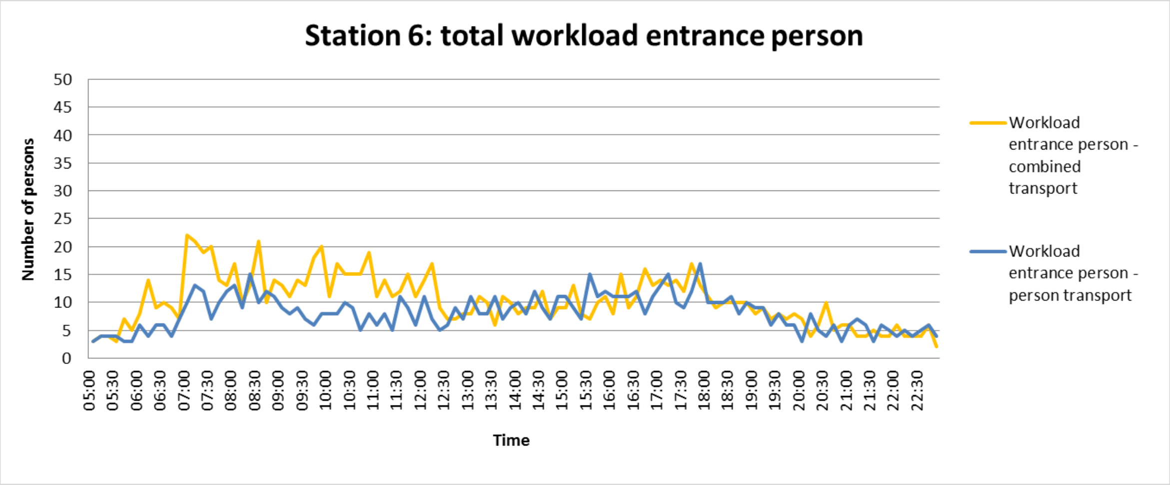
- Station S3:



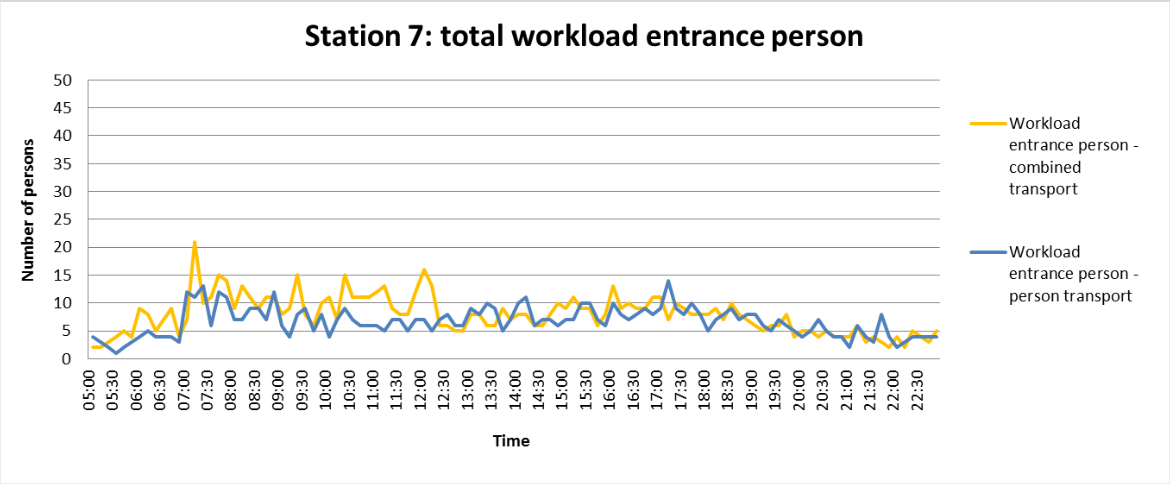
- Station S4:



