Master thesis to obtain the academic degree
Diplom-Ingenieur

Material flow simulation of an urban ropeway - combined transport of people and goods - extension

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Acknowledgement

This master thesis was the last stepping stone of my M.A. study programme „Production Science and Management“ at the Technical University of Graz. I chose the topic of urban ropeway transport because of its actuality and the future importance of mitigating the inner-city pollution problems; as well as the fascinating, cross-theoretical problem-solving opportunity it provides.

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Many thanks!

Alexander

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

This master thesis deals mainly with specified evaluations of a ropeway concept for combined passenger and goods transport for the inner-city area of Graz. The impetus for this was the rapid growth of urban traffic and the resulting problems of conventional road traffic such as degradation and maintenance of road infrastructure, traffic jams and emissions. New forms of mobility must, therefore, be found and investigated in order to counteract these costly problems. With the help of combined ropeway systems in cities, which transport people and goods, traffic volume and related costs could be reduced. In a previous master thesis, the first parameters for such a ropeway project had already been established, which were layed out in defined scenarios. In the course of this, new task areas for the new simulation model were also set.

The main task of this work is, therefore, to integrate the required extensions and parameter adaptations into the already existing basic model of a material-flow model simulation and to calculate and evaluate these for defined scenarios.

In the first step, this thesis determines which parts of the underlying simulation model can be adopted, and which have to be revised. Based on the findings, new simulation limits were evaluated, and furthermore, new scenarios defined. In a next step, those were tested with defined parameters.

After the definition process, a thorough appraisal of all new extensions of the system was carried out. For this purpose, new data was collected and integrated into the system. In this part of the thesis, particular focus was given to the logistics processes. Those were explicitly addressed and researched in a thorough literature review, so that they could be incorporated into the simulation as realistically as possible.

The next phase involved the step-by-step integration of the newly defined areas into initial simulation model. After the integration of each step, each new extension was evaluated and verified to ensure that the adaptation met the mandatory requirements.

After general evaluation of the final model, again, each scenario is recalculated, using the defined scenario-specific parameters. If necessary, additional adjustments were made wherever the system could not meet the requirements.

The fifth and final phase comprises the analysis and documentation of each scenario. The scenarios were compared with each other and the benefits and drawbacks were pointed out. Also, system constraints were developed to predict how long individual scenarios could be used to reach capacity and how high the utilisation of gondolas and logistics staff would be.

Kurzfassung

Diese Masterarbeit befasst sich im Wesentlichen mit spezifizierten Auswertungen eines Seilbahnkonzepts für den kombinierten Personen- und Gütertransport für den Innenstadtbereich von Graz. Anstoß hierzu war das schnelle Wachstum an urbanen Verkehr und den daraus resultierenden Problemen des konventionellen Straßenverkehrs wie Baustellen, Staus, Emissionen. Es müssen daher neue Formen der Mobilität gefunden und untersucht werden, um dem entgegenzuwirken: Mit Hilfe von kombinierten Seilbahnsystemen in Städten, die Menschen und Güter transportieren, können diese Probleme reduziert werden. In einer vorhergehenden Masterarbeit wurden bereits erste Parameter für ein solches Seilbahnprojekt ausgearbeitet, die nach Abschluss der Arbeit in definierte Szenarien festgelegt wurden. Im Zuge dessen wurden auch neue Aufgabenbereiche für das neue Simulationsmodell angesetzt.

Die Hauptaufgabe dieser Arbeit ist es somit, die erforderlichen Erweiterungen und Parameteranpassungen in das bestehende Basismodell einer materialflusstechnischen Modellsimulation zu integrieren und diese für definierte Szenarien zu berechnen und auszuwerten.

Im ersten Teil der Arbeit wurde herausgearbeitet, welche Teile des zugrundeliegenden Simulationsmodells übernommen werden können und welche überarbeitet werden müssen. In Anlehnung daran wurden auch neue Simulationsgrenzen bewertet, und Szenarien definiert die mit festgelegten Parametern getestet und ausgewertet werden.

Nach dem Definitionsprozess war es erforderlich, alle neuen Erweiterungen des Systems auszuwerten und ausreichend Daten zu sammeln, um sie in das bestehende System integrieren zu können. Hierbei wurden speziell die abzuwickelnden Logistikprozesse betrachtet. Diese wurden entsprechend literarisch recherchiert in die Simulation eingearbeitet.

Die nächste Phase beinhaltete die schrittweise Implementierung der neuen Bereiche in das Simulationsmodell. Nach jedem Implementierungsprozess wurde jede neue Erweiterung bewertet und verifiziert, um sicherzustellen, dass die Adaption die geforderten Anforderungen erfüllt.

Nach der Auswertung des endgültigen Modells wurde dann für jedes Szenario mit den definierten szenariospezifischen Parametern ausgewertet. Entsprechende Anpassungen wurden vorgenommen, falls das System die Anforderungen nicht erfüllen konnte.

Die fünfte und letzte Phase umfasste die Analyse und Dokumentation jedes Szenarios. Die Szenarien wurden miteinander verglichen und Vor- und Nachteile aufgezeigt. Außerdem wurden Einschränkungen der Systeme ausgearbeitet, um vorhersagen zu können, wie lange einzelne Szenarien genutzt werden können, bis sie die Kapazität erreichen und wie hoch die Auslastung von Gondeln und Logistikpersonal ausfallen.

Abbreviations

EU European Union

CEP Courier – Express – Parcel: parcel delivery services

MU Moving unit: a mobile object in Plant Simulation to model flow of material

S1-S11 S…Station, 1…station number 1, 2…station number 2 and so on.

DES Discrete event simulation

SC Scenario; e.g. SC4 would be Scenario 4

Task Work order generated by the simulation that the worker must fulfil/process.

ITL Institute of Logistics Engineering TU Graz

ISV Institute of Highway Engineering and Transport Planning TU Graz

tu Time unit

EU European Union

CEP Courier – Express – Parcel: parcel delivery services

VDI Verein Deutscher Ingenieure

IBV Engineering Office for Regional Planning and Development, Transport and Traffic Economics, Geography

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1 Introduction

The paper study „E-Commerce-Study Austria 2018" [E-C18] from the KMU Research Austria and Trade association Austria showed, that the existing 4.3 million Austrian clients of domestic and foreign internet platforms spent a total of about 7.9 billion euros in 2018. This is a 5 per cent increase compared to 2017 (as illustrated in Figure 1-1).
Meanwhile, 1.8 million of all online shoppers indicated that they are already shopping via smart devices. That pertains to 24 per cent of all Austrians aged 15 or older. The increase after the previous year 2017 is a whopping 20 per cent.

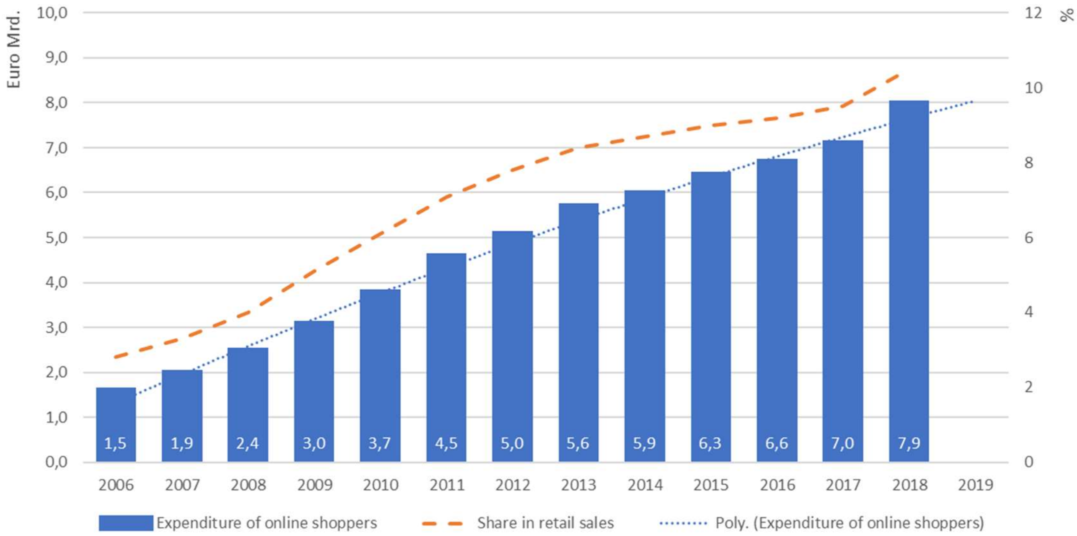


Figure 1-1: Expenses E-Commerce Austria (plus trend line) [E-C18]

With these growing relevance of online retail systems in mind, there will be a need for alternative transport concepts in order to meet the increased demand for parcel delivery service. The master thesis of Dipl.- Ing. Simon Naderer - "Urban ropeway – material flow study of a ropeway system for the combining transport of people and goods" has already been written to counteract this trend and its related dimensions.

Another context for the thesis was, a strategy set up by the European Union (EU), namely a policy to achieve a clean urban transportation and traffic system. The procedure foreseen in the "European Urban Mobility" strategy sets two deadlines until the year 2030 and 2050, respectively [Eur17].

Hence, essential objectives in this paper relate to the planned reform of private transportation of goods and people, as well as emissions. Those objectives are:

- Until 2030 halving the use of conventionally fueled cars in cities, and until 2050, no use of conventionally powered cars in urban areas anymore.
- Achieving a CO^2 free logistic infrastructure in major urban centres by 2030.
- Cutting transportation emissions by 60% compared to the year 1990 until 2050
- Promotion of sustainable urban mobility forms like walking, cycling, public transport and new ways of car use and car ownership.

In order to analyse a possible pathway to the attainment of above mentioned objectives, this master thesis deals with the estimation of the potential use of urban ropeway system in the city of Graz. It suggests a combined use as public transport system for people, as well as a logistical system for the shipment of goods (parcels in particular). The aim is to find a viable solution to organize transport and shipment into the city center of Graz, taking into consideration the extended requirements in terms of system boundaries and supplementary adaptations for various years.

Figure 1-2: Urban ropeway system [Dop18]

1.1 Tasks

The key task of this thesis is to integrate the required extensions and parameter adaptations into the existing basic model in Plant Simulation and, then, to calculate and evaluate these for defined scenarios.

- In the first step, this thesis determines which parts of the underlying simulation model can be adopted, and which have to be revised. Based on the findings, new simulation limits were evaluated, and furthermore, new scenarios defined. In a next step, those were tested with defined parameters.

- After the definition process, a thorough appraisal of all new extensions of the system was carried out. For this purpose, new data was collected and integrated into the system. In this part of the thesis, particular focus was given to the logistics processes. Those were explicitly addressed and researched in a thorough literature review, so that they could be incorporated into the simulation as realistically as possible.

- The next phase involved the step-by-step integration of the newly defined areas into the initial simulation model. After the integration of each step, each new extension was evaluated and verified to ensure that the adaptation met the mandatory requirements.

- After general evaluation of the final, elaborated model, each scenario is recalculated, using the defined scenario-specific parameters. If necessary, additional adjustments were made where ever the system could not meet the requirements.

- The fifth and final phase includes the analysis and documentation of every scenario. The scenarios were compared with each other to show possible benefits and drawbacks. Also, limitations of the system were worked out to be able to predict how long the particular scenarios can be used until they reach the defined maximum capacity.

1.2 Outline

This master thesis is divided into different sections in order to enable an efficient and comprehensible view of the relevant content.

The first part is the introduction of the thesis, including facts of the output model and the task and targets of the thesis are described in detail.

The second part contains the theoretical fundamentals of the master's thesis, such as material flow and simulation processes as well as the basic logistics processes.

The next chapter defines the initial model on which the later expansions and scenarios are constructed. All areas and parameters inherited from the original model are also disaggregated and adapted to the new model if necessary.

The fourth section explains the urban ropeway extensions and simulation conditions. It is also shown how the implementations were inserted.

Chapter number five includes the analysed categories and the main results, as well as a comparison of the most critical areas of the simulations.

The concluding chapter of the thesis contains a summary of the entire topic, a conclusion on the results and possible further limitations of the system area.

2 Theoretical basis

The following chapter will provide essential background knowledge, including the processes of the material flow, the simulation, and the logistic. This intermediate step should help to provide a better overview of the individual steps which will be presented and to be able to follow the progress of the work efficiently.

2.1 Material flow process

One of the main objective of today's material flow systems is to illustrate the process steps each element in a given system must go through and identify all possible connections during the simulation process. Processes are arranged mostly serial (P1.1 to P1.n), parallel (P1, P2, Pm) or a combination of this two, depending on the steps each material has to process (pass a specific process once or more often). The higher the flexibility, the higher the degree of crosslinking and the more difficult the theoretical treatment of the process is. Figure 2-1 shows such a possible network structure.

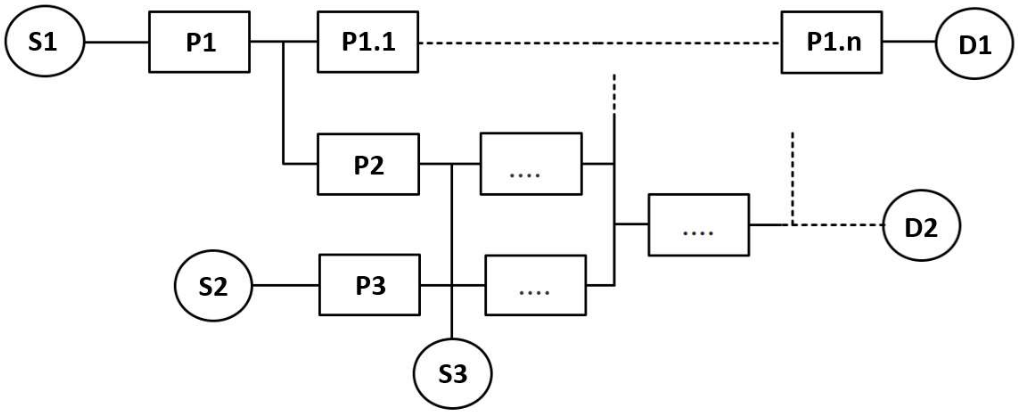


Figure 2-1: Network structure in material flow systems [AF09]

- S …Source (creates elements, like transport material, goods, persons)
- P …Process (edits the respective elements according to the specifications)
- D …Drain (remove the element from the system)

The transfer of the found solutions into a simulation model requires qualitatively and quantitatively suitable modelling. For example, where to set waiting points or set a sufficient buffer capacity.
In order to be able to characterise such a system, there are various parameters. The most important are:

- throughput, maximum throughput
- capacity utilisation
- cycle time

A more detailed explanation of the above parameters can be found in the following chapters.

2.2 Throughput, Maximum throughput

An essential task of material flow theory is the determination of (material) throughput at critical points of the material flow system.
On a line of length l, units (Ln) move at speed (v) from a source (S) to a drain (D). It is imagined that the elements are "generated" by the source, regardless if this is their actual source. A sophisticated network line can be broken down into simple lines if the line is not continuously connected (buffer, transfer points). [AF09]

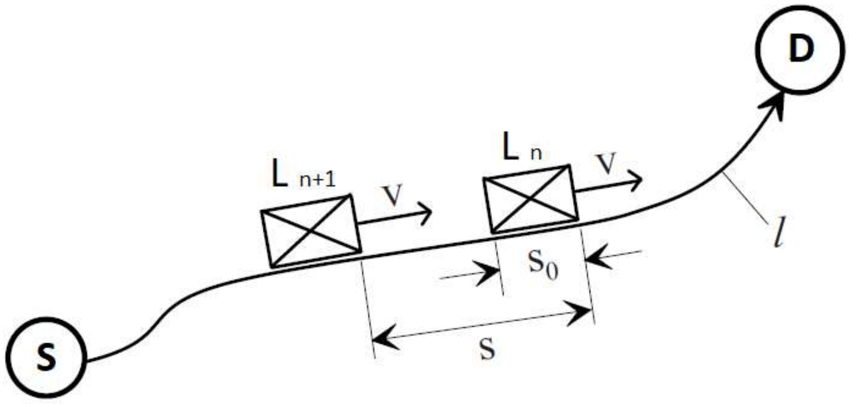


Figure 2-2: Units (L) on a transport route (l) [AF09]

- S ...Source
- D ...Drain
- v ...velocity of element
- l ...transport route
- s ... distance between elements
- s_0 ...length of element
- L_n ...Load element n
- L_{n+1} ...Load element n+1

The throughput and efficiency of a system or station always refer to a specific time unit [tu] or calculation time, whose length depends on the requirements. [Tru19]

The operational throughput λ is defined as follows:

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

As Equa. (2-1) shows, the operational throughput depends on the operational throughput of the velocity (v) of the elements and the distance (s) between them. The velocity is usually not constant, depending on starting and braking operations.

The ultimate or boundary throughput γ is defined as follows:

$$\gamma = \frac{v\_max}{s\_min} \qquad [\frac{\text{loads}}{\text{tu}}] \qquad \text{Equa. (2-2)}$$

The ultimate or boundary throughput is depending on the minimal possible distance between the elements and the maximal possible velocity.

The (theoretical) maximum throughput γ is defined as follows:

$$\boldsymbol{max\gamma = \frac{v}{s0}} \qquad [\frac{\textbf{loads}}{\textbf{tu}}] \qquad \text{Equa. (2-3)}$$

The maximum throughput uses the virtually zero distance between the elements, but this is not possible in practice.

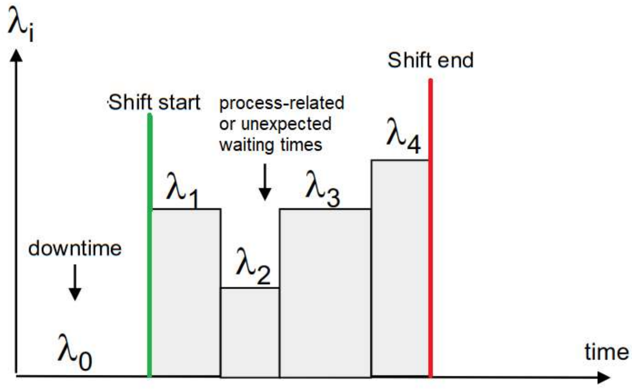


Figure 2-3: λi during different phases of a production process [AF09]

In reality, it has to be considered mostly a mixture of the operationally probable throughput and the technically maximum possible throughput (limit throughput) as displayed in Figure 2-3.

2.3 Degree of utilisation

If the operational throughput λ is smaller than the ultimate or maximum throughput γ, the transport route is not fully utilised. The degree of utilisation ρ is used to describe that behaviour:

$$\boldsymbol{\rho = \frac{\lambda}{\gamma} \leq 1} \qquad [-] \qquad \text{Equa. (2-4)}$$

2.4 Cycle time

On the assumption of a regular "delivery" cycle of the source, the elements are travelling at equal intervals. With the delivery time (or travel time) τ of a delivery unit from the source to the drain, Equa. (2-5) provides the cycle time τ as the reciprocal of the throughput λ:

$$\boldsymbol{\tau = \frac{1}{\lambda}} \qquad [\textbf{sec.}] \qquad \text{Equa. (2-5)}$$

2.5 Queuing theory

The queuing theory is an essential part of the simulation model, but was mainly inherited from the base model and is therefore only mentioned briefly in the following chapter. More detailed explanations can be read in the Master's thesis of Dipl.- Ing. Simon Naderer - "Urban ropeway – material flow study of a ropeway system for the combining transport of people and goods." [Nad18]

The queuing theory is the mathematical consideration of queuing or waiting in lines. These queues can contain elements such as people, objects, or information. In this thesis, these elements would be people, parcels, roll containers and empty, nested roll containers.
A primary queuing system mostly consists of an arrival process, the queue itself, the service process for attending to those elements, and departure process from the system. [Lim18]

2.5.1 Characterising a queuing system

A basic queuing system includes various processes, as [AF09]:

- Arrival process. The arrival process merely is how elements arrive, alone or in groups, arrive at specific intervals or randomly.

- Service process. This process includes the length of time an element is processed, the number of servers available to process the element, one by one or in batches.

- Service discipline refers to the rule by which the next element is selected, e.g. Priority Service, First-come-first-served, or other situations may call for other types of service.

- Waiting and service area. The number of elements (e.g. roll container) allowed to wait in the queue may be limited based on the buffer space available.

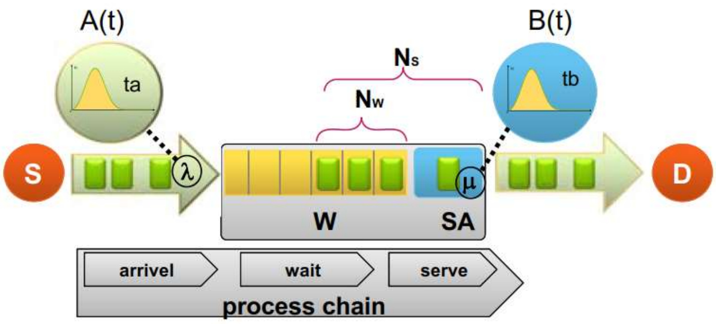


Figure 2-4: Queueing model [Tru19]

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

2.6 Simulation process

Simulation is often used, to test new features of a real system or to solve a problem without affecting real production, or when used during a planning phase, long before the real system is created. As shown in Figure 2-5, the starting point of simulation is mostly a real system (problem or test phase). The simulation model tries to represent the real system as detailed as possible to generate the best results, which then will be interpreted, and if necessary, recalculated with new parameters. This cycle will be passed as long, as the results fit best for the real system and can be implemented.