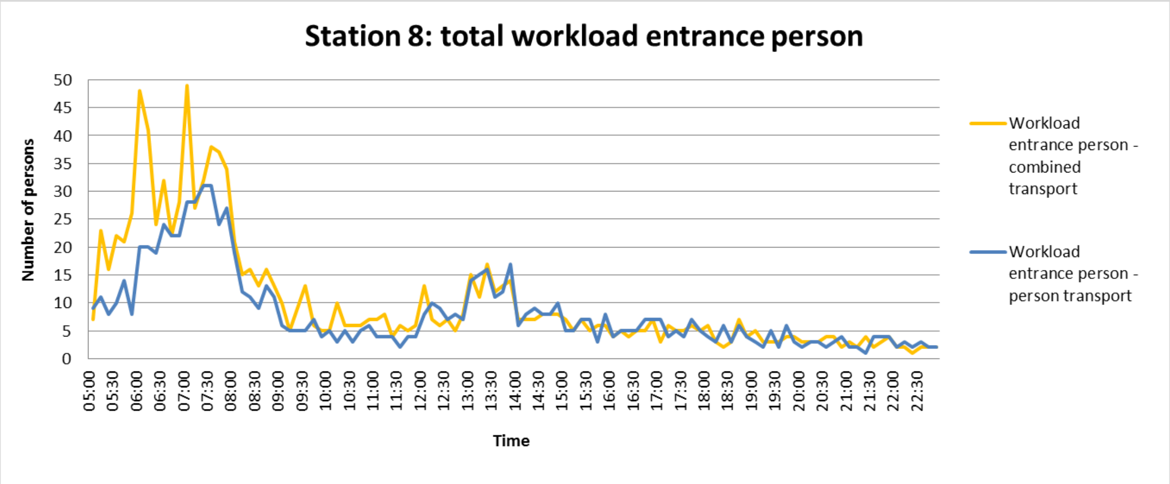
- Station S6:



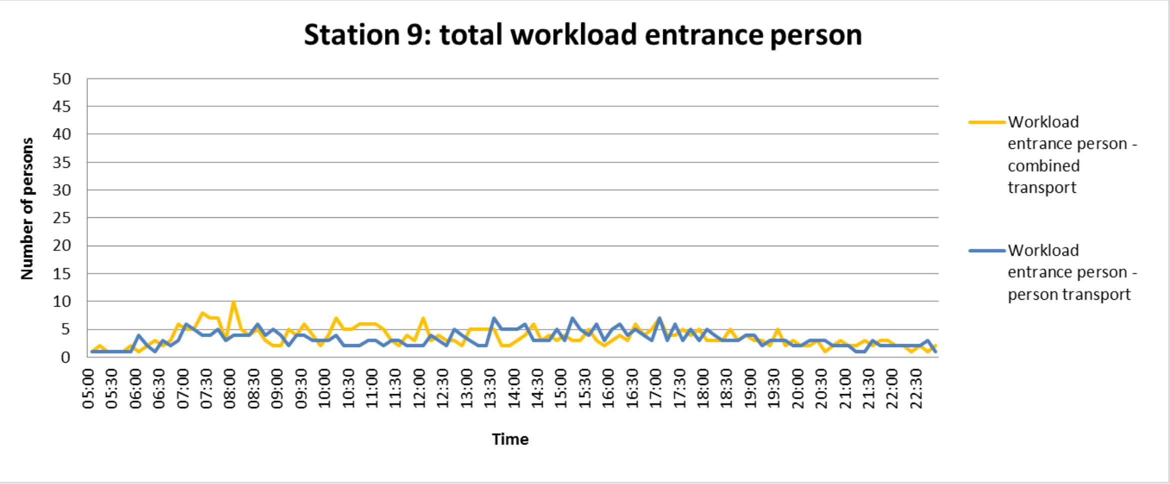
- Station S7:



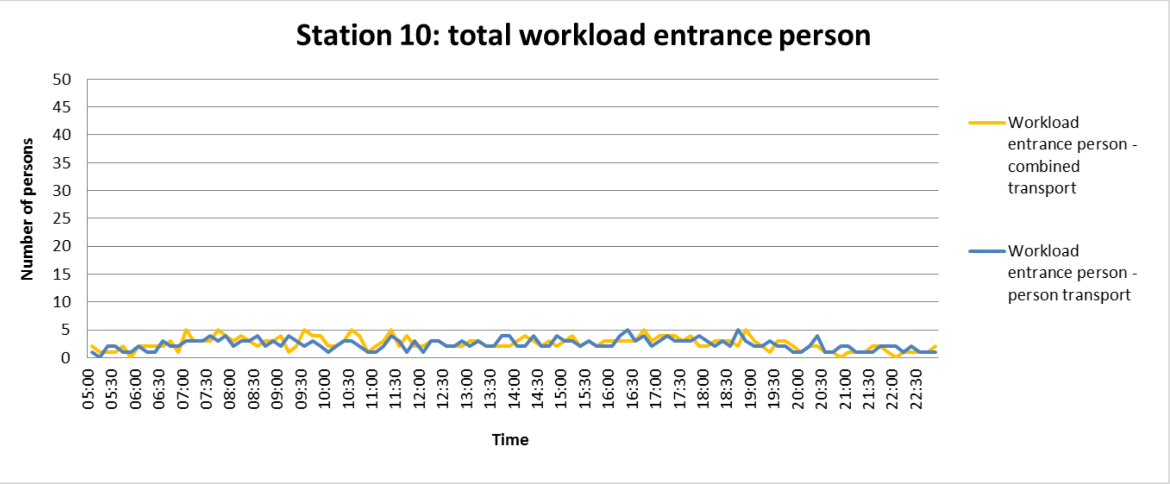
- Station S8:



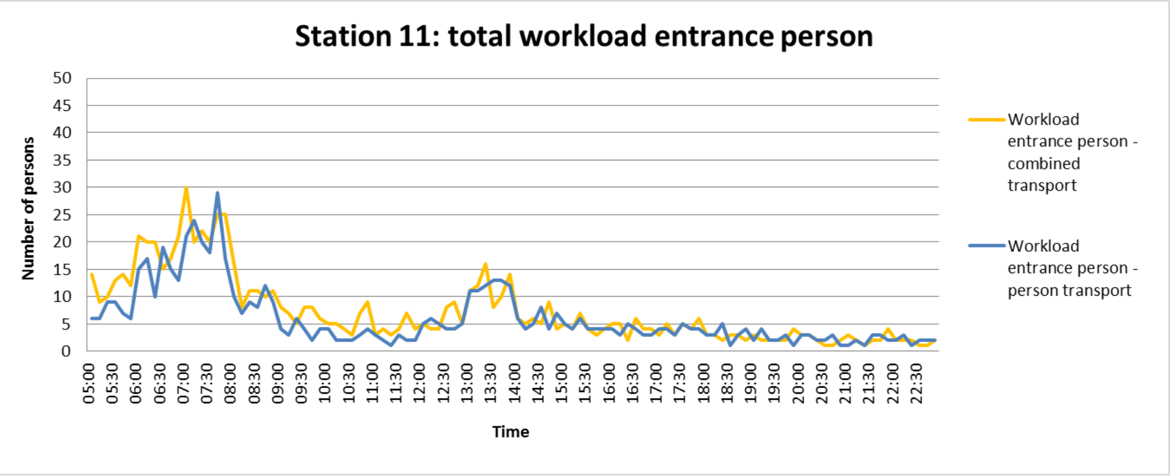
- Station S9:



- Station S10:



- Station S11:



9.5 List of files

Master thesis report (*.pdf)

▪ 2018_08_16_urban_ropeway_paper_v1_SN.pdf	PDF document containing the written report

Urban ropeway model – Plant Simulation Model File (*.spp)

▪ ropeway_model_v17_SN.spp	Plant Simulation file: Simulation model of the urban ropeway system for the combining transport of people and goods

Input files (*.xlsx, *.xlsm)

▪ Parameter_simulation_ropeway_v8_SN.xlsm	Excel file to generate the input files for the simulation model
▪ Gueterbefoerderung_v3_Betriebszeit0500_2300_SN.xlsx	Excel file to configure the time-variation curve for goods transportation
▪ Personenbefoerderung_v4_Betriebszeit0500_2300_SN.xlsx	Excel file to configure the time-variation curve for passenger transportation
▪ Ropeway_parameter_v4_SN.xlsx	Excel file to calculate input parameters

Analysis files (*.xlsx)

▪ 1_Analysis_workload_buffer_v3_SN.xlsx	Excel file to analyse buffer workloads
▪ 2_Analysis_workload_gondola_report_v2_SN.xlsx	Excel file to analyse gondola utilization and output report