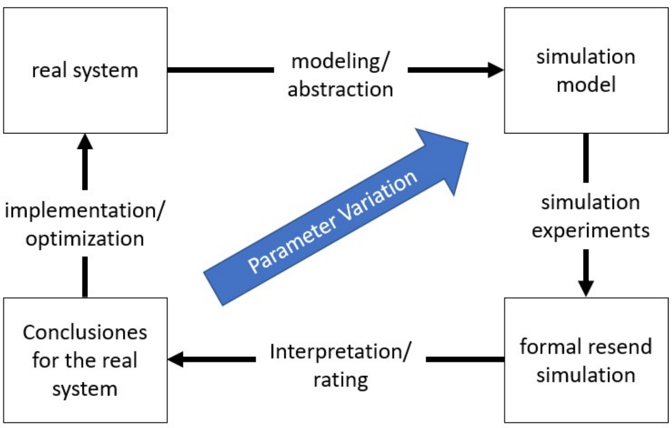


Figure 2-5: Basic principle of the simulation method, own representation [Tru12]

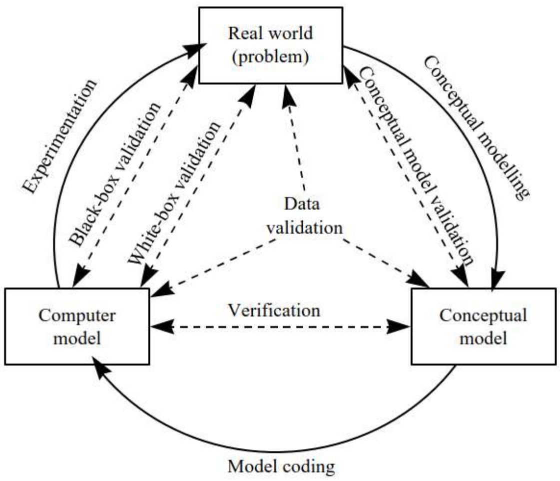


Figure 2-6: Model verification and validation in the modelling process [Rob00]

One crucial point is to continuously verificate and validate the results of each more significant simulation step. These interests are essential to check, if the right output is evaluated, and are they treated within the required tolerances. Such a process is shown in Figure 2-6.

2.6.1 Plant Simulation-Software

Plant Simulation is an object-oriented material flow simulation software, based on a DES (Discrete Event Simulation) -software. The discrete simulation use time sequences to produce certain events at random or random time intervals, which initialise the (next) system state. [Sie19]

Complex problems are mostly elusive, so it is a general approach to divide the problem into smaller problems (subproblems), which are simpler to handle. This approach is known as decomposition. Therefore, the overall solution to a complex problem consists of several smaller solutions corresponding to each subproblem. This approach is called “modular design”. Object-oriented design enhances modular design by providing classes as the most critical decomposition (modular) unit. A program structure is organised like an assembly of classes. [Gar09]

2.6.1.1 Classes and Attributes

In modelling a real-world problem, collections of similar objects are identified. Classes are then defined as abstract descriptions of these collections of objects, which are objects with the same structure and behavior. A class defines the attributes, and behaviour for all the objects of the class. [Gar09]

The classes Sub_Station and Main_Station inherit the existing attributes from Station, which means that if those attributes were updated in the class Station, then that update will be reflected in both, Sub_Station and Main_Station as well. However, inheritance only works from the origin to the subclass (Top-Down). When an inherited attribute is changed in Sub_Station or Main_Station, the inheritance for that attribute is disabled and the changes are not reflected in the class station. Besides, it can instantiate and derive from Sub_Station and Main_Station like any other class. [Mar17]

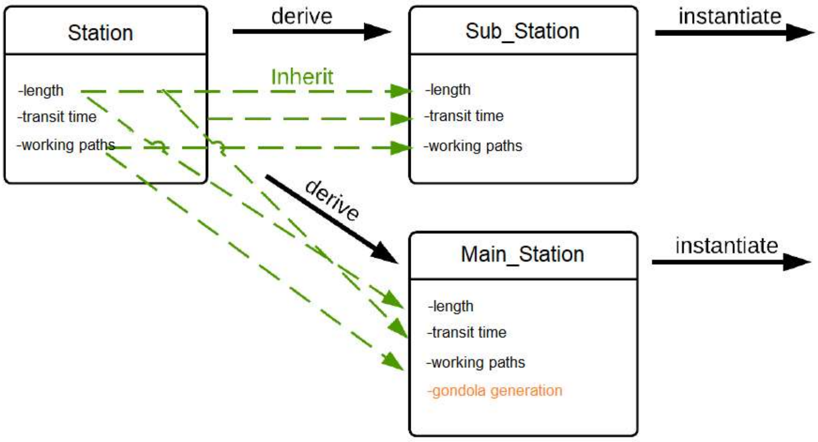


Figure 2-7: Basic principles of object orientated programming [Mar17]

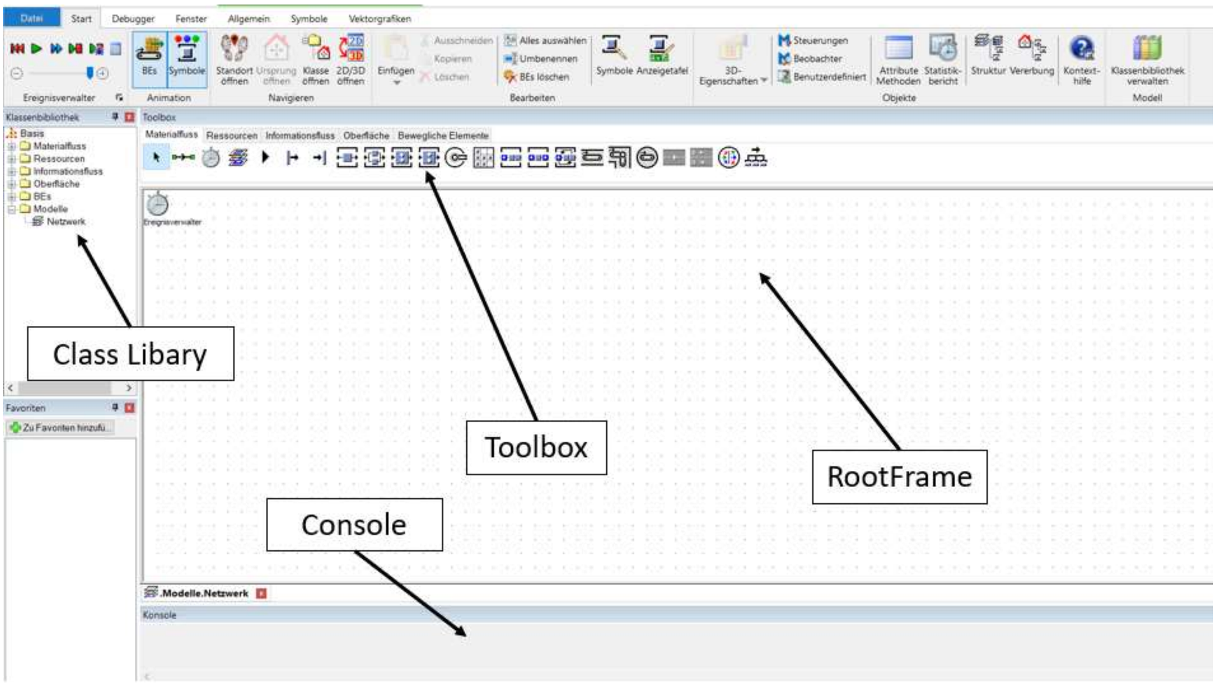


Figure 2-8: Start surface of plant simulation own representation

- Class Library
  Full view of all available object classes in the current model.
- Console
  In this window, the processed function steps are shown.
- Toolbox
  A structured view of object classes in the model.
- RootFrame
  Holds all the elements from which the model consists.

Special features:

- Real object orientation or object-oriented programming with polymorphism and encapsulation
- Inheritance Mechanisms: Users create libraries of their objects that can be reused. In contrast to a copy, a change in the library (object class) also leads to a change of the derived objects (children).
- Complex structures can be structured more clearly on several (logical) levels. This structure facilitates a top-down and bottom-up approach.
- Openness to accept data from other systems (e.g., Access or Oracle databases, Excel worksheets or SAP).

For the modelling process of the ropeway system, the Siemens software Tecnomatix Plant Simulation 11 TR2 (64-bit) is used.
Also, the following sources were considered as tutorials:

- "Plant Simulation und SimTalk"- Steffen Bangsow [Ban11]
- "Simulation Modelling using Practical Examples: A Plant Simulation Tutorial " - Martijn R.K. Mes [Mar17]
- Lecture documents of the ITL institute 309.016 [Tru12]
- "Tecnomatix Plant Simulation - Compact Student Training" [Sie16]

2.7 Ropeway systems

Installing cable transport systems as urban public transport is not a new idea. Urban ropeway systems are competing with, and in some cases exceeding the performance characteristics of conventional public road transport:

- high transportation efficiency
- low noise level compared to road-bound vehicles
- always on time, not any delays as a result of car-jams or accidents
- ecologically beneficial
- bridge ability of obstacles (rivers, roads, buildings)
- high automation grade
- fast (Ropespeed between 6 m/s and 8 m/s possible)
- tourist attractivity (view)

The continuous increasing urbanisation creates a growing demand for variable and efficient public transport infrastructure. Moreover, with the rethinking and promoting greener propulsion and transportation technologies, urban ropeway systems become more and more attractive for bigger cities. [RYA12]

In Figure 2-9 is shown, how the essential ropeway transport could look. The two basic station types are:

- Main stations (green area)
  Are located at both ends of the ropeway system
- Sub stations (orange area)
  Are located between the main stations with individual distances to each other

Between two stations the gondolas are attached to the main cable (or cables, depending on the used ropeway system) and travel at the max rope speed (blue area).When a gondola arrives at a station, it is decelerated and disconnected from the main cable and passes through the station at a reduced speed to allow passengers board and alight easier. As the gondola leaves the station, it accelerates up to the maximum rope speed again.

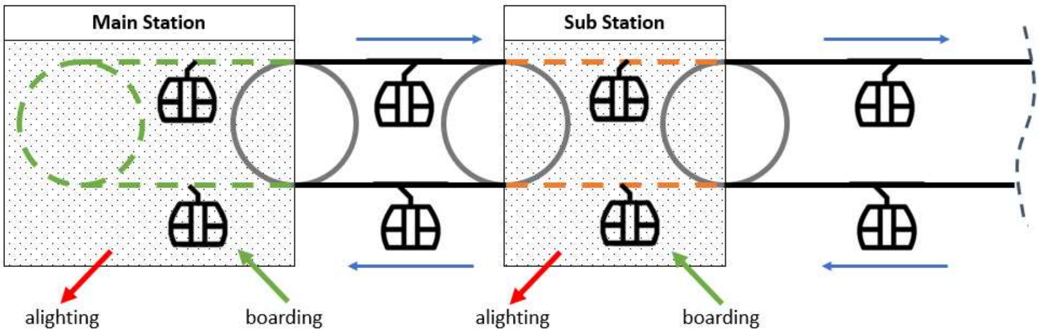


Figure 2-9: Basic ropeway principle, own representation

In order not to go beyond the scope of this master thesis, no further details are given on the funicular ropeway and gondola characteristics. Those can be found in the master thesis authored by Dipl.-Ing Naderer Simon. [Nad18]

2.8 Logistic process

One of the main factors in which this work differs from the previous master thesis is the more detailed consideration of logistics processes, about workers and their fields of work (tasks). Since it is part of the master thesis task to identify and depict the individual logistics areas more precisely, the following subsections provide a closer look at the individual subareas of logistics.

2.8.1 Logistics in general

The umbrella term logistics consists of the planning, manage and control of the material and immaterial flow of goods within a company, between partner companies and between suppliers and end users [HSD18].

This reflects best the 6-R-rule of logistics defined by Reinhardt Jünemann [Rei89]: "The right objects must be available to customers in the right quantity at the right time with the right information at the right cost in the right place with the right quality."

Increasingly more often also from the 7-R rule is mentioned, in which the "right customer" is additionally added as another element. Often referred to as a quantum leap from the classic logistics perspective to a customer-oriented perspective.

Crucial for today's networked and global orientation of materials management is the basic idea of the so-called supply chain. It stands for process-oriented materials management that covers the entire area from demand to production and logistics. [Log17b]

2.8.2 Sales logistics

Sales logistics encompasses all tasks for the planning, control, provision and optimisation of processes along the value chain. Sales logistics cover a complete view of all distribution policy processes that play a role in the transfer of goods. It is, therefore, also called distribution logistics. Due to the direct connection to the goods transfer point, the term (sales-side) marketing logistics can also be used for sales logistics.
The task of sales logistics is the external market supply. It acts as a link between the production logistics and the inquiring customers.

By achieving a sustainable competitive advantage, companies want to create a unique selling proposition and achieve above-average success. In general, the aim is the minimisation of distribution costs while maintaining a delivery service level. [Log13a]

2.8.3 Warehouse logistics

Logistics encompasses all tasks for the planning, control, provision and optimisation of processes along the value chain. Warehouse logistics determine how own and non-company goods are stored and managed in the warehouse, as used in the cityhub and the distribution station. The task of warehouse logistics is thus to define systems for all types of storage, picking and goods transport from goods receipt to goods issue.

Figure 2-10: Warehouse logistics, an example of proLogistik [Log17a]

The goal of warehouse logistics is the optimal use of warehouse functions. All stations of a warehouse work together and are dependent on each other. All goods within the warehouse must be accessible at all times, both on the warehouse shelf and in the system. New products must be quickly and adequately stored and available again for a sale or stock transfer. [Log13b]

3 Urban ropeway – basics

The third chapter describes the kick-off point for the simulation, and the required scenarios serving a model in Plant Simulation. Mr Naderer Simon created this model during his master's thesis : "Urban ropeway – material flow study of a ropeway system for the combining transport of people and goods" [Nad18].
This model was then adapted step by step to the required extensions. In the following sub-chapters, the main parameters relevant to the model used in the simulation are shown in basic.

All other input data, like additional technical parameters were acquired by expert interviews with IBV-Fallast, the ITL institute of TU Graz, as well as the previous Master thesis.

3.1 System containment

3.1.1 System scope

In order to get an overview of which aspects of cargo generally need to be simulated and later analysed, a system scope has been defined, to indicate the limits of the planned system (observed fields in the thesis). At the outset, a cargo quantity was set. These are individual parcels with variable size, arriving the system defined by a daily time-variation curve. Depending on the scenario, the total amount of packages may vary, depending on the forecasted annual expectation. As a primary transport unit, a standardised roll container, which is loaded by a random distribution, has been defined. This is recorded in three state variants: full, empty and nested. The transport unit analyses, in particular, its passage and transport time as well as the space requirements of the transport containers, Figure 3-1.

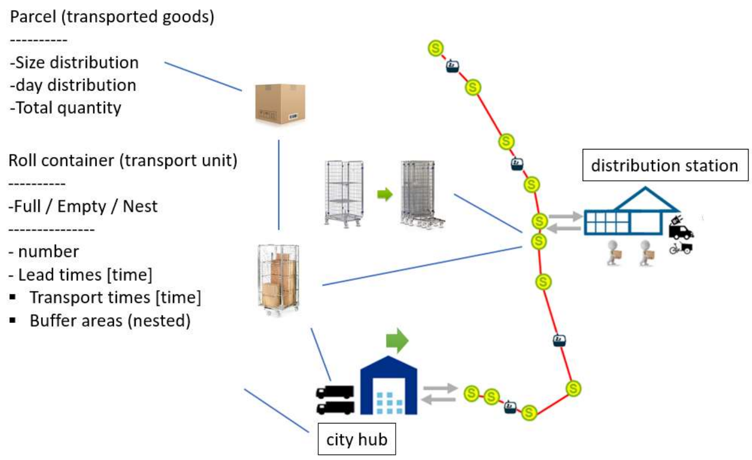


Figure 3-1: System scope for the goods including transport unit, own rep.

The secondary transport takes place with gondolas. We distinguish between two types: passenger and non-passenger gondolas. Non-passenger gondolas or transport gondolas are further divided into two sub-groups: cargo transport gondolas and empty roll container transport gondolas. Cargo transport gondolas transport the regular roll containers for the city, or the returns from the city, whereas the empty container gondolas transport the empty, nested roll containers from the distribution station. The capacity, number and various relevant time phases of all gondolas are monitored.
There are also two types of stations used in the simulation. Those for pure passenger transport and those for combined passenger and cargo transport. Stations for people monitors travel times and waiting time changes. For combined ones, throughput times and buffer areas (see Figure 3-2) are additionaly analysed.

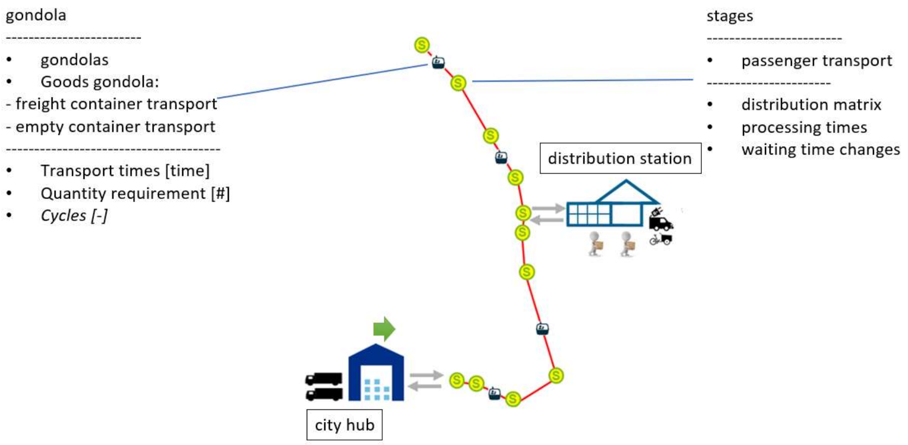


Figure 3-2: System scope of the ropeway system, own rep.

In the defined scenarios, there is a cityhub and a distribution station in use. These are interfaces and allow a connection to the environment for persons and goods. In particular, the required layout and the incoming and outgoing goods are evaluated. For this purpose, the gondola level was adapted, and each station was supplemented by one distributor level and one transport lift (see Figure 3-3). Logistics staff were also introduced to handle the associated tasks. Their workload, working routes and shift times are assessed individually.

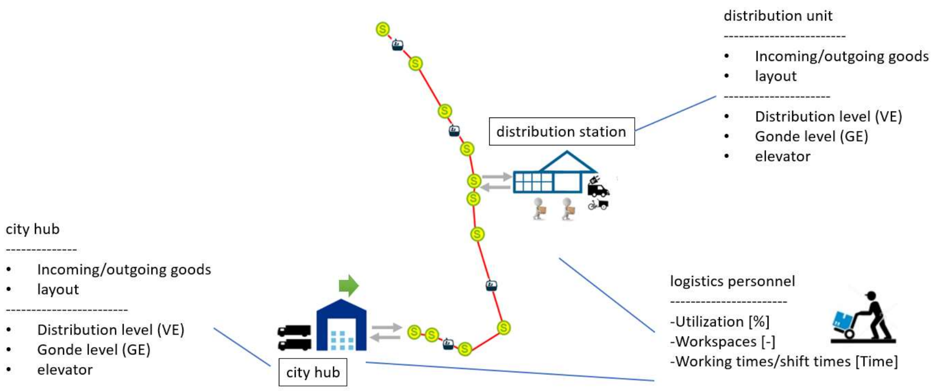


Figure 3-3: System scope of goods-conveying stations, own rep.

3.1.2 System accrual

In the system definition, a distinction is made between the delineation of the simulation and the definition of the system according to the project definition. The simulation limits contain all process steps from the creation to the deletion of the individual elements (packages, persons, nests). The system boundary limits the project view to the crucial areas. There is a difference between the boundaries because it is required for the simulation to buffer or relocate used elements in certain areas. These processes are, however, irrelevant to the scoped system and are therefore processed outside the system boundary. (see Figure 3-4).

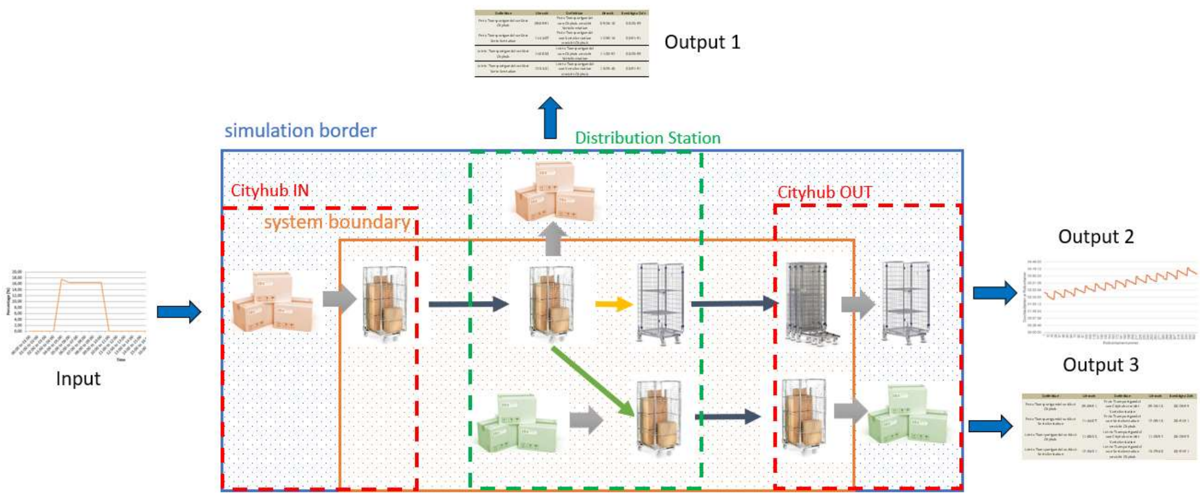


Figure 3-4: Difference between the system and simulation limit, own representation

Figure 3-4 shows the simulation model limit (blue) and the system limit (orange). Also, the cityhub (red) and the distribution station (green) are pictured, but in simplified form. Via the input, the packages for the distribution station are generated (as well as for the returns in the distribution station). In the simulation, the goods arrive as individual packages and are then combined for the system into a group of four roll containers, so-called "packs" of 4, and stored temporarily. The parcels then enter the system as filled roll containers. The parcels then leave the system, depending on their destination via a roll container, either in the distribution station (see Figure 3-5) or in the cityhub (see Figure 3-6). Roll containers can be filled or leave the system as nested roll containers (only in the cityhub).

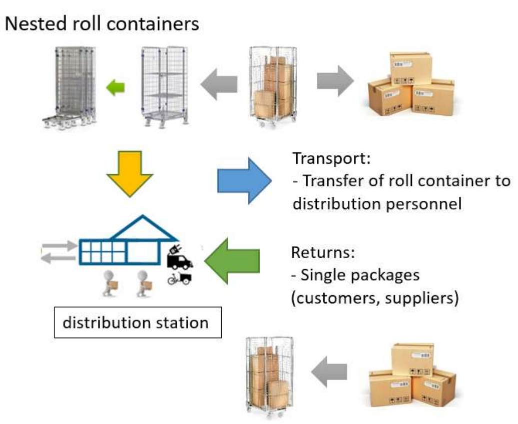


Figure 3-5: Incoming and outgoing goods in the distribution station (simplified), own rep.

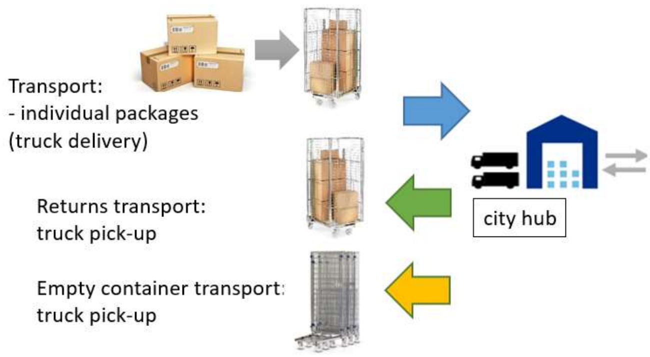


Figure 3-6: Incoming and outgoing goods in the cityhub (simplified), own rep.

Passengers are also generated in the simulation, and their path is studied. The individual persons are detected in the system as soon as they enter the entrance station (see Figure 3-7). When leaving the destination station, the respective person is retaken out of the system and the time required between these stations is recorded and evaluated for each station. The limiters of the simulation and the system are identical when looking at the persons.

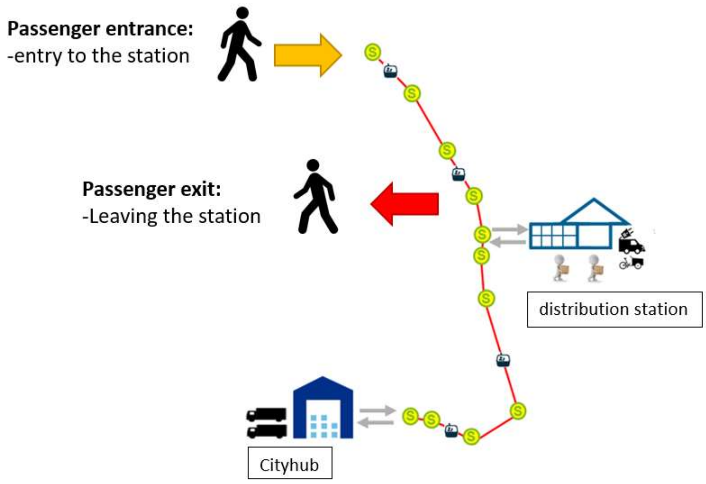


Figure 3-7: Passenger registration in the system (simplified), own rep.

Table 3-1 summarises the most critical parameters of the following scenarios.

Table 3-1: Parameters examined for the individual scenarios

element	examined parameters
City hub/ distribution station	- *Layout and processes [-]* - Goods traffic [# / time] - Staff throughput [persons / time] - Waiting for time changes [time] - Buffer areas [m²]
logistics staff	- Workload [%] - Work paths [m] - Working area [-] - Working hours / shift times [time]
roll container	- Cycle times [time] - Transport times [time]
gondola	- Transport times [time] - Quantity requirement [#] - *Cycles [-]*

3.1.3 Operating parameters

Main parameters were defined for the particular scenarios at the beginning of the project (see Table 3-2). These parameters are then utilised in all scenarios and remain constant during the simulation.

Table 3-2: Main parameters that are used identically for all scenarios

Parameter	Value
effective turnaround person time	44,00 sec
adequate lead time goods and person	88,00 sec
rope speed	7,50 m/s
gondola speed in stations	0,20 m/s
length Station (Simple)	9,00 m
length of station (double)	18,00 m
gondola cycle	42,00 sek
passenger gondola to transport gondola	5 to 1
passenger volume processing	30480 #

Expert interviews with IBV-Fallast determined all further input data and additional technical parameters, the ITL Institute of the Graz University of Technology and the previous master's thesis of Naderer Simon. These can be found at the beginning of the individual chapters of the scenarios ("SZ X: boundary conditions - system parameters").

3.2 Start and initial conditions

3.2.1 Initial condition - Route

In the course of the project ROPEWAY_POT [Kur14], different routes for the cable car system in Graz were worked out. In cooperation with the engineering office Planum Fallast and the ITL Institute of the Graz university of technology, the route "3-S_Lang - PF1.1" was selected and analysed in more detail.
The route "3-S_Lang - PF1.1" consists of 11 stations, which are connected to a three-way orbit. Figure 3-8 shows the route: The northernmost stop Weinzödlbrücke with the southern course along the Mur to Puntigamer bridge and the final EAST - WEST branch to the terminus in Webling.

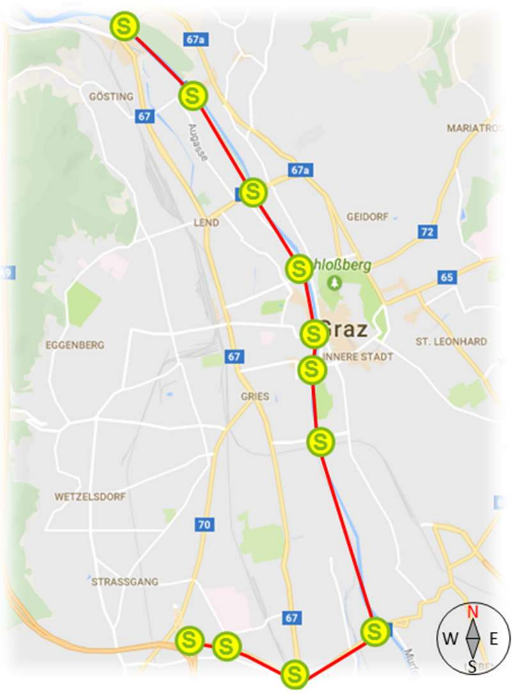


Figure 3-8: Network route ropeway system “3-S_Lang - PF1.1” [Kur14], [Nad18]

The total length of the ropeway system is calculated to 11.886 km per direction, the individual stations and their distances are listed in Table 3-3 from north (P&R Weinzödlbrücke) to south (P&R Webling).

Table 3-3: Network route "3-S_Lang - PF1.1" station distances

Nr.	station name	length between stations [m]	cumulated 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

3.2.2 Initial condition - Ropeway network

The ropeway network defines the positions of city hubs and distribution units for goods transport on the ropeway system.

- Cityhub: Interface station, located outside the city area for the delivery of goods to the ropeway system.
- Distribution station (unit): Interface station in the inner-city area for distribution of goods - pick-up station

For the simulation studies to be carried out, the ropeway network with a cityhub in the south at the ropeway station in Webling and a distribution unit at Andreas Hofer Platz was selected. Figure 3-9 below shows the ropeway network: number 2 of the cityhub for goods transport to the city and number 4 of the distribution unit for goods distribution.

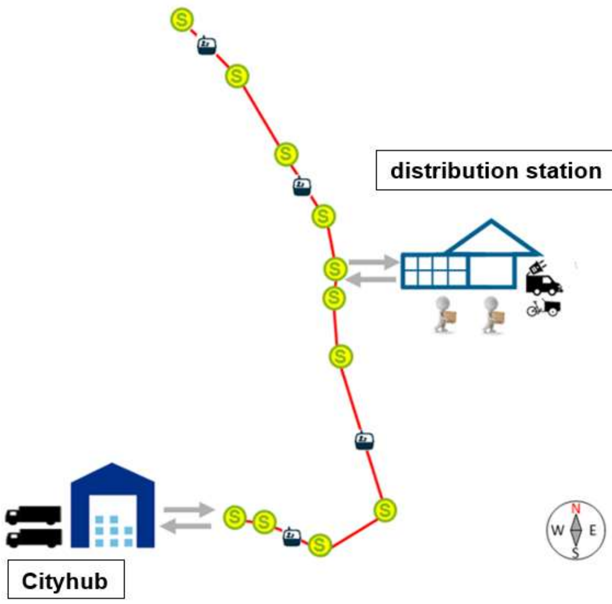


Figure 3-9: simplified presentation of the two goods handling stations [Nad18]

3.2.3 Initial condition - Station layout

The station layout defines the arrangement of person transfer and goods handling in the individual stations. Due to the simpler gondola and station design, the station layout "4b" was chosen, which is illustrated in Figure 3-10. For goods transport, the outer door opens and goods can be unloaded or loaded (By definition a gondola can only be loaded or unloaded). For passenger transport, the inner door opens and the passenger exit and/or passenger entrance takes place.

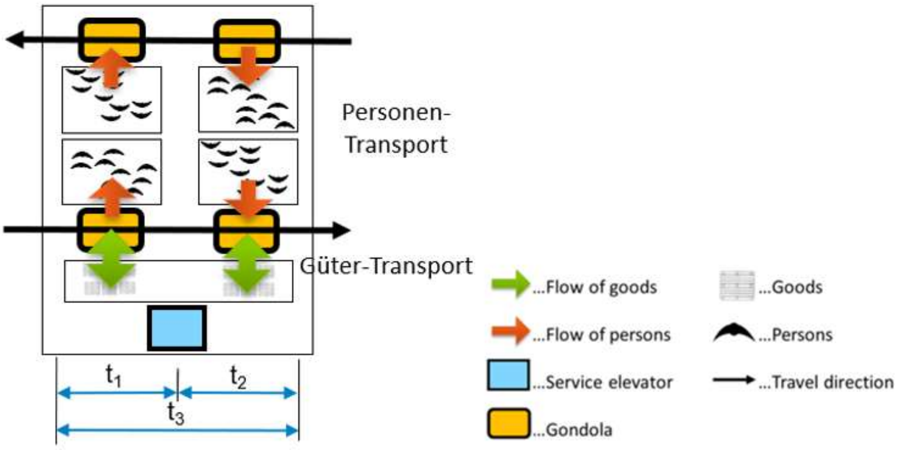


Figure 3-10: Station layout - 4b [Nad18]

At stations where goods are not transhipped, the central area for loading and unloading goods is omitted and leads to a passenger exit and entrance, Figure 3-11. The effective station length was assumed to be 9 m, as in the case of goods transshipment.

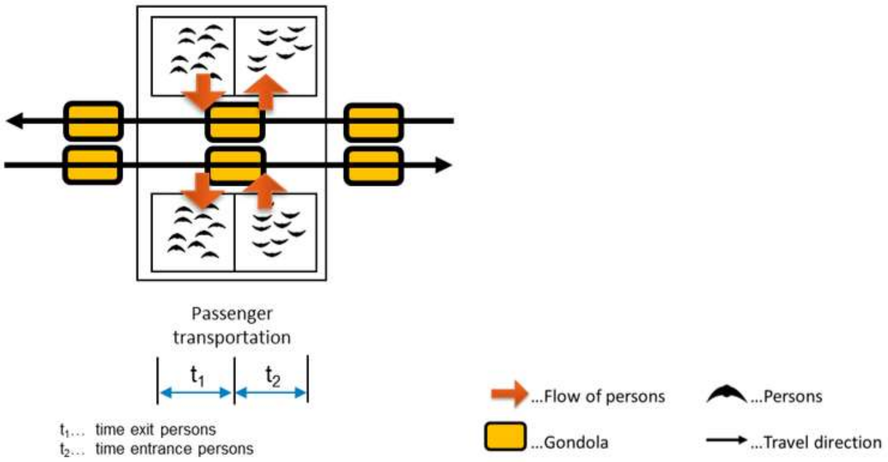


Figure 3-11: Station Layout - Serial Arrangement Person Transfer [Nad18]

3.2.4 Initial condition - Expected goods volume

Large and small parcels that are currently delivered by CEP (courier, express and parcel services) to service providers (e.g. DHL, DPD, Post) are defined as goods that are to be transported with the ropeway system. The number of goods per working day was calculated from the annual volume of parcels from Austria and CEP studies from the major German cities of Berlin, Hamburg, and Munich. This study result in a parcel quantity per inhabitant of 0.103 parcels per working day, Table 3-4.

Table 3-4: Volume of goods based on CEP volumes Austria, Berlin, Hamburg, and Munich

Boundary conditions for Cargo volumes [Bra18], [Ing16], [RF17], [Bun15], [Nad18]		
Goods (CEP #) per person per working day	**0,103**	From CEP market Austria and CEP market Berlin, Hamburg, Munich
Returns Quote of the total volume of goods determined in the delivery area	**15%**	100% of the volume of goods entering the city 15% of the volume of goods leaving the city
Assumption Growth CEP Market	**~6 % p.a.**	5.9% from BIEK study 2017 [KJ17]
Persons in extradition area (2018)	**139.121**	From districts (1-6) around Andreas-Hofer-Platz
Skimmable percentage of goods delivery in the delivery area around the distribution node (Andreas-Hofer-Platz)	**50%**	Assumption due to planned political restrictions around parcel delivery in the inner-city area

From the previous assumptions, different quantities of goods result for each year and transport direction, as shown in Table 3-5. Details on transport time and transport direction can be found in the respective boundary conditions of the individual scenarios.

Table 3-5: Quantities of goods per year and transport direction

Transport direction	**Basis**	**2018**	**2025**
The volume of goods in the city	-	7200 #	10750 #
The volume of goods from the city	-	1080 #	1609 #

3.2.5 Initial condition - Expected person volume

For the selected ropeway route "3-S_Lang - PF1.1" the preliminary project: “ROPEWAY_POT” [Kur14] with consideration of day tourists and excursion tourists results in a passenger volume of about 30480 persons per working day at the ropeway system. Due to the use of random numbers and probabilities the individual numbers per Station fluctuates slightly (+/- 5 persons depending on simulation). Table 3-6 shows how the persons are subdivided on average into the individual cableway stations:

Table 3-6: Number of people at the stations per working day

Nr.	station name	persons per working day
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
	Sum	30480

The figures in Table 3-6 show a high concentration of entrances in the inner-city area and at the two P&R stations. The boarding persons are subject to different target probabilities depending on the boarding station, which are defined with the numbers of the target probability matrix of Table 3-7 [Nad18].
The target probability matrix provides an essential indication of the target station of the entering persons. It indicates the probabilities (FROM – TO relation) when a person enters the ropeway system at a specific station to which station the person may travel.

Table 3-7: Target probability matrix

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

Also, the boarding behavior of the persons at the respective stations is subject to a daily time-variation curve, which defines the percentage distribution (weighting) of persons per hour at the cableway stations. Since the two cableway stations, Weinzödlbrücke and Webling P&R are adjacent to each other, a separation into a daily time-variation curve for P&R stations and a daily time-variation curve for the remaining standard stations is done.

3.2.5.1 Daily time-variation curve standard station-persons

The daily time-variation curve for standard stations is based on a data collection of the usage times of public transport:

- Public transport Styria [ISV18]
- Public transport in the city of Zurich [Rob12]
- Public transport in the city of Berlin [Mar16]

The calculated daily time-variation curve (blue) for standard stations is shown in Diagram 3-1, picturing a morning peak between 07:00-09:00 and an evening peak between 16:00-18:00.

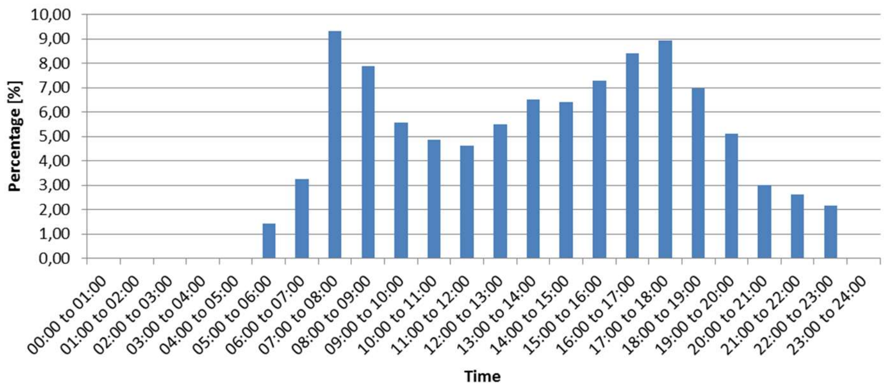


Diagram 3-1: Daily time-variation curve (persons) at standard stations [Nad18]

3.2.5.2 Daily Time-variation curve P&R Station-People

The daily time-variation curve at P&R cableway stations is made up of 30% of the daily time-variation curve of standard cableway stations and 70% of the daily time-variation curve from the EAR91 standard, which describes the usage behavior of P&R installations. The resulting daily time-variation curve (orange) at P&R stations is shown in Diagram 3-2. The characteristic morning peak (early morning traffic) and the short peak towards evening are there pictured.

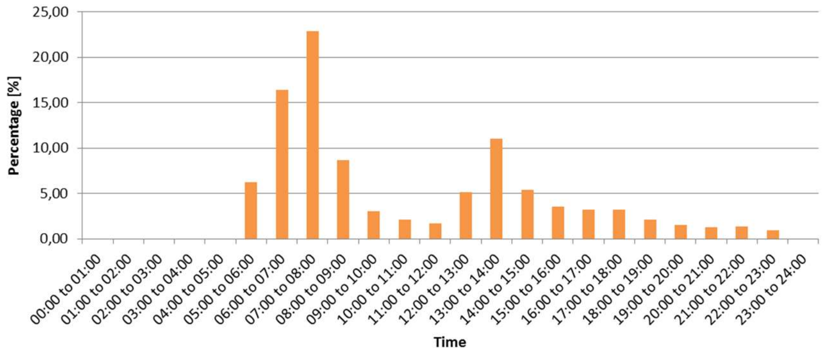


Diagram 3-2: Daily time-variation curve (persons) at P&R stations [Nad18]

3.2.6 Initial condition - Travel time - persons

The travel time is evaluated from entering the start station to the left of the person at the destination station. The person is recorded in the system as soon as he or she enters the start station (or exit station). When leaving the destination station, the person is removed from the system and the time required between these stations is recorded and evaluated for each station. The average travel time is then calculated from this data. Depending on the process, waiting times may occur. However, since this is not an essential aspect of the simulation, only a change in waiting time is determined in comparison to the pure transport of passengers.

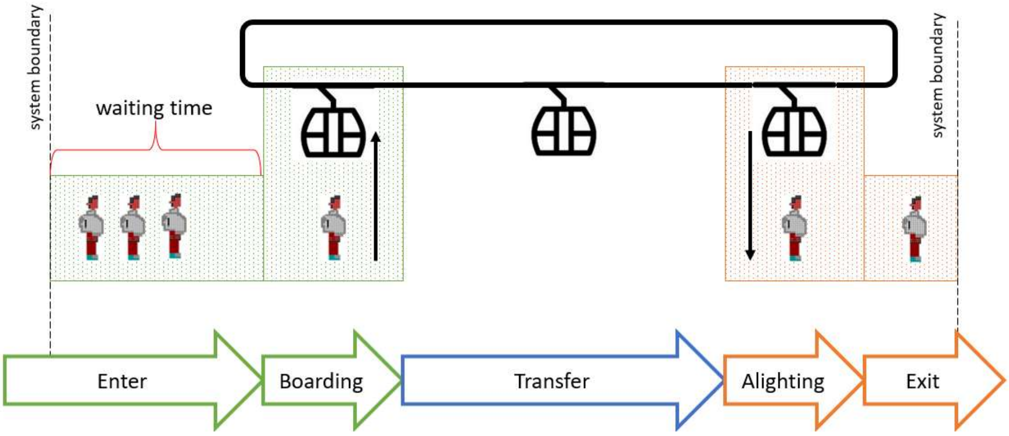


Figure 3-12: Process of the person throughput in the system, own representation

4 Urban ropeway model adaption

4.1 Project structure

The task was to simulate different simulation scenarios with the impletion of the newly defined requirements in the material flow software “Plant Simulation” in order to picture and estimate the package transport using a ropeway system.
The basic model by Dipl.-Ing. Naderer Simon (Master thesis: Ropeway II: Material flow simulation of ropeways for the combining transport of people and goods in urban areas [Nad18]) is used as a base.
To keep an overview during the project, it has been structured and divided into subgroups (or working groups). This project structure is displayed in Figure 4-1.

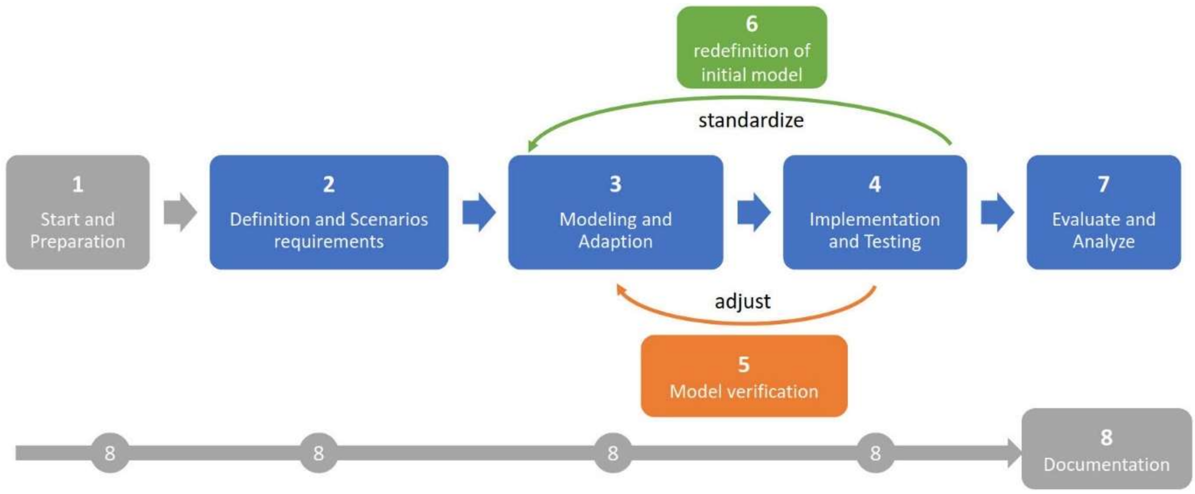


Figure 4-1: Project steps of the material flow study, own representation

As illustrated in Figure 4-1 the project consists of eight key elements:

1. Start and Preparation
   The first phase includes the familiarisation with the software used and the basic structure of the base model. Also, literary background research was conducted on individual subject areas.

2. Definition and Scenario requirements
   In the second phase, the scenarios to be processed are defined. Which configuration should be processed, what are the main parameters and which ones could be experimented with and changed in the simulation.

3. Modelling and Adaption
   In this phase, the existing model is examined more closely. The previously defined parameters and scenarios are roughly compared with the evaluation possibilities of the base model.

4. Implementation and Testing
   In order to make it easier to control the correctness of the model, the target model was divided into smaller subgroups (adaptations), which are then gradually incorporated into the existing model.

5. Model verification
   After each error-free test of the extension, the new initial model is checked for plausibility, whether the new simulation results are identical to those of the previous model.

6. Redefinition of the initial model
   After each new adaptation, the initial model is redefined with those adjustments. The next expansion will then be built on the adapt version. This procedure makes it easier to record the changes and errors in the are easier to determine.

7. Evaluate and Analyze
   When all extensions are implemented, the model is tested with the same parameters as the initial (base) model. It is checked whether the results obtained are plausible and technically and logically explainable. If this is the case, the model is simulated with the predefined new main parameters and the essential areas are evaluated.

8. Documentation (Lessons Learned)
   In the final phase, all the significant results of the thesis are collected and documented. This also includes any successful, completed implementation of an extension.

4.2 System specification -Data Model

A data model is used to characterise the elements within the system and also to picture in detailed an urban ropeway system. The data model illustrates the basic model structure and is the conceptual model for the modelling process in the plant simulation. Figure 4-2 shows the data model for the combined transport of people and goods. The starting point here was also the data model developed from the previous master's thesis [Nad18], which was then revised to meet the new requirements.

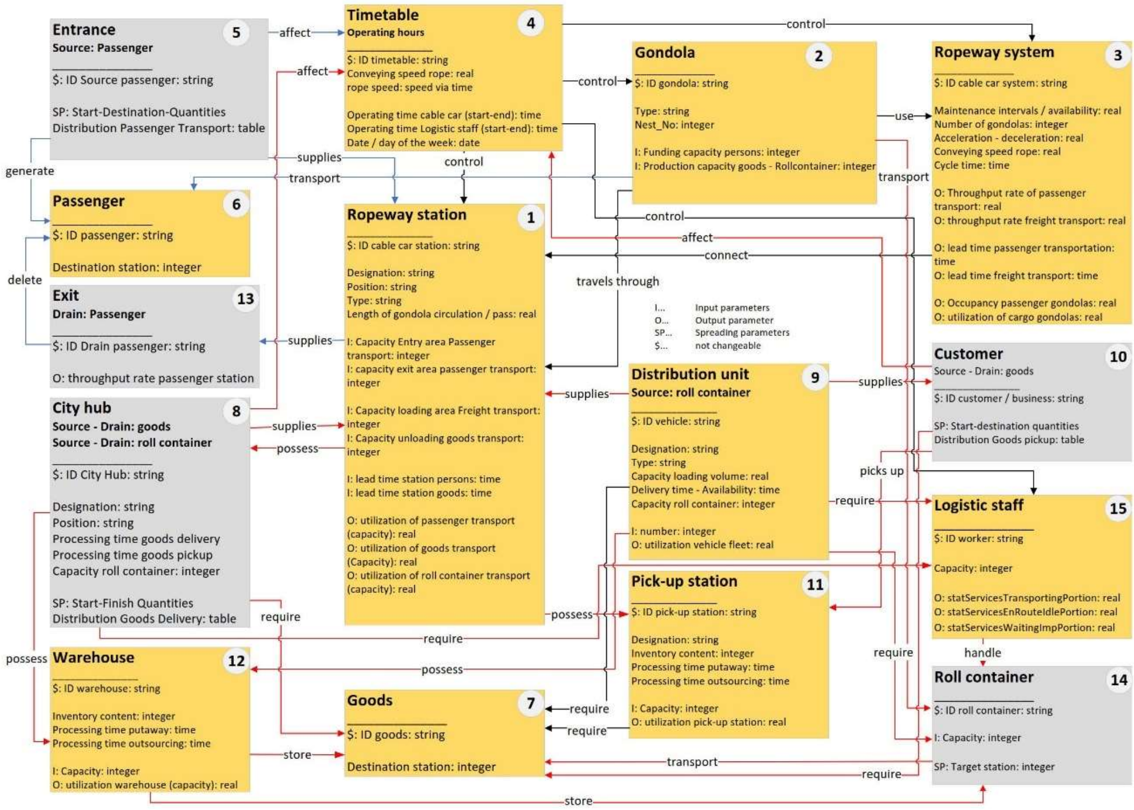


Figure 4-2: Data model of the ropeway system

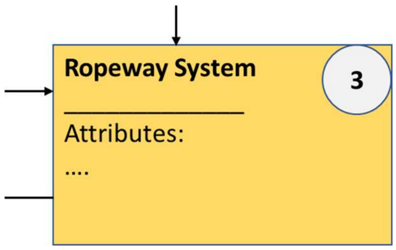
The data model consists of following basic notations:

- Classes: Entities in the system that represent an element.
- Attributes: Each class contains attributes that characterise and define the class. Attributes are distinguished between input parameters, output parameters, spread parameters and standard parameters or different parameters.
- Relation: Shows the correlation and how these two classes interact with each other

The data model also illustrates in color the interaction with the environment and thus, its system boundaries. Grey classes are located at the system boundaries, while yellow classes have no contact with the environment. The red arrow indicates relations to goods, blue to passengers and black are general ones.

In Table 4-1, the station class of the data model is described exemplarily by its representation, attributes and relations, while relations are assigned in the from-to direction. The complete and detailed description of each class can be found in the appendix, in chapter 7.2: “Data Model” on page 113.

Table 4-1: Data model description – Class: Ropeway System

<table>
<tr><th colspan="2">Class: Ropeway System (Class Nr.3)</th></tr>
<tr><td colspan="2">
</td></tr>
<tr><th>Attributes</th><th>Relations</th></tr>
<tr><td>I. $: ID cable car system: string

II. Maintenance intervals / availability: real
III. Number of gondolas: integer
IV. Acceleration-deceleration: real
V. Conveying speed rope: real
VI. Cycle time: time

VII. O: Throughput rate of passenger transport: real
VIII. O: throughput rate Cargo transport: real

IX. O: lead time passenger transportation: time
X. O: lead time Cargo transport: time

XI. O: Occupancy passenger gondolas: real
XII. O: utilisation of cargo gondolas: real</td><td>• control via Timetable
The timetable controls the ropeway system. It determines at what time the system is active and the currently driven rope speed.

• connect via Ropeway Station
There are stations in the system. They allow persons or roll container to enter or leave the ropeway system.

• use via Gondola
The gondolas are attached to the cable (Ropeway system) when travelling between stations. They transport persons and roll containers.</td></tr>
</table>

The data model shows the high complexity of the ropeway system. In order to keep a better overview, the individual parameters, delimitations and requirements are explained in the next chapters. Incipient, with the areas which could be taken over from the initial model (including possible, minor adjustments) and at the end, the extensions and their implementation steps are illustrated.

4.3 Simulation scenarios

In the first steps, the scenarios to be evaluated were defined for the project. This results into five target scenarios:

- Scenario 1: ECO scenario pure passenger transport (basis)
- Scenario 2: ECO Scenario 2018 1-1
- Scenario 3: ECO Scenario 2018 2-2
- Scenario 4: ECO Scenario 2025 1-1
- Scenario 5: ECO Scenario 2025 2-2

The first scenario serves as a reference scenario. It is simulated without transport gondolas, with the same number of passengers as for the following scenarios. Likewise, it is simulated over the same operating period as then for the following scenarios.

- Scenarios for 2018 are analysed with the expected goods volumes for the year "2018".
- Scenarios with 2025 are analysed with the expected goods volumes for the year "2025".

For scenarios ending in 1-1, one worker is deployed at the gondola level, and the distributor level. Scenarios which ending in 2-2 use two workers in each area.

4.3.1 Varieties of pure gondolas

The simulations use so-called "single-grade" gondolas, meaning that passenger gondolas only transport people and transport gondola can thus only accommodate roll container. Transport gondolas are further defined in:

- Cargo roll container transport gondolas
- Empty roll container transport gondolas

Cargo roll container transport gondolas only transport filled roll containers. Empty container gondolas only transport the empty, nested roll container.
It is also defined in the first phase that transport gondolas in the stations can only be either loaded or unloaded.

4.3.2 Fixed distribution of the gondolas

Based on the master thesis "Urban ropeway" [Nad18], several possible gondola distribution potentialities have already been developed. In the course of the project meeting, the fixed gondola distribution of 5 to 1 is defined. This distribution means that after five-person gondolas a non-person gondola (Cargo- or empty roll container) follows, as seen in Figure 4-3.

The cycle within the transport gondolas is defined as 7 to 1 (and 8 to 1 due to rounding tolerances), so every 7th (8th) transport gondola is followed by an empty roll container gondola.

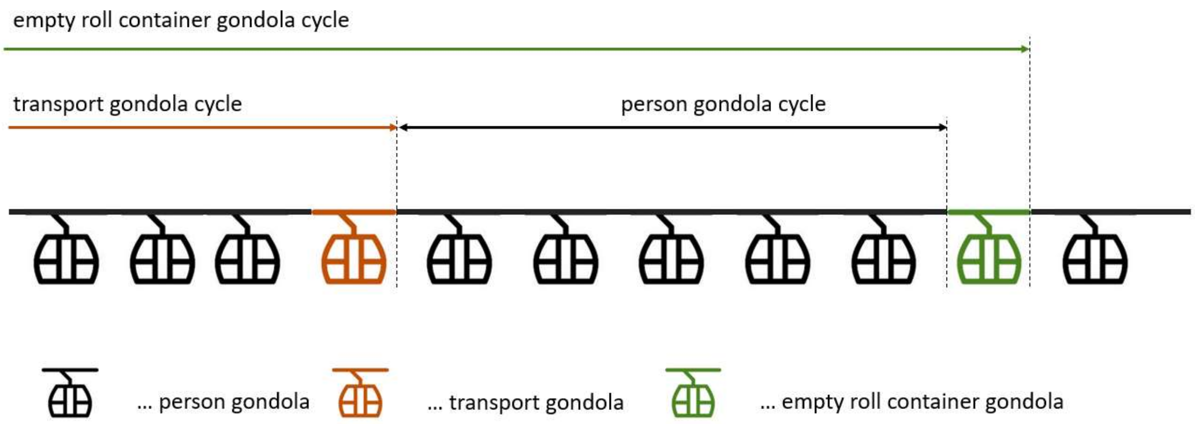


Figure 4-3: gondola distribution, own representation

4.4 Roll container

Each roll container is filled with a random number of individual parcels (using the Erlang-distribution). The maximum filling volume is set at 550 dm³.
In order to guide the roll containers, which are transported to the city and back to the cityhub, these are combined into so-called "nests." The roll containers from the cityhub are unloaded in the distribution station, and the roll containers are then nested in 12 pieces (Figure 4-4). Two nests are then loaded into the empty container gondolas. The system contains two empty container gondolas at intervals of 7 (or 8) transport gondola cycles.
The dimensions of the nested roll containers (length 3,06m and width 0,86m) are designed to fit in the gondolas.

Figure 4-4: Roll containers (RC / N1) are combined to form "nests." [Wan18]

4.5 Empty roll container cycle

Roll containers are transported from the cityhub into the city, and from the distribution station out of the city (returns). There they are unloaded at the distribution station and processed in the application of further distribution logistics steps. By definition, however, these steps are outside the system under consideration and are therefore not illustrated in detail.
To avoid excessive accumulation of roll containers in the distribution station, these are summarised in so-called "nests".
For their transport, transport gondolas are skipped in the CityHub (not filled). They are then loaded with nested empty containers in the distribution station. (Empty containers gondolas)

Table 4-2: Parameters for the nested roll containers

Empty roll container transport gondolas		
Number of empty container gondolas	2	#
Empty containers gondola numbers	3, 12	
Nests per empty container gondola	2	#
Roll container per nest	12	#

Figure 4-5 briefly illustrates the "empty roll container"- principle. As input for the system, filled roll containers (goods receipt) are assumed. They are combined into "packs" of 4 and stored. When a free transport gondola is available, it is loaded, and the gondola transports the roll containers to the distribution station, where they are unloaded again. The roll containers are then brought to the distributor level, unloaded, processed in the application of further warehouse logistic (and sales distribution logistic) steps, and the empty roll containers are combined into nests. These nests are then transported via the empty roll container transport gondolas to the cityhub and leave the system there.
Only those roll containers that are not requisite in the distribution station for the transport of returns are transported back again (+/- tolerance).

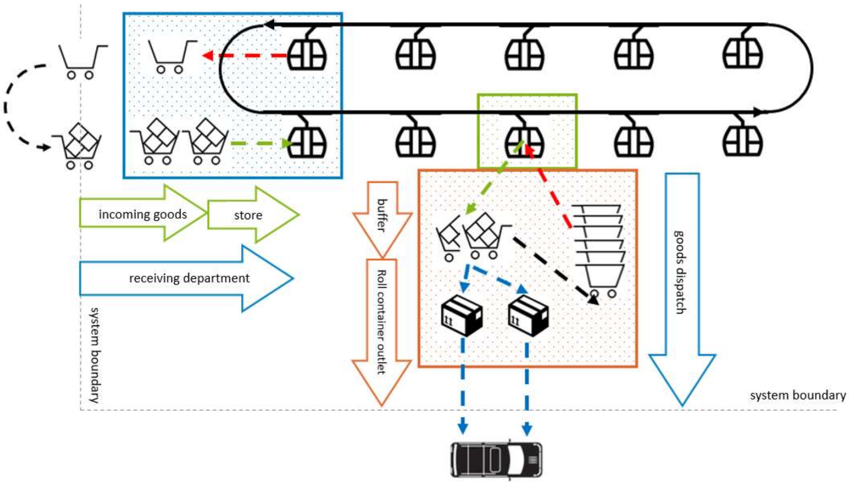


Figure 4-5: Empty container handling process, own representation

4.6 Layout and Logistic staff

The same logistic staff is used for the different scenarios (same basic parameters). For scenarios with the ending 1-1, one worker each is used at the gondola level (orange area) and the distribution level (green area). For scenarios with the ending 2-2, two workers are used in each of the respective areas. Figure 4-6 pictures these two levels.

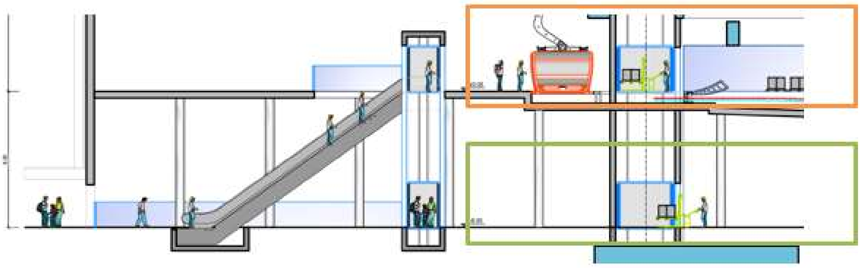


Figure 4-6: Working levels [LEI18]

Figure 4-7 shows the entire front view of the gondola station, as developed by Leitner AG [LEI18].

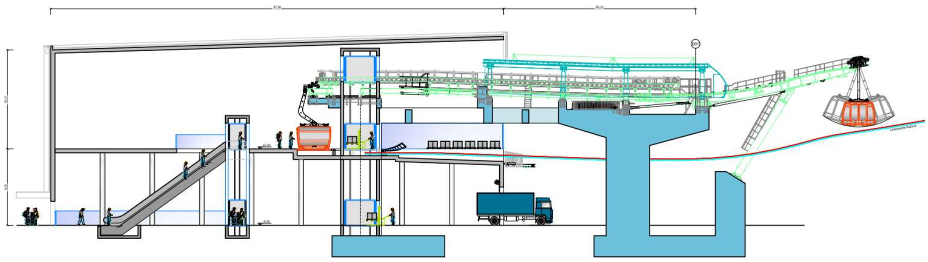


Figure 4-7: Gondola station, front view [LEI18]

Figure 4-8 shows the floor plan of the gondola station. The green area is the one where the goods would be handled. The following chapters contain possible primary sections of those areas and which tasks are carried out there.

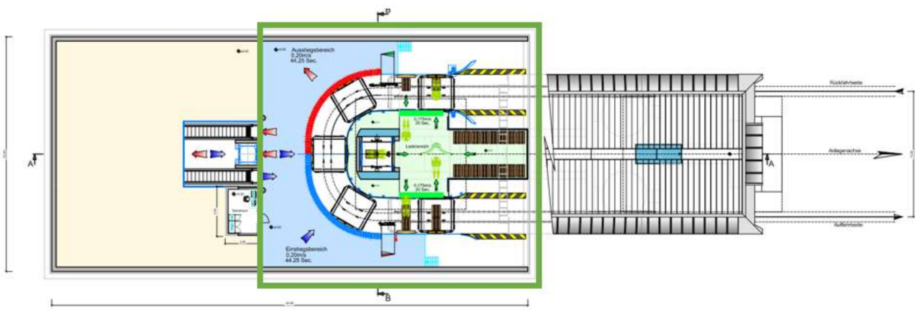


Figure 4-8: Gondola station, floor plan [LEI18]

4.6.1 Layout assumptions Gondola level

For the gondola level (orange area in Figure 4-6 on page 47) at the cityhub and the distribution station, an identical layout is assumed, as displayed in Figure 4-9. The real floor plan may differ (cityhub semicircular working area) but will include the same workspaces.

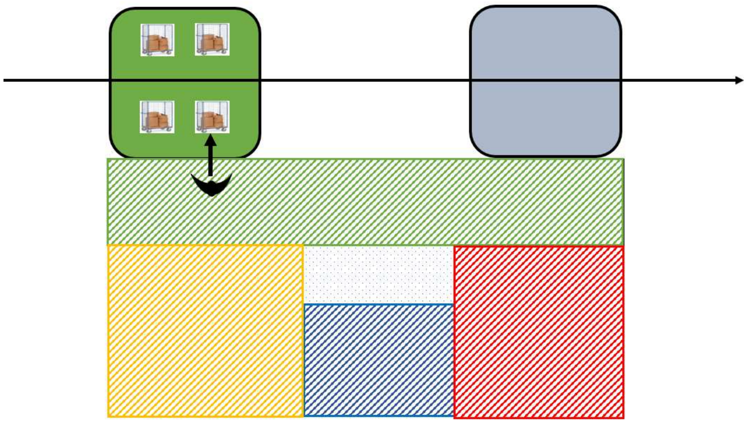


Figure 4-9: Layout assumptions gondola level, own representation

Primary tasks of the worker:

- loading and unloading the transport- and empty roll container transport gondolas (green zone)
- transport and intermediate storage of the roll containers (red zone) and the empty, nested roll containers (yellow zone) for the elevator or gondola transport
- loading/unloading the elevator (blue zone)

The tasks vary slightly between the workplaces in the cityhub and the distribution station. The worker in the cityhub only has to transport regular roll containers to the gondola and store them temporarily and unload the nested roll containers. The worker in the distribution station, on the other hand, also has to store nests temporarily and load them if necessary.
It may happen that a worker does not start from a defined starting point, but has to interrupt another activity or intentionally interrupt it prematurely. The difference or deviations of these routes do not have a serious effect on the overall system.

The task areas are described in more detail in chapter 7: Appendix in Table 7-13: Work areas of the workers at the gondola level on page 129.

4.6.2 Layout assumptions distribution level - Cityhub

In the cityhub, the roll containers intended for the city reach the system. Here the worker has the task of load and unloads the elevator (returns and empty roll containers).
The elaborated layout would be provided for the green area in Figure 4-8 on page 47.

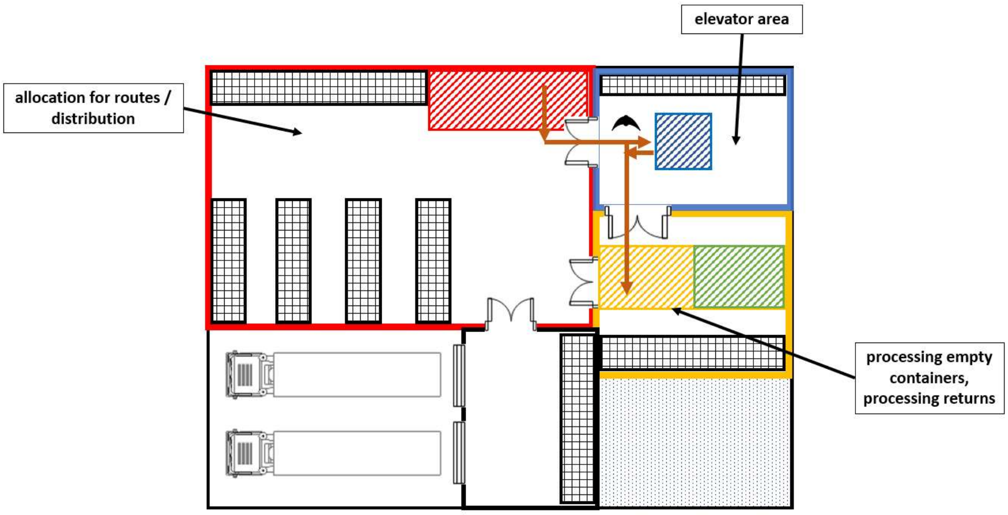


Figure 4-10: Layout assumptions distribution level - cityhub, own rep.

Primary tasks of the worker:

- Transport and store temporarily the roll containers in the elevator area (red area to blue area) and transporting the roll containers for further processing
- unload the elevator with returns (green zone) or nested, empty roll containers (yellow zone)

The task areas are described in more detail in chapter 7: Appendix in Table 7-15: Work areas of the workers at the distribution level (Cityhub) on page 129.

4.6.3 Layout assumptions distribution level - distribution station

The layout for the distribution level of the distribution station has more considerable distances and temporary storages, due to the necessary buffer areas for the arriving roll containers, the empty containers and the returns. The main tasks of the work here are unloading the elevator and, from a specific point in time, loading returns and empty containers. The elaborated layout would be provided for the green area in Figure 4-8 on page 47.

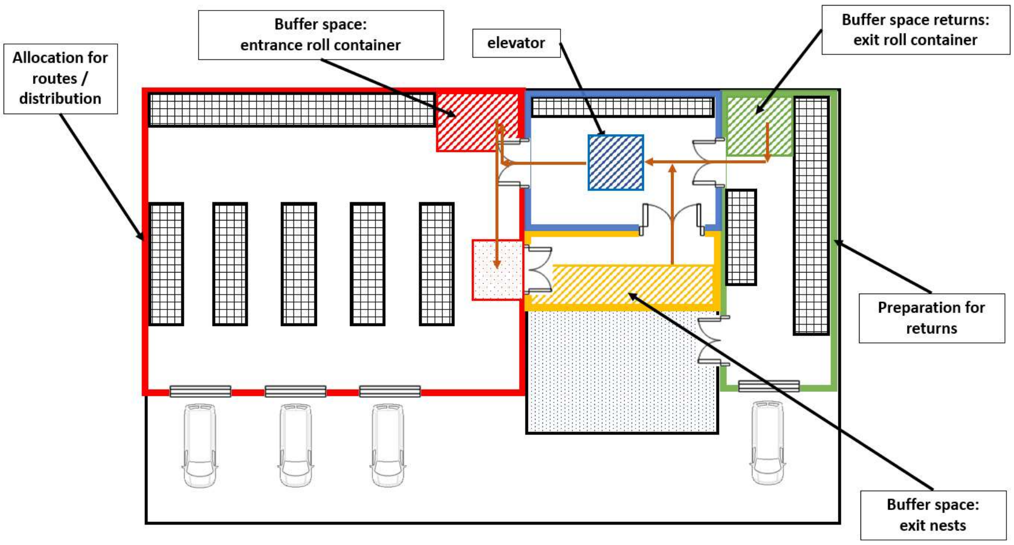


Figure 4-11: Layout assumption distribution level - distribution station, own rep.

In these areas, the tasks in the cityhub and the distribution station differ slightly. The worker in the distribution station has to pick up nested empty containers in addition to the return containers, whereas the worker in the cityhub only has to unload them from the lift and guide them out of the system. Also, as mentioned before, the layout assumptions differ from the long ways and extended task areas. The worker in the distribution station must pick up the empty roll containers from one buffer location and join them together to form nests in another buffer area, as well as the transport of the returns.

The task areas are described in more detail in chapter 7: Appendix in Table 7-14: Work areas of the workers at the distribution level (distribution station) on page 129.

4.6.4 Logistic Staff

Logistic staff are classified into two categories. The first category is how long they have to work according to the shift schedule to be able to handle the transport capacities (as defined in the Gantt charts in Table 4-4 and Table 4-5). The other category is the active working time. How long is each logistics staff busy at their place of work.

Main parameters of logistics staff:

- Speed: 1 m/s
- Effectiveness: 100 %
- Carrying capacity: 1 # (roll container or nest)

Workspaces:

- transport to the city
- transport from the city
- empty container transport

Figure 4-12: Logistics staff - Plant Simulation

Table 4-3: Number of logistics staff used by their area of use

Area of use	2018 1-1	2018 2-2	2025 1-1	2025 2-2
cityhub distribution level	1	2	1	2
cityhub gondola level	1	2	1	2
distribution station distribution level	1	2	1	2
distribution station gondola level	1	2	1	2

4.6.4.1 Gantt chart

In scenario 2018 1-1 and 2018 2-2, the individual workflows are carried out as shown in Table 4-4:

- The blue areas illustrate the period in which the respective roll container transport takes place. The time delay towards the end of the container transport to the city results from the definition that only loading or unloading is allowed. The worker in the distribution center must, therefore, wait until the last roll container has arrived before he can start loading for transport out of the city.

- The green areas indicate the period in which the empty roll containers will be transported. The return transport of roll containers from the same day to the city can only be started later, as roll containers have to pass through a particular cycle beforehand. However, if necessary, the remaining, unused roll containers from the previous day can be sent back (not done in the simulation as only one day is simulated).

- The orange areas illustrate the necessary shift length for the logistics staff in the individual positions
  Depending on the workplace, logistics staff may have to work longer hours. The longest is the logistics staff in the Cityhub because they have to be active until the last roll container. Logistics staff in the distribution station, on the other hand, can start later and finish their shift from the last roll container sent away.

In scenario 2025 1-1 and 2025 2-2, the individual workflows are carried out, as shown in Table 4-5. The only difference to scenarios 2018 1-1 (and 2018 2-2) is the extended working time required by logistics staff for their individual tasks, but the compulsory procedure is identical.

Table 4-4: Gantt chart - ECO scenario 2018

ACTIVITY	START	END
Roll container transport city ub to distribution station	05:00	11:00
Roll container transport Distribution station to cityhub	11:40	12:40
Return transport of empty roll containers (previous day)	05:20	06:30
Return transport of empty roll containers (current day)	06:40	12:10
Worker Cityhub (distribution level)	04:50	13:30
Worker Cityhub (gondola level)	05:00	13:30
Worker Distribution station (distribution level)	05:20	12:40
Worker distribution station (gondola level)	05:20	12:50

Table 4-5: Gantt chart - ECO scenario 2025

ACTIVITY	START	END
Roll container transport city ub to distribution station	05:00	14:00
Roll container transport Distribution station to cityhub	14:40	15:50
Return transport of empty roll containers (previous day)	05:20	06:30
Return transport of empty roll containers (current day)	06:40	15:50
Worker Cityhub (distribution level)	04:50	17:00
Worker Cityhub (gondola level)	05:00	16:50
Worker Distribution station (distribution level)	05:20	16:00
Worker distribution station (gondola level)	05:20	16:10

Tolerance : +/-5 min

4.7 Modelling and Adaption

4.7.1 Initial model

As already explained in the previous chapters, the model from the master thesis of Naderer Simon: "Urban Ropeway" [Nad18] is used as initial model of the simulation. Figure 4-13 shows the general view, which contains the sections M1 and M2 of the initial model.

- Section M1 includes the subway system consisting of Main_Stations and Sub_Stations.
- Section M2 includes the evaluated tables. After completing the simulation, the corresponding data from the individual elements (stations) is stored there.

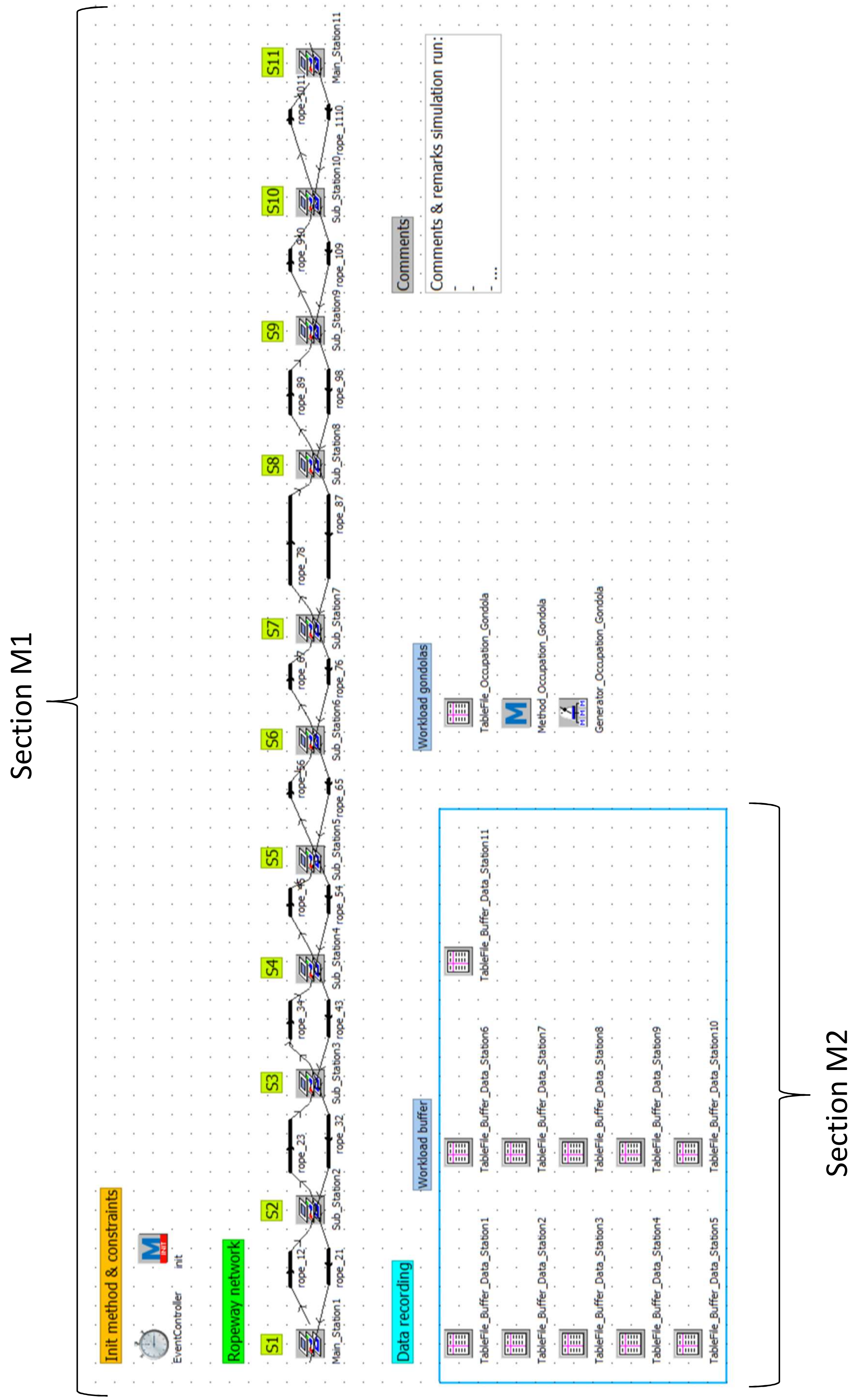


Figure 4-13: The initial model with sectors M1 and M2

Entered in detail is now a Sub_Station used. This station is simplified again in the sections M3, M4 and M5. The Main_Station contains in general of the same core elements, so it is not pictured in more detail.

- Section M3 contains basic simulation methods. Methods for reading in, time setting, generation of gondolas.
- Section M4 includes the elements for loading and unloading of the gondolas. Differences here are the loading and unloading process for persons and goods.
- Section M5 includes the two transportation directions (routes) of the gondolas within the station

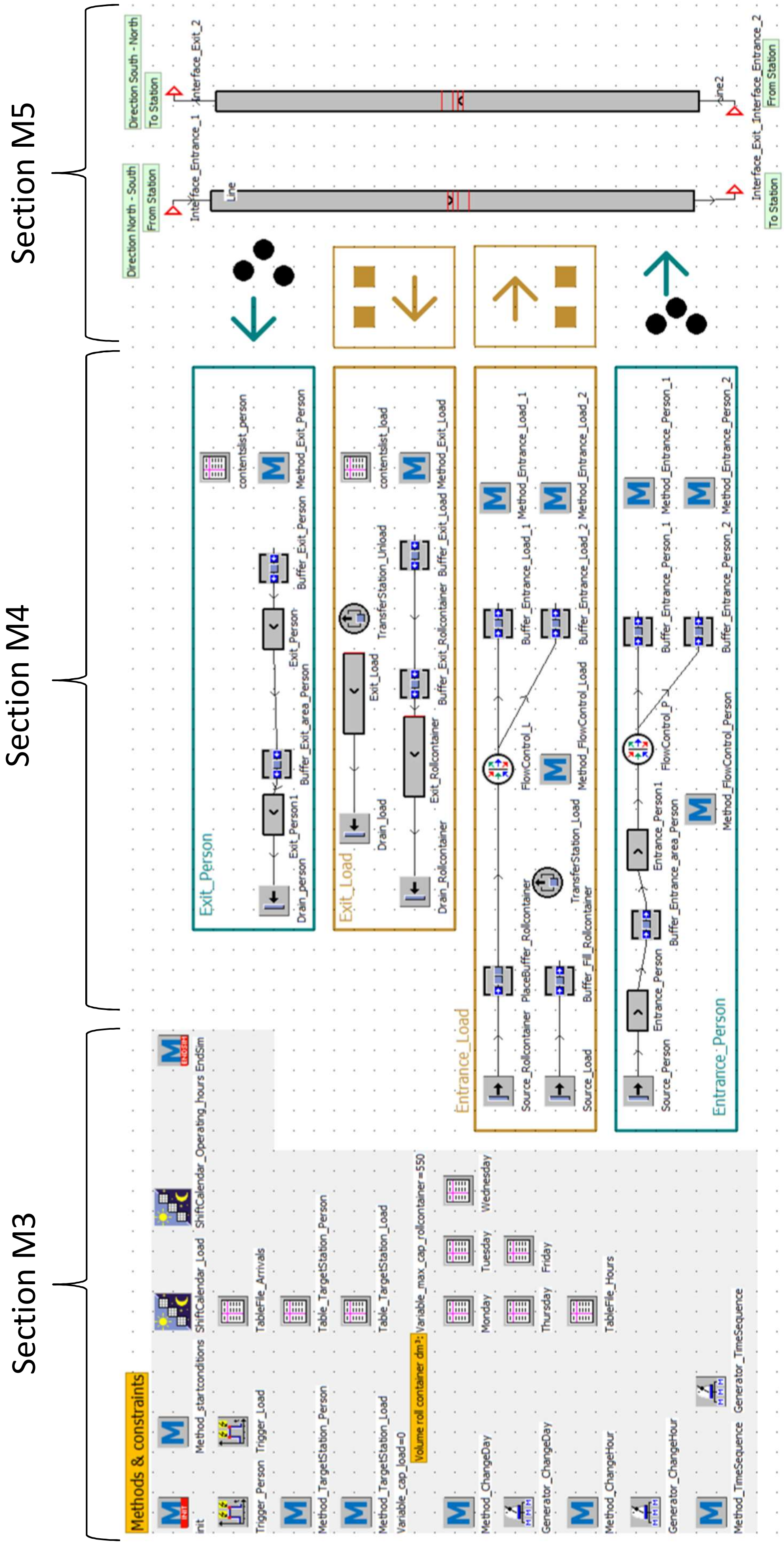


Figure 4-14: The initial model with sectors M3, M4 and M5

A more detailed description is omitted in this context since this was already done in the master thesis of "Urban Ropeway" [Nad18]. In the following chapters, therefore, the individual extensions and their monitoring, as well as the modification of the existing model, are discussed.

4.8 Implementation and Testing

To understand how changes, affect the simulation result, the project has been broken down into smaller subprojects and then incorporated step by step. After each implementation, the new model is tested, to what extent the new model initial model differs.

The conceptual model must be implemented in the simulation software used. The prerequisite for the implementation is that the modeller has fully understood the system to be mapped and can structure it well. Depending on the simulator, the type of implementation takes place via the parameterisation of building blocks and via the input of networks or programming with a simulation language. The effort required for implementation can vary greatly, depending on the model concept and the type and user-friendliness of the simulation tool used. The range extends from the simple

In most cases, strategies and specific control rules must be newly created (usually programmed). The documentation of the model in the source code should also be part of the implementation, followed by the control of the created software model. The syntactic check of the program is usually done by the modelling system itself. The logical check to ensure that the simulation model created is a sufficiently accurate representation of the original system is carried out with the steps of verification and validation.

4.9 Model verification

4.9.1.1 Model Verification

In the verification phase, it is ensured that the simulation program is syntactically correct and the logical functionality is properly implemented. [Küh06] According to the urban ropeway system, it is checked if the adaptation fulfils the new requirements. Since the main parameters between the initial model and the adapt model were not changed, the output data must be approximately identical between the models.

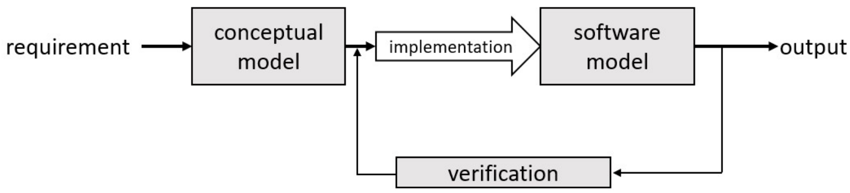


Figure 4-15: Model verification process [Küh06]

As shown in Figure 4-15 verification is checking, if the generated software model characterizes the conceptual model outputs.

Following the instructions of Kühn [Küh06], the following methods were used to verify the ropeway model:

- Plant Simulation debugger, to detect programming errors
- Plant simulation animations, to analyse congestions and paths of individual elements
- Comparison with the initial model, which is tested with the same parameters to conclude any deterioration.
- Comparison with previously created Excel tables

4.9.2 Plant Simulation debugger

The debugger makes it possible to analyse the simulation more precisely at specific points, using so-called “breakpoints”. It also allows running through certain program lines or methods in "step by step" mode, allowing to detecting programming errors such as wrong names or miss calls of methods.

Since the debugger is a central part of the Plant Simulation software, it has been in use from the first use of the program to the final version.

4.9.3 Plant simulation animations

Plant Simulation animation makes it possible to reproduce various elements in digital form. Elements such as gondolas, roll containers and workers are displayed. When the simulation is stopped, each element can be evaluated individually and tracked through the entire simulation process.

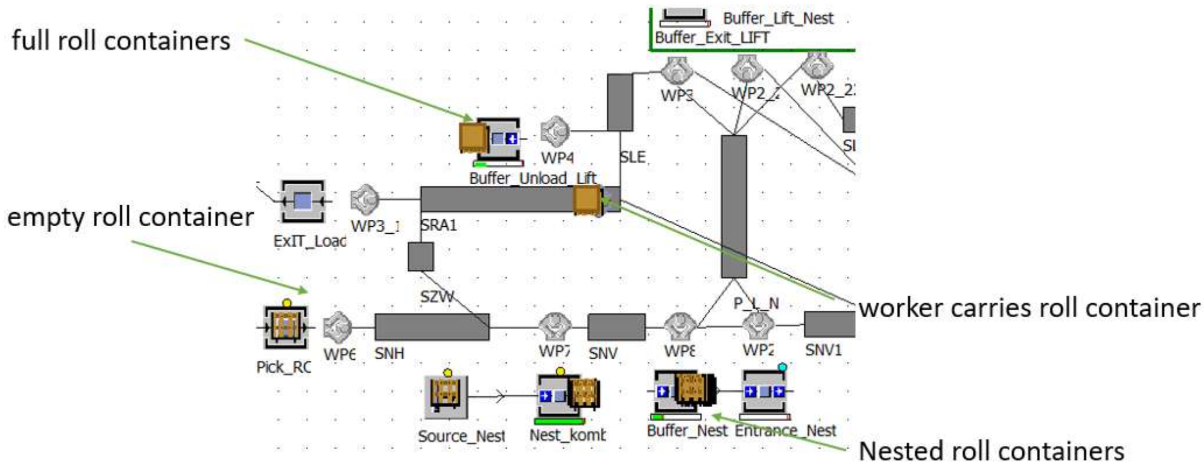


Figure 4-16: Detailed view from a plant simulation animation evaluation

4.9.4 Comparison with the initial model

During the first implementation phases, the main parameters were not changed compared to the initial model. Therefore, before implementing the extension, the simulation was tested, which tapped the main parameters and then compared with those after implementing the extensions. Except for the changes during the random and percentage distribution as well as the variable filling of the roll container, all values had to be approximately identical. If this was not the case, it had to be repaired accordingly. If this was not possible, the change was noted accordingly and further compared with these values.

4.9.5 Comparison with previously created excel tables

Since a first software model from the previous master's thesis was already developed, an excel list was created to estimate the expected expenses. This list made it possible to detect implausible results immediately.

The models were also compared with the simulation experiments of the previous master thesis.

4.10 Redefinition of the initial model

4.10.1 Model adaptions

It is much easier to debug a simplified, divided, step-by-step model with minimal details than it is to debug a large and complex model. The following chapter provides a breakdown of all enlargements and explains the specific implementation processes simplified.

The following chapters describe the specific implementation processes simplified. The exact description of each element and used method are displayed in more detail in chapter: 7.1: "Description simulation model" on page 97.

4.10.1.1 Implementation of the redefined parameters

In comparison to the previous Master's thesis [Nad18], some new requirements are assimilated by expert interviews with IBV-Fallast and the ITL Institute of the Graz University of Technology.
The first step in the implementation process was, therefore, to incorporate the defined operating parameters into the initial model (see 3.1.3 Operating parameters on side 29).
Adjustments such as the location of the distribution station and the cityhub were determined. Its throughput times, the arriving goods and time intervals are set according to the requirements.
The defined loading and unloading of the gondolas were also unilaterally defined in the course of the project. Therefore, the required methods were added and no longer needed were removed from the model (see chapter 3.2.3: "Initial condition - Station layout" on page 33).
The new model was then compared to excel lists, to check the plausibility of the results. The newly obtained model then serves as the base for further adaptations.

4.10.1.2 Extension to a customizable rope speed

As one of the first elementary changes in the model, the possibility of changing the rope speed hourly has been added. The primary methods and lists are illustrated in Figure 4-17.

- Section D1 shows all elements, which are responsible for storing the read in rope speed times at a specific time. The read process is executed via the "Initial methods" when the simulation is started. A worksheet of the excel list "Ropeway_parameter_v2_ab" is read in which the respective rope speeds are stored in.

- Section D2 includes the necessary elements to change the time hourly and define time steps.

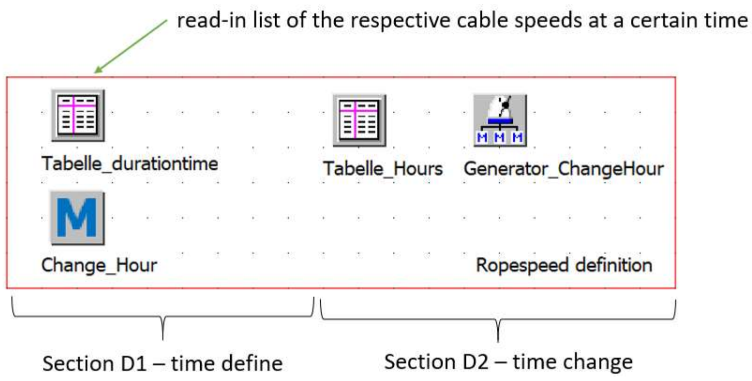


Figure 4-17: Ropespeed definition

4.10.1.3 Extension to numbered transport gondolas

The next extension was the numerical marking of the transport gondolas. The new requirements include returning the empty roll containers from the distribution station to the cityhub. This requirement made it indispensable to reserve individual gondolas only for this purpose. It was decided to do this periodically. The existing structure of the loading and unloading methods, as well as the odd number of transport gondolas in total, made it necessary to define the empty roll container cycle based on the particular gondola numbers.
In Figure 4-18 supplemented methods and variables are mapped.

- <u>Section D1</u> map all the required methods for the counting process, including the essential variables.

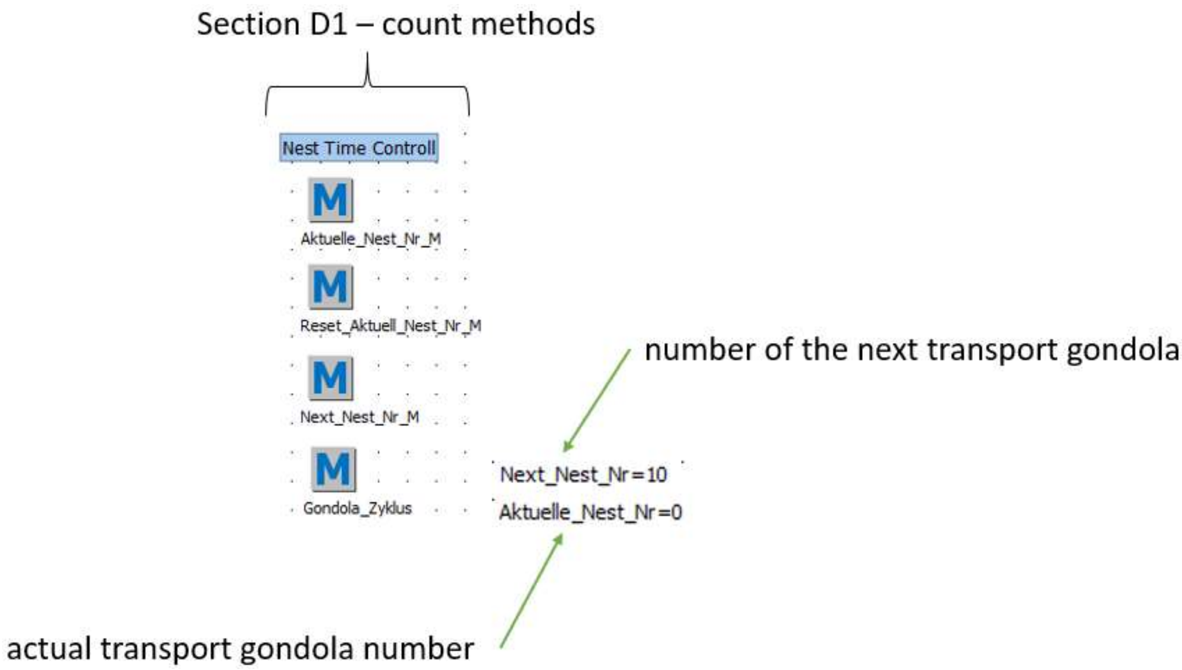


Figure 4-18: Methods for the transport gondola counting process

The transport gondolas are adapted with a leading number, a "Nest_Nr" when they are generated. If a gondola triggers a counting method, the number is recorded and compared. If it meets the current settings, it is either loaded or unloaded with regular roll containers, or loaded/unloaded with nested, empty roll containers.

4.10.1.4 Adapting gondola creation

In the initial model, the simulation generates gondolas from both directions. So, from S1 and S11(cityhub) which are the end stations in both directions (or diverting stations for the gondola system). In addition, every time a gondola pass S1 or cityhub (S11), a method checks whether it is filled or empty. If it is empty, it determines whether the current gondola cycle (in our case 5 to 1) is still being complied with or whether the type of gondola has to be changed.
As a result, transport gondolas could become passenger gondolas and vice versa, to fulfil the correct gondola cycles (monitored via the method: “Method_Set_Gondolatyp” which continuously compares and redefines the gondola type).

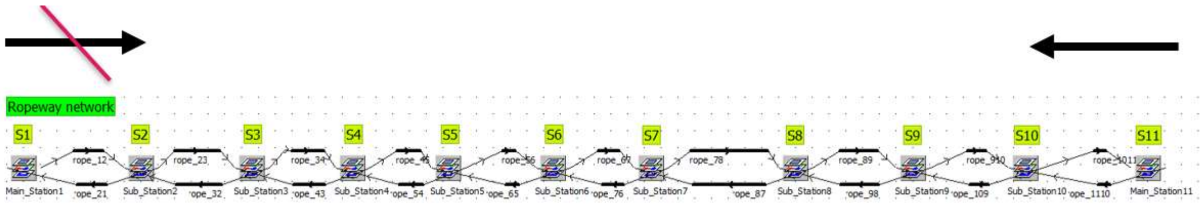


Figure 4-19: Creation direction of the gondolas in the new model, one way

Consequently, the system has been changed so that the gondolas are now only fed from one station, as pictured in Figure 4-19. The definition of the individual types now only takes place at the beginning of the simulation and is accessible throughout the entire simulation period. This setting also leads to more realistic simulation, as the gondola types cannot be changed in the real model.

The disadvantage of this change is the cycle error in the gondola sequence. Due to rounding, inaccuracies lead to a cycle error between the last and the first gondola. The time interval between gondolas is at this point, 336 seconds instead of 252 seconds. Which, however, would occur at the real model as well. Hence, this deviation is treated as a minor downside.

- Section D1 in Figure 4-20 picture the essential elements to generate, set and count the requested gondola distribution.

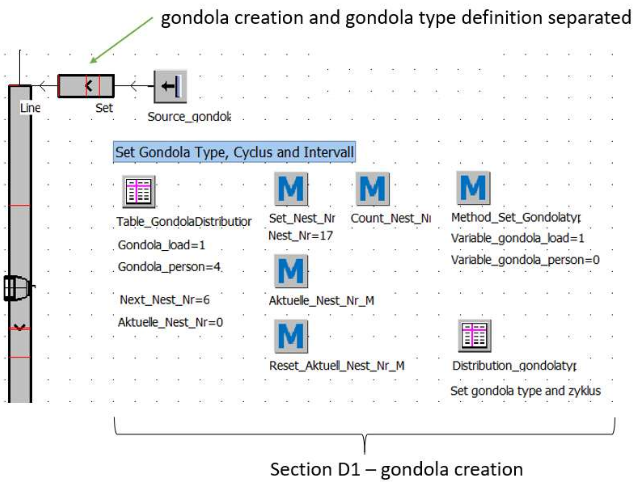


Figure 4-20: Detail of gondola generation and typesetting

4.10.1.5 Worker in the cityhub on the gondola level

The next expansion step was the implementation of a worker at the gondola level in the city hub. Previously, the process had been simulated and represented by simple element blocks and time buffers.
It is now supplemented by following additional elements (Figure 4-21):

- worker
- worker path
- workplace and
- processing station

The following Figure 4-21 displays one of the first versions of this implementation process.

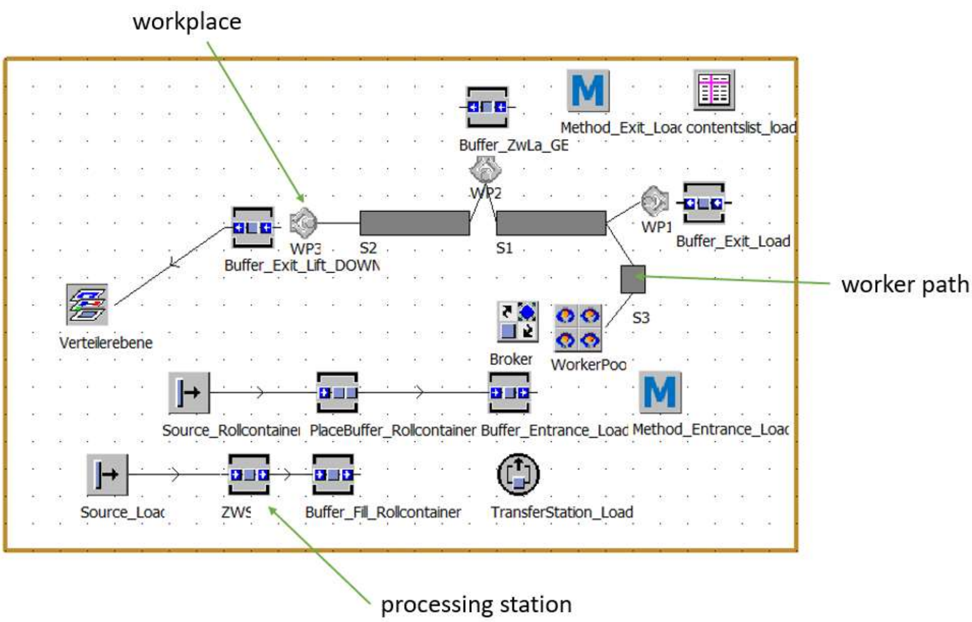


Figure 4-21: Work area in the gondola level in the cityhub (first phase)

It was not possible to map the entire worker area immediately, as it is the most complicated element. Therefore, step by step, a section was extended until the final version could be reached, as displayed in Figure 4-22.

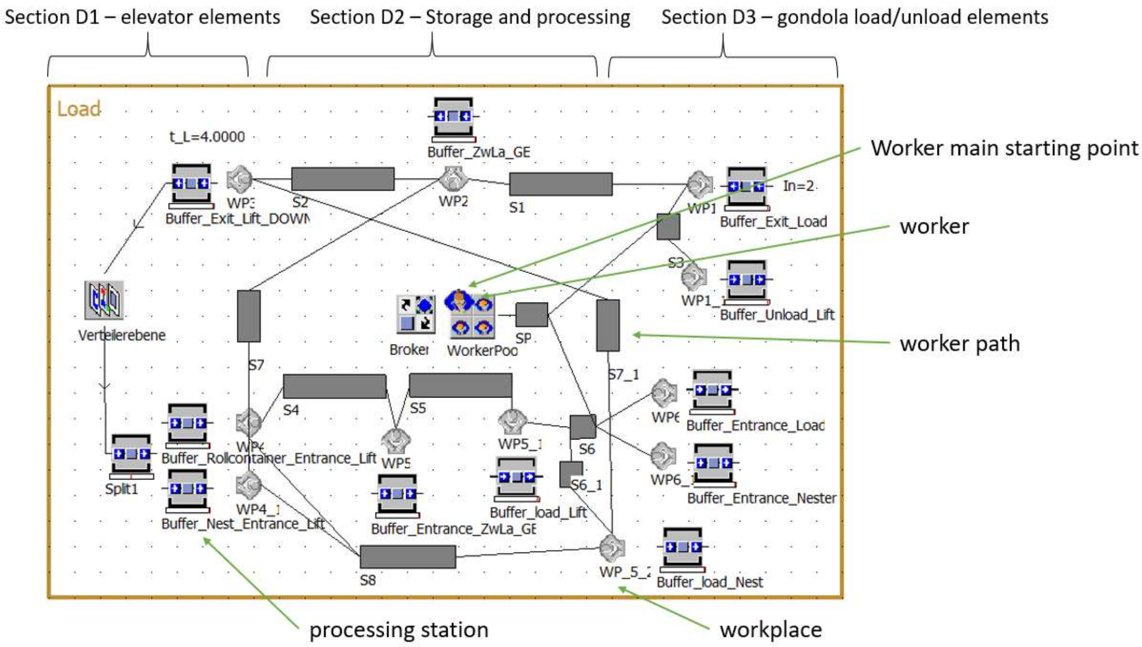


Figure 4-22: Work area in the gondola level in the cityhub (final version)

- <u>Section D1</u> contains the necessary elements for the visualisation and handling of the transfer of the roll containers from the gondola level to the elevator (see in detail at chapter 4.10.1.8: “Simulation model extended by the elevator” at page 68).

- <u>Section D2</u> illustrates mostly all the intermediate storage points (Buffer) and connecting paths shown.

- <u>Section D3</u> displays the required processing stations to load and unload the incoming gondolas.

4.10.1.6 Extension the distribution level in the cityhub

Next, the distribution level is created in the cityhub. This level is the area in which the roll containers arrive, are stored temporarily and then transferred via lift to the gondola level.
As shown in Figure 4-23, a substantial increase in the model was started. It turned out that for the generation of the parcel’s additional buffers (shown in the figure as “temporary storage”) are needed. Every hour a new simulation step is called up in the system. Thus, a new number of packages is released for the single hour, i.e. brought into the simulation. Via the daily time-variation curve and read in through the worksheet in excel file “Ropeway_parameter_v2_ab”. If now the primary storage should be just occupied, and not all packages of the previous hour were processed, the remaining roll containers would be deleted. To prevent this, the process block "ZWS" was inserted, which can take up the unprocessed roll container and store them until there is enough capacity to handle their transport.

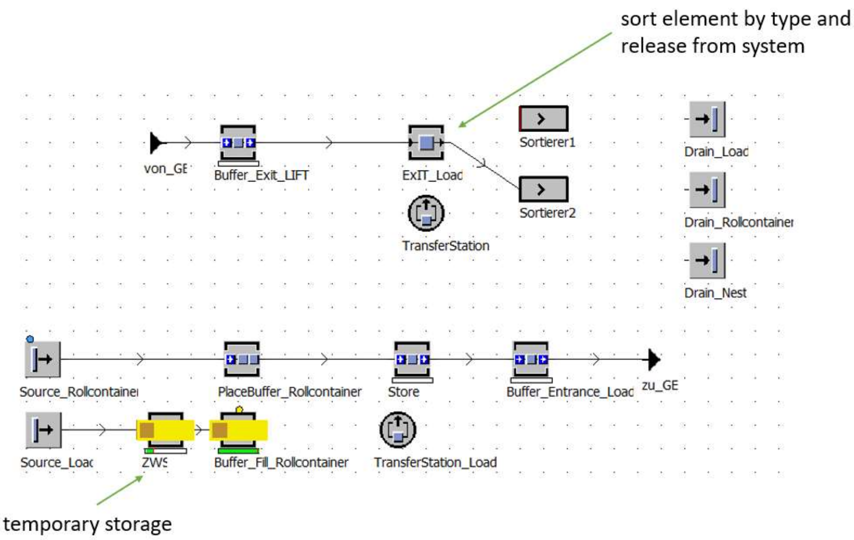


Figure 4-23: Work area on the distribution level in the cityhub (implementation phase)

4.10.1.7 Worker in the cityhub on the distribution level

After completion of the implementation of the distribution level, it was adapted for the use of a worker, as shown in Figure 4-24.

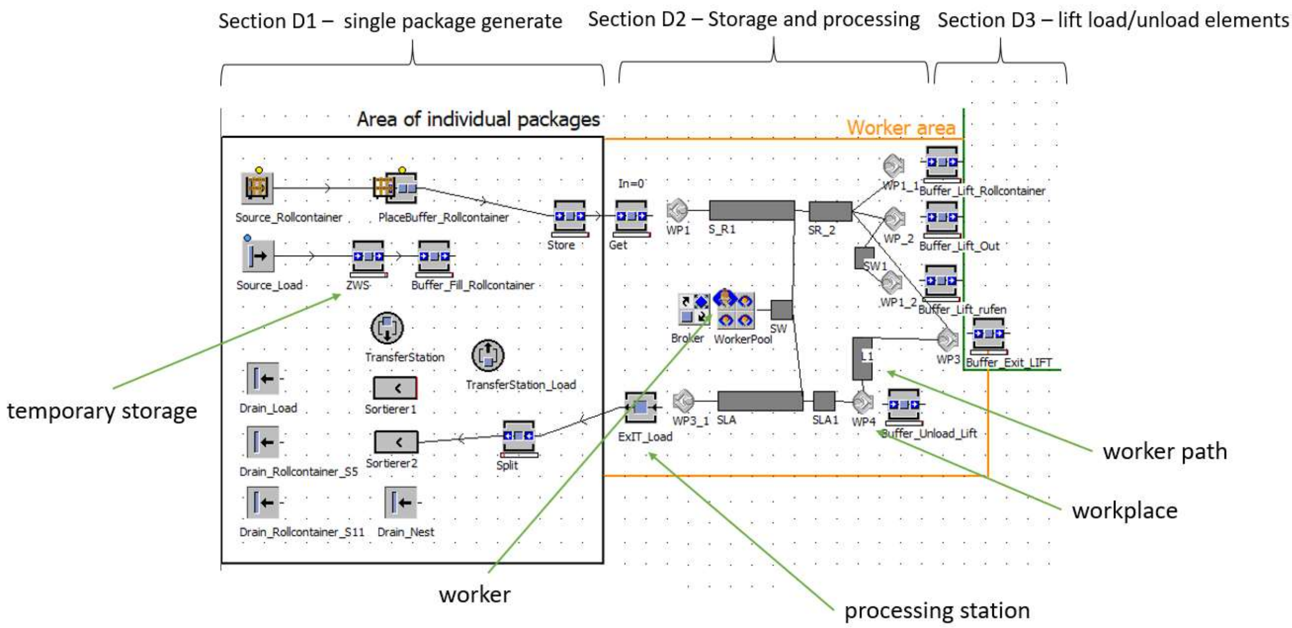


Figure 4-24: Work area on the distribution level in the cityhub (final version)

- Section D1 summaries all elements which are compulsory for the rationing of the single packages. As already explained in the previous chapter, this is relevant for the simulation, but not for the system. The system boundary is therefore, between section D1 and D2.

- Section D2 contains intermediate storage points and connecting paths shown similar to them at the gondola level.

4.10.1.8 Simulation model extended by the elevator

Another requirement included a transport lift to connect the two levels. The next step was thus, to create a lift, which transports the roll containers (filled and nested) between the levels, displayed in Figure 4-25.

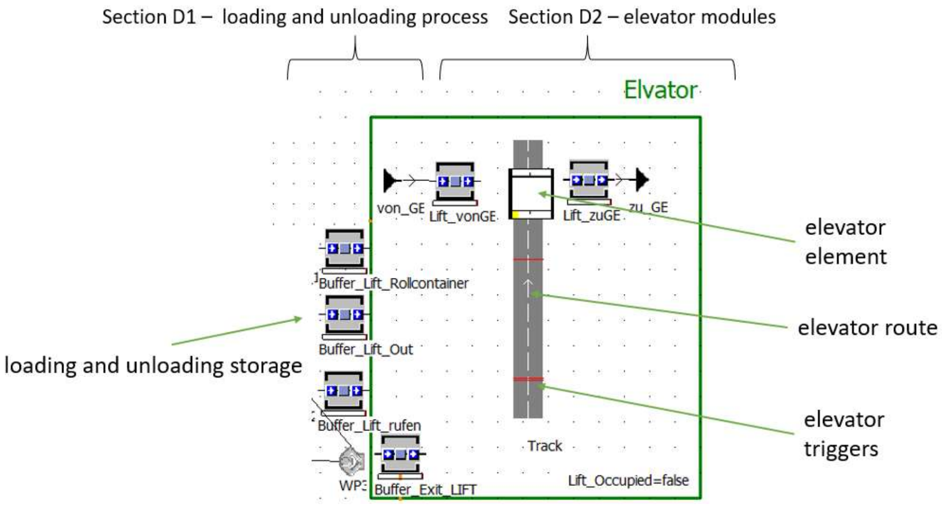


Figure 4-25: Elevator modules at the cityhub (final version)

- <u>Section D1</u> includes the elements to allow the display of the load and unload process of the elevator. It also contains common storage spaces of the load and unloads of the elevator section.

- <u>Section D2</u> contains the essential elevator components, like the elevator path and the elevator cabin as well as the process elements to allow a connection to the gondola level.

4.10.1.9 Worker in the distribution station on the gondola level

The base for the gondola level of the distribution station was the cityhub. This level was copied and extended with the areas for the empty, nested roll containers (red area), as seen in Figure 4-26.

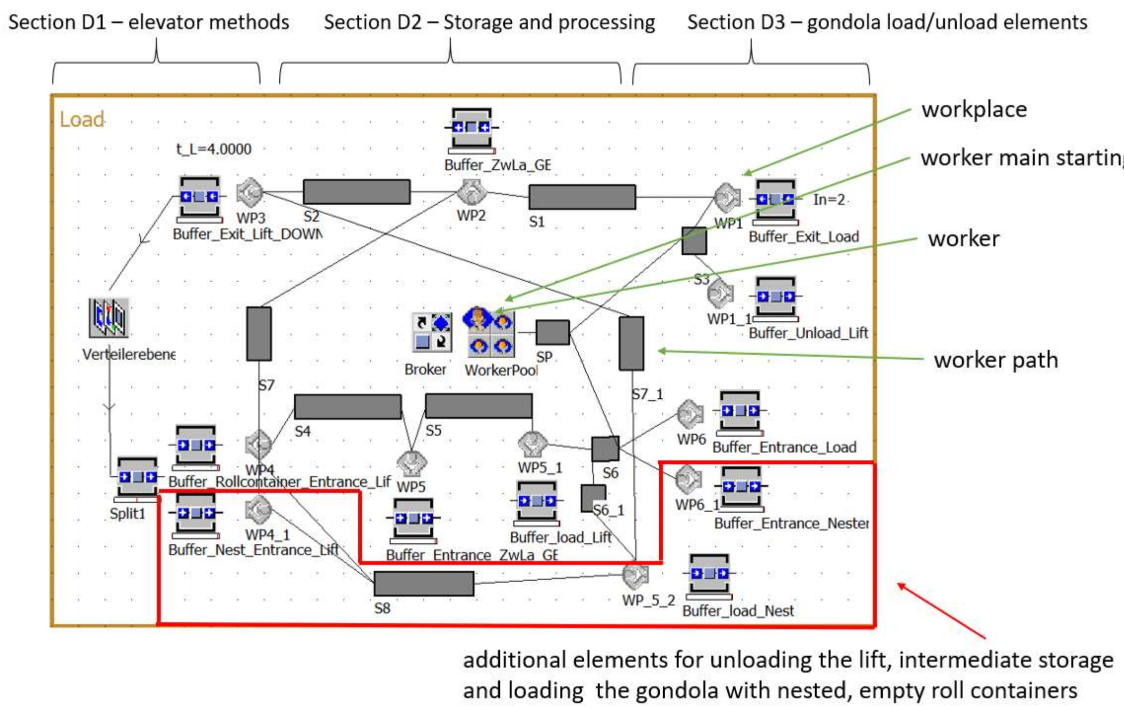


Figure 4-26: Work area in the gondola level in the cityhub (final version)

Besides, this level consists of precisely the same structure as the one at the cityhub:

- Section D1 contains the obligatory elements for the visualisation and handling of the transfer of the roll containers from the gondola level to the lift.
- Section D2 shows mostly all the intermediate storage points and connecting paths.
- Section D3 displays all the required processing stations to load and unload the incoming gondolas.

A Sub_Station, which is not used as a distribution station is not illustrated. These were inherited unmodified and can be seen in the master thesis from Mr. Naderer.

4.10.1.10 Expand distribution level and worker in the distribution station

As aforesaid the case with the gondola level, the layout of the distribution level is also copied and expanded to include the additional areas and storage facilities for returns, see Figure 4-27.

- Section D1 is the layout area in which the roll containers arrive from the cityhub and are unloaded. Unloading is performed by a method, since it is outside the system boundary and therefore not relevant for the defined system. The packages are then deleted and evaluated. The empty roll containers are returned back individually to the system after a defined processing time, collected and nested through the workers (red area) in sector D2. The return process then takes place similarly to the regular roll containers, only instead of four these proceed in groups of two.

- Sector D2 is the same as in the cityhub, with customisations for the new paths and the additional tasks.

- Sector D3 is principally the same process as the sector at the distribution level from the cityhub, where the returns are generated, based on the daily time-variation curve and read in via the worksheet in the excel file "Ropeway_parameter_v2_ab".

- Section D4 contains the required elements for the visualisation and handling of the transfer of the roll containers from the gondola level to the lift

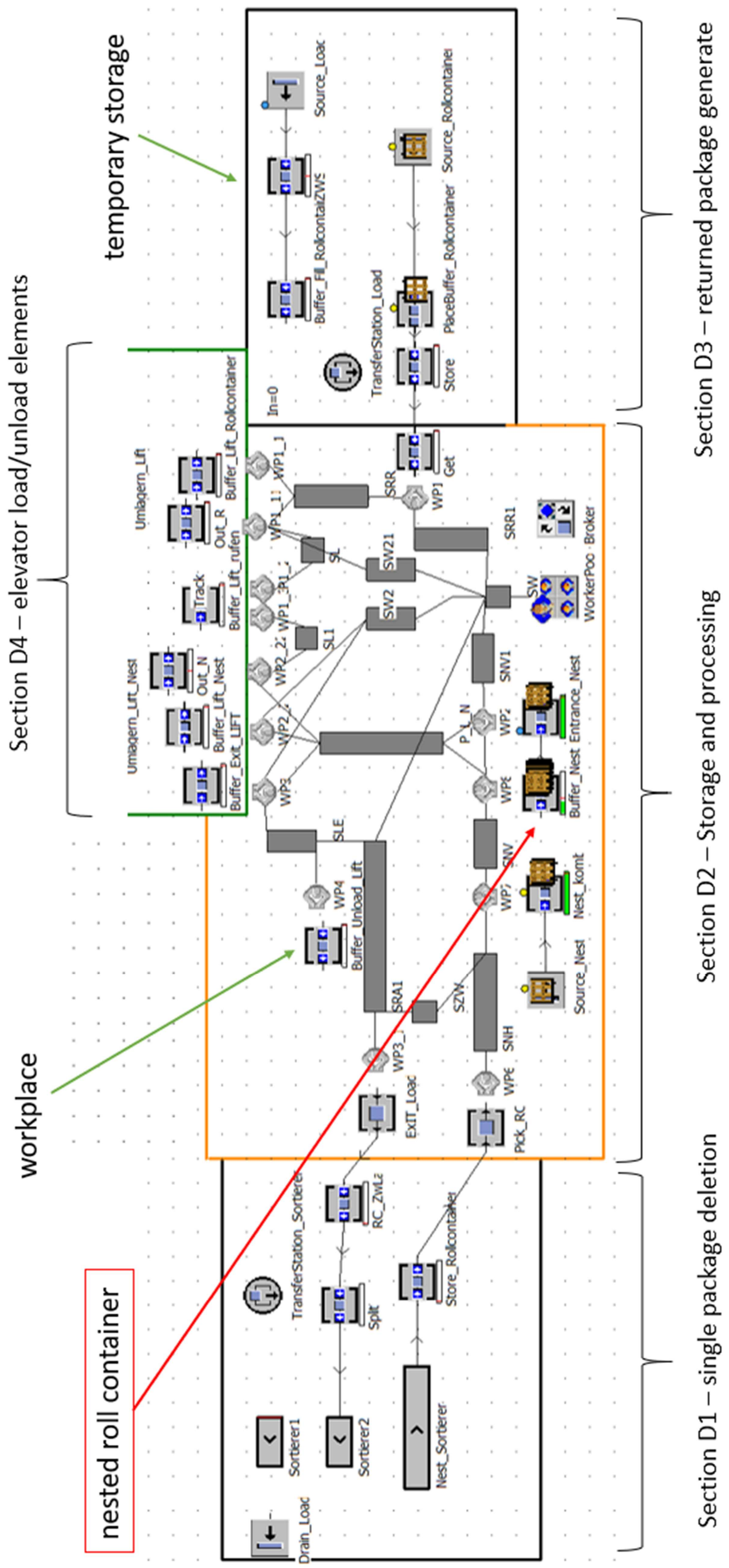


Figure 4-27: Work area on the distribution level in the distribution station (final version)

4.10.1.11 Expansion of an elevator in the distribution station

The elevator in the distribution station consists of the same elements as the one in the cityhub, see Figure 4-28. However, it was extended by a central storage place for the nested roll containers and modulated accordingly. The working principle instead remains unchanged.

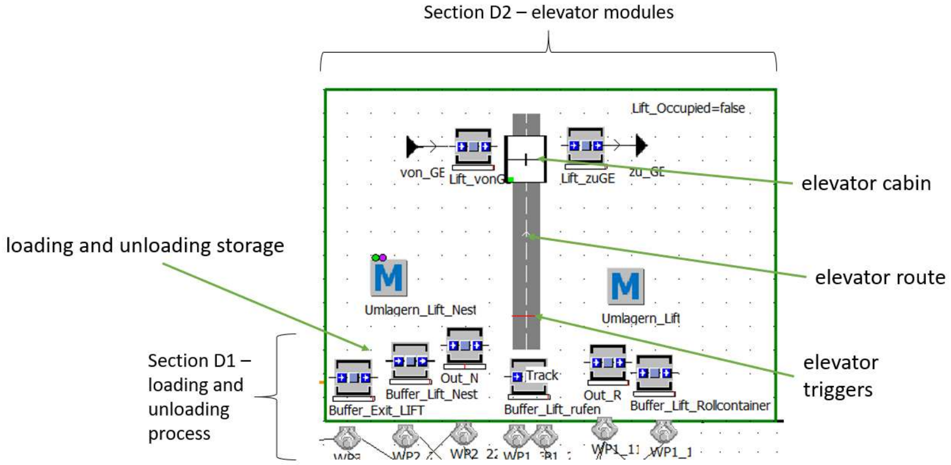


Figure 4-28: Elevator modules at the distribution station (final version)

- Section D1 includes all the necessary elements to allow the display of the load and unload process of the elevator. It also contains common storage spaces of the load and unloads of the elevator section.

- Section D2 contains the essential elevator components, like the elevator path, the elevator cabin as well as the process elements to allow a connection to the gondola level.

4.10.1.12 Implement evaluation methods for the simulation model

As the last adjustment, various evaluation methods were added. Previously defined areas and processes were monitored during the entire simulation period using diagrams, charts and tables.

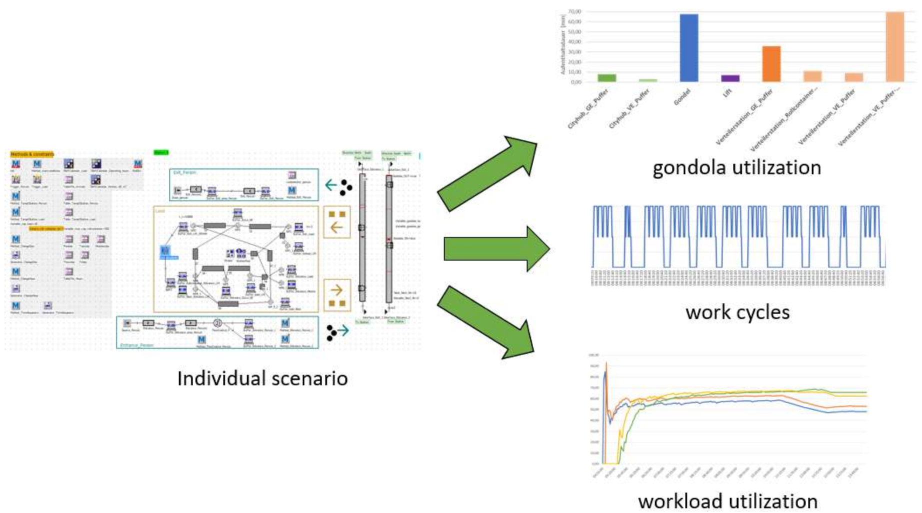


Figure 4-29: Evaluation of various areas for the individual scenario

The main evaluated areas:

- Layout and Processes [-]
- The volume of goods [#/time]
- Throughput of persons [persons/time]
- Travel time of the persons [time/person]
- Waiting-time changes of the persons [time]
- Buffer areas [m^2]
- The utilisation of logistics staff [%]
- Working routes of the logistics staff [m]
- Areas of work of logistics staff [-]
- Working times/shift times of logistics staff [time]
- Throughput times of roll containers [time]
- Transport times of roll containers [time]
- Quantity required for roll containers [#]

5 Evaluate and Analyze

The following chapter analyses and evaluates one of the defined scenarios. The main topics and outcomes are briefly reviewed.

In order to gain a better overview of which data and parameters have been calculated and which have been defined in advance, they are presented in tables in two variants:

Table 5-1 illustrates which parameters have been predefined. (Simulation relevant assumptions made in advance, such as rope speed or amount of goods)

Table 5-1: Table type "own parameters"

Table 5-2 illustrates which parameters and results we have received from the particular simulation scenario (e.g., number of roll containers, times, ...)

Table 5-2: Table type "Simulation results"

In the following subchapters, only “Scenario 4: ECO Scenario 2025 1-1” will be explained in more detail in the evaluation process in the following section. The remaining scenarios are appended and evaluated in the same way and shown in the appendix.

See the Appendix on page 97 for:

- Scenario 1: ECO scenario of pure passenger transport (basis)
- Scenario 2: ECO scenario 2018 1-1
- Scenario 3: ECO scenario 2018 2-2
- Scenario 5: ECO Scenario 2025 1-1

5.1 Scenario 4: ECO Scenario 2025 1-1

In the following subchapters, ECO Scenario 4: 2025 1-1 is evaluated in detail. The other scenarios are assessed to the same scheme.

5.1.1 SC 4: boundary conditions - system parameters

Table 5-3: describes the cable car-specific input values for this simulation scenario:

Table 5-3: Boundary Conditions - System Parameters SC 4: ECO Scenario 2025 1-1

Boundary conditions - system parameters: SC 4: ECO Scenario 2025 1-1		
Network Structure		
city hubs	1	
distribution stations	1	
Station Layout		
station layout 1	Serial arrangement: person exit - person entry	
station throughput time with goods handling	88	sec
station throughput time without goods handling	44	sec
System Parameter		
operating time: Persons	Start 5:00 End 23:00	
operating time: Goods 1st cycle	Start 04:55 End 14:00	into the city (CH to VS)
operating time: Goods 2nd cycle	Start 14:30 End 17:00	from the city (VS to CH)
gondola cycle	42	sec
rope conveying speed	7,5	m/s
conveying speed rope (stations)	0,2	m/s
gondola acceleration	1	m/s^2
gondola deceleration	1	m/s^2
transport capacity passengers	35	per gondola
transport capacity roll container	4	per gondola
transport volume roll container	550	dm^3
passenger gondolas on the system	87	gondola
Transport gondolas in the system	15	gondola
Empty roll container transport gondolas in the system	2	gondola

Table 5-4 shows the target probabilities of individual persons for a particular station. These probabilities are identical for all scenarios and are charted in Chapter 3.2.5.

Table 5-4: Input parameter persons: SC4: ECO Scenario 2025 1-1

Boundary conditions - input parameters: SC 4: ECO Scenario 2025 1-1		
Distribution of persons		
target probability matrix	charted in Table 3-7	%
number of persons	charted in Table 3-6	persons

Table 5-5 shows the parameters for Cargo transport. Specifically, the time at which the parcels are started to be transported to the respective station. The arrival of the respective individual packages is always assumed one hour in advance in order to have enough material in stock at the start of the operation to enable continuous work.

Table 5-5: Boundary conditions - input parameter goods: SC 4: ECO Scenario 2025 1-1

Boundary conditions - input parameters: SC 4: ECO Scenario 2025 1-1		
Total goods per station		
S11- cityhub south (Webling)	10750	#
S5 - Andreas Hofer Platz	1609	#
Distribution - Goods - into the city (CH to DS)		
S11 - Goods 1st cycle	Start 05:00 End 14:00	
S11 - Goods 2nd cycle	Start - End -	Not used for this scenario
Distribution of goods into the city (CH to DS)		
quantity of goods	see Table 5-6	
daytime curve	see Diagram 5-1	
Distribution - Goods - from the city (DS to CH)		
S5 - Goods 1st cycle	Start 14:30 End 17:00	
S5 - Goods 2nd cycle	Start - End -	Not used for this scenario
Goods distribution - from the city (DS to CH)		
quantity of goods	see Table 5-7	
daytime curve	see Diagram 5-2	

5.1.2 Time-variation curve goods - cityhub

The assumed day curve for the individual arriving packages in the cityhub was chosen in such a way that at the start of the shift at 05:00 the workers already have enough roll container containers available to enable continuous working. The first arrival of the individual packages (%) is set at 04:00 and will be continued until 10:00 a.m., evenly distributed. The curve shows only at what time individual packages arrive and how many, it does not illustrate their further processing time or storage in the later system. The same percentage distribution was used as in scenarios 2 and 3, only the quantities were adjusted to 2025.

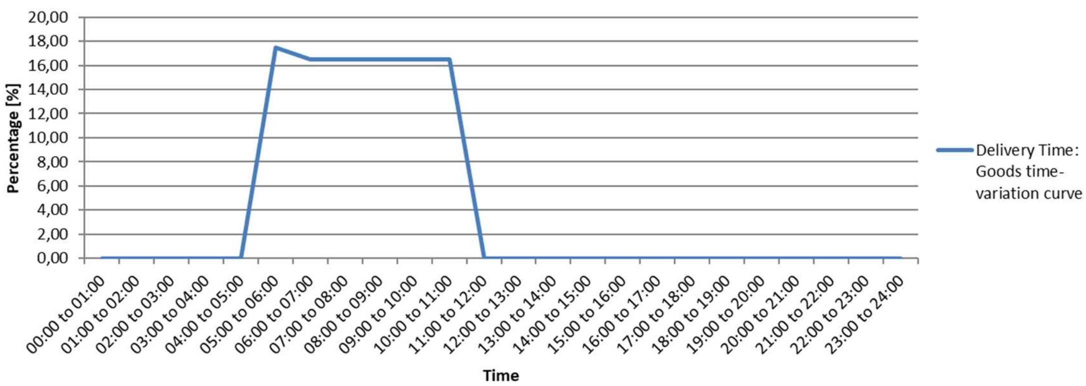


Diagram 5-1: Time-variation curve of the individual arriving packages in the cityhub

As a supplement to more accurate documentation, Table 5-6 illustrate how many individual packages (#) arrive in the system at that time (operating time [hh:mm:ss]). The number of incoming packages (quantity of goods) is then distributed evenly from the starting hour (operating time) to the 59th minute. However, it is started here to convey material one hour before the start of operation in order to have sufficient buffer material available at the start of the operation. The times can deviate strongly from the actual time of use.

Table 5-6: Distribution - Goods - in the city (CH to VS)

Goods distribution in the city (CH to VS): ECO scenario 2025 1-1	
operating time [hh:mm:ss]	quantity of goods
00:00:00	0
01:00:00	0
02:00:00	0
03:00:00	0
04:00:00	1881
05:00:00	1774
06:00:00	1774
07:00:00	1774
08:00:00	1774
09:00:00	1774
10:00:00	0
11:00:00	0
12:00:00	0
13:00:00	0
14:00:00	0
15:00:00	0
16:00:00	0
17:00:00	0
18:00:00	0
19:00:00	0
20:00:00	0
21:00:00	0
22:00:00	0
23:00:00	0

5.1.3 Time-variation curve goods - distribution station

Similar to the daily curve for the cityhub, the arrival of the individual packages is also assumed in the distribution station one hour before the start of the return shipment (13:00-14:00). The diagram also shows only the arrival times and their quantity in per cent. The later use or storage is not shown here. In comparison to scenarios 2 and 3, the individual packages (roll containers) must be delivered at a later point in time.

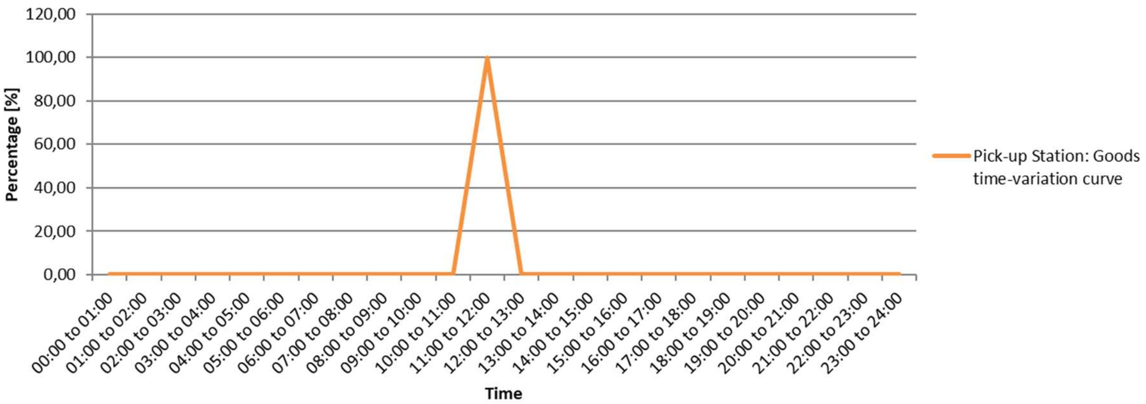


Diagram 5-2 : Time-variation curve of the arriving packages in distribution stations

The transport of individual packages from the city is only possible once the last roll container has arrived from the cityhub. As in the previous table, Table 5-7 illustrate how many individual packages (#) arrive in the system at that time (operating time [hh:mm:ss]). The number of incoming packages (quantity of goods) is then distributed evenly from the starting hour (operating time) to the 59th minute. However, it is started here to convey material one hour before the start of operation in order to have sufficient buffer material available at the start of the operation. The times can deviate strongly from the actual time of use.

Table 5-7: Distribution - Goods - from the city (VS to CH)

Distribution of goods from the city (VS to CH): ECO scenario 2025 1-1	
operating time [hh:mm:ss]	quantity of goods
00:00:00	0
01:00:00	0
02:00:00	0
03:00:00	0
04:00:00	0
05:00:00	0
06:00:00	0
07:00:00	0
08:00:00	0
09:00:00	0
10:00:00	0
11:00:00	0
12:00:00	0
13:00:00	1609
14:00:00	0
15:00:00	0
16:00:00	0
17:00:00	0
18:00:00	0
19:00:00	0
20:00:00	0
21:00:00	0
22:00:00	0
23:00:00	0

5.1.4 SC 4: boundary conditions – workers

In the following Table 5-8 the general parameters of the workers in the system. The working times shown are shift times (including theoretical breaks).

Table 5-8: Boundary conditions - Workers: SC 4: ECO Scenario 2025 1-1

Boundary conditions - Workers: SC 4: ECO Scenario 2025 1-1		
General information		
Number of workers per level and station	1	
carrying capacity	1	#
speed	1	m/s
effectiveness	100	%
Working hours		
cityhub		
1st shift	Start 4:50 End 17:00	
2nd shift	Start - End -	Not used for this scenario
shift times	12:10	h
distribution station		
1st shift	Start 5:20 End 16:10	
2nd shift	Start - End -	Not used for this scenario
shift times	10:50	h

5.1.5 SC 4: boundary conditions – nested roll container

Roll container containers are transported from the cityhub to the city. There they are unloaded and processed. In order to prevent excessive accumulation of roll containers, they are combined into so-called "nests".
For their transport, transport gondolas are skipped (not filled) in the city hub. They are loaded with empty containers in the distribution station. (Empty container gondolas). The exact procedure for the return of the empty roll container can be found in chapter 4.5 on page 45.

Table 5-9: Nests: Scenario 4: ECO Scenario 2025 1-1

Nests: Scenario 4: ECO Scenario 2025 1-1		
empty roll container gondolas		
Number of empty roll container gondolas	2	#
Empty container gondola numbers	3, 12	
Nests per empty container gondola	2	#
Roll container per Nest	12	#

5.2 SC 4: Evaluation

The following chapter analyses and evaluates scenario 4. The main topics and results are briefly discussed.

5.2.1 Mean travel time - throughput – people

For the mean travel time and the daily throughput, the values in Table 5-10 results. The throughput figures at the stations show a high number of exits in the inner-city area and at the P&R facilities outside the city. Since probabilities, random numbers and percentages are used to simulate, these times can deviate slightly from different simulation runs even with the same simulation parameters. However, these deviations remain within limits and vary only slightly between simulations.

Table 5-10: Value table for average travel time - throughput for passenger transport

Station no.	MU type	Average throughput time	Throughput
Station 1	Person	00:20:03	2783
Station 2	Person	00:14:06	925
Station 3	Person	00:11:44	2684
Station 4	Person	00:12:54	3595
Station 5	Person	00:13:27	6194
Station 6	Person	00:13:50	4338
Station 7	Person	00:12:27	3285
Station 8	Person	00:13:55	3298
Station 9	Person	00:16:20	1024
Station 10	Person	00:19:24	476
Station 11	Person	00:21:29	1878
			30480

The analysis of the mean travel time at the stations shows short travel times in the inner-city areas and an increase to the outer stations (Webling and Weinzödlbrücke) Diagram 5-3. In comparison, pure passenger transport was shown (blue bars). The combined transport (yellow bars) shows an increase in average travel times by approx. 40 seconds per station. This combination corresponds approximately to a gondola cycle.

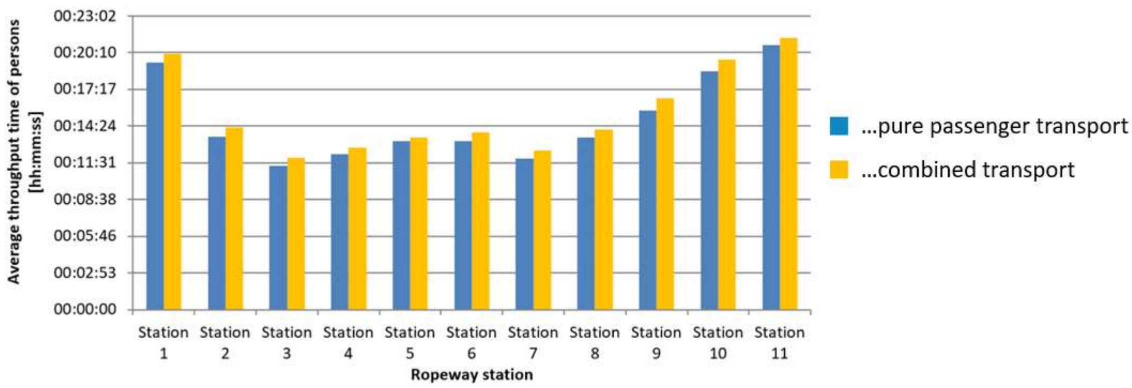


Diagram 5-3: Average travel time passenger transport, own representation [Nad18]

5.2.1.1 Detail: Number of persons - Station S11

The following Diagram 5-4 shows the arriving, waiting for persons for station S11 over the operating period. At the beginning of the steady increase, the early morning traffic and the start of work are due. The persons travel from outstations S1 and S11 to the center. The different times after work ensure that the number of people in the evening tends to flatten out. Compared to scenarios 2 and 3, there is a difference. However, this is due to the probability distribution of passenger destinations. (In each simulation run the persons are ranked (distributed) differently, so it can come to larger or smaller maximum values which in sum are identical to other scenarios).

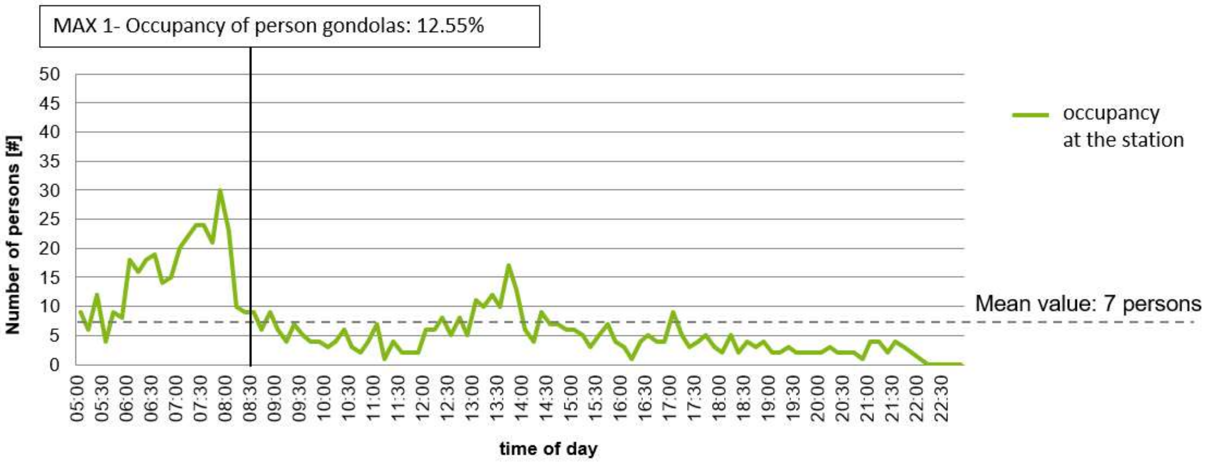


Diagram 5-4: Passenger volume in Cityhub over operating time, own rep. [Nad18]

5.2.1.2 Detail: Number of persons - Station S5

Unlike the outstations, the more centrally located stations do not have to cope with peak traffic at the start of operations. However, there is a higher number of people in the waiting areas than in the outstations over the entire operating period Diagram 5-5. The larger waiting groups tend to occur in the afternoon. (In each simulation run the persons are arranged (distributed) differently, so larger or smaller maximum values which in sum are identical to other scenarios can occur.

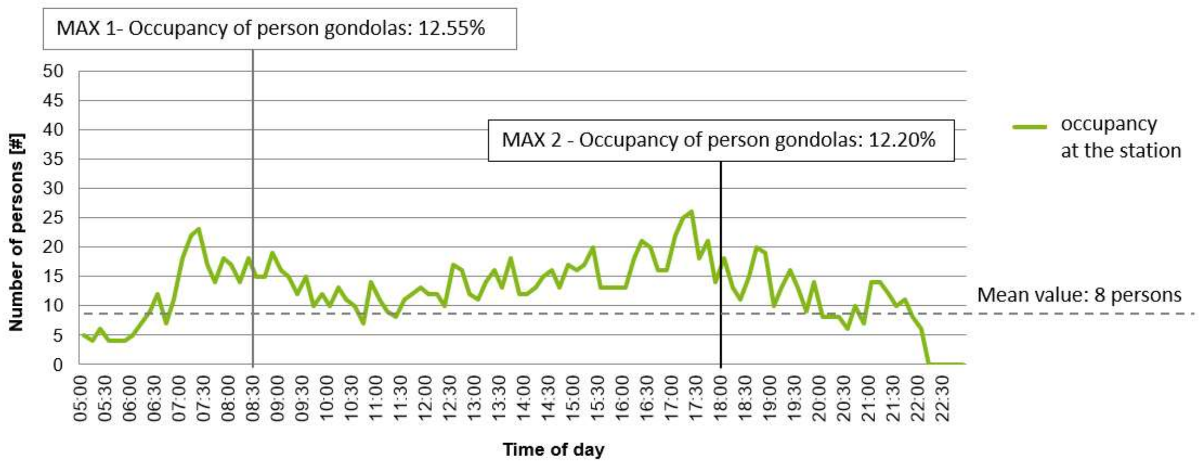


Diagram 5-5: Number of persons in distribution station over operating time, own rep. [Nad18]

5.2.2 Gondolas

5.2.2.1 Detail: gondola - waiting times

Diagram 5-6 shows the maximum occupancy of the individual gondolas of the entire operating period with regard to the corresponding gondola numbers.
The waiting time per station in the various simulation runs a maximum of two gondola cycles (84 seconds), but in most runs, one gondola cycle (42 seconds) was the maximum waiting time increase. Diagram 5-6 shows the maximum content of each gondola during the simulation period. The gondolas in the lower part of the diagram (below 5 #) are the transport gondolas and the empty container gondolas. The person gondolas which follow directly after a transport gondola are all higher loaded and better utilised, as the following ones. The reason for this is because people also arrive at the station during a transport gondola cycle, and have to await this cycle to access the next person gondola.
The average passenger gondola occupancy is just under 18 persons.

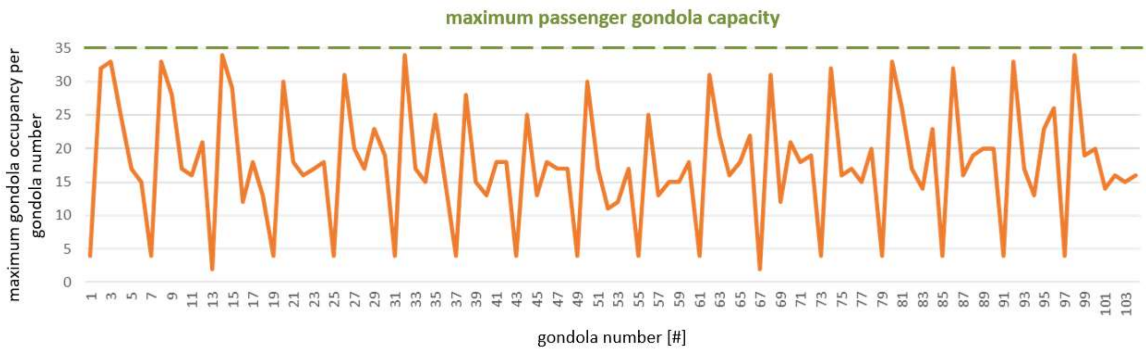


Diagram 5-6: Maximum occupancy per gondola, own rep.

In detail, the following diagram shows the direct and indirect following gondola (No. 32 and No. 33) after a non-person gondola (No. 31).

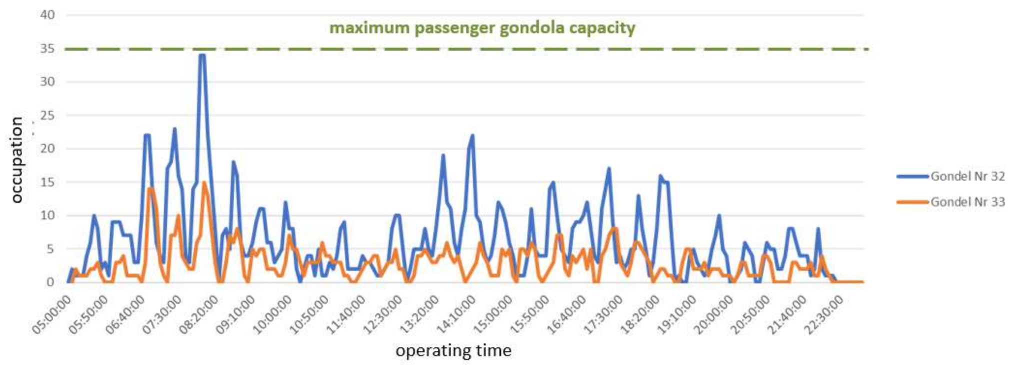


Diagram 5-7: Max. capacity of the direct and indirect following gondola of a transport gondola

The blue line shows the current content per operating time of the following gondola (No. 32) after a non-person gondola (No. 31). There is a single peak, but it does not reach the maximum capacity of the gondola. (35 persons per gondola). The orange line shows the gondola following directly (No. 33). This means that the gondola capacity is never utilised more than 50% during the simulation run. For this simulation run, the conclusion can be drawn that the increased waiting time for persons must is a maximum of one gondola cycle (42 seconds).

5.2.2.2 Detail: Gondola - capacity utilisation

In this scenario, too, the capacity utilisation of the gondola varies according to type and period of use:

- Passenger gondolas: 05:00 to 23:00
- Goods gondolas: 05:00 to 17:00
- Empty container gondolas: 06:45 to 15:50

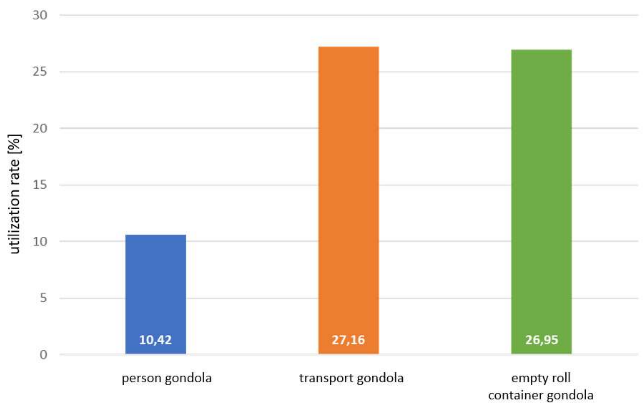


Diagram 5-8: Average gondola utilisation over the respective operating period

The utilisation of passenger gondolas does not change here compared to scenario 2. The situation is different for transport gondolas and empty roll container transport gondolas. As these are operated longer and with more goods, their capacity utilisation also increases slightly.

Of all types, passenger gondolas have the lowest load factor (10.42%). The reason for this is the high number of passenger gondolas, which, however, has a positive effect on the average waiting time.

For the transport gondolas, the respective transport route is decisive. Transport gondolas travel the longer distance unloaded (depending on the layout between S5 and S11), but the loaded distances are always fully loaded. They are therefore better utilised (27.16%).

Empty roll container transport gondolas travel a longer distance loaded, but in a shorter period. They are therefore used to roughly the same capacity as the transport gondolas (26.95%).

Diagram 5-9 shows the utilisation of passenger gondolas between two non-passenger gondolas. The direct follow-up gondola (No. 1) to a non-person gondola is the one with the highest load factor in all cases (between 17% and 25%). The subsequent indirect gondolas then never reach an average occupancy rate of more than 12%.

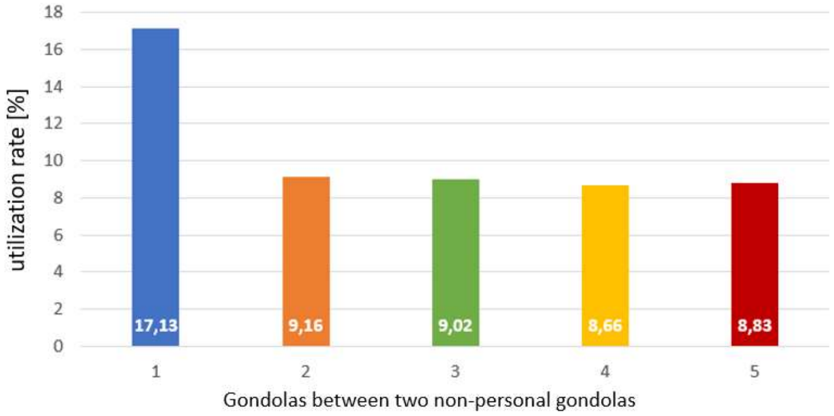


Diagram 5-9: Non-person gondola utilisation between two transport gondolas

5.2.3 Average lead time - throughput – goods

The average cycle time is used to calculate the time a load (parcel) needs to travel from start station (station) to destination station (Table 5-11). Individual parcels from the cityhub take longer to load because the layout means that they can only be loaded and unloaded in one direction (see Figure 3-10: Station layout - 4b [Nad18]). In addition, a certain number of gondolas are designed as empty roll container transport gondolas and therefore cannot be loaded with the regular return consignments. The times are identical to those from other scenarios, since only the quantity of transports changes, parameters such as transport route or gondola cycle remain the same.

Table 5-11: Value table average lead time - throughput

station	BE Typ	Average lead time	throughput
Andreas-Hofer-Platz	Load	1:04:59	1609
P&R Webling	Load	0:34:45	10750

5.2.3.1 Detail: Gondola times - general

Figure 5-1 shows how long gondolas require on average between the focused stations. As already explained above, loading and unloading in is only carried out in one direction due to the chosen layout.

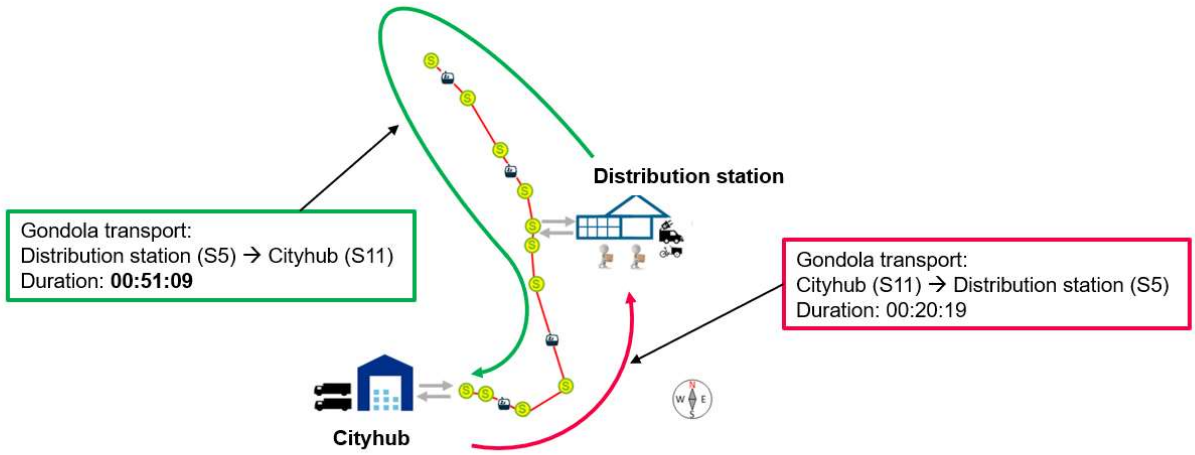


Figure 5-1: Transport times between cityhub and distribution station, own rep.

The figure above illustrates the transport times in the respective transport direction.

Table 5-12: Transport times between individual stations of transport gondolas

Definition	operating time	Definition	operating time	time required
First transport gondola leaves cityhub	05:05:51	First cityhub transport gondola reaches distribution station	05:26:10	00:20:59
First transport gondola leaves distribution station	14:43:34	First transport gondola from distribution station reaches cityhub	15:34:43	00:51:51
Last transport gondola leaves cityhub	14:05:33	Last transport gondola of cityhub reaches distribution station	14:26:03	00:20:59
Last transport gondola leaves distribution station	16:00:00	Last transport gondola of distribution station reaches cityhub	16:51:51	00:51:51

Diagram 5-10 illustrates the time at which each key gondola leaves or arrives at the station. Depending on the choice of return gondolas, the necessary goods transport may already have been completed, but the accrued roll containers still have to be returned. This can lead to longer shift times.

5.2.3.2 Detail: Empty container gondola times - general

In order to return the roll containers from the distribution station, they are combined to so-called "nests", which are then loaded into empty container gondolas. Empty container gondola parameters can be found in Table 4-2.

Table 5-13: Transport times between individual stations of empty container gondolas

definition	operating time	definition	operating time	time required
First empty container gondola leaves the distribution station	06:44:01	First empty container gondola reaches cityhub	07:35:10	00:51:51
Last empty container gondola leaves distribution station	15:14:29	Last empty container gondola reaches cityhub	16:05:39	00:51:50

The average transport time for empty container gondolas is the same as for normal return gondolas due to their structure. Diagram 5-10 shows the most critical points in time. The simulation was designed so that the last gondola is a regular transport gondola and not an empty container gondola. Otherwise, there would be unintentionally long waiting times for the worker. Since the simulation calculates with random numbers, the number of individual packages in the roll containers varies, and different end times can occur. However, the latest possible time that was reached was assumed for the shift times (arrival of the last empty container gondola in the cityhub at 16:05:39).

The blue line shows the fill level of the buffers of the individual packages of the city hub; the orange line is enlarged and shows the fill level of the buffer in the distribution station. The respective numbers are assigned in Table 5-12 and Table 5-13.

1. First transport gondola leaves cityhub
2. Last transport gondola of distribution station reaches cityhub
3. First empty container gondola leaves the distribution station
4. Last empty container gondola reaches cityhub

Diagram 5-10: Arrival and departure times of relevant gondolas, own rep.

5.2.3.3 Detail: Roll container turnover station S11

The rolling containers arriving at the distribution station are unloaded there and grouped into nests. This results in certain waiting times for the roll containers. The turnover time include the transportation between the station levels and the stations itself. Table 5-14 shows the average handling time of the respective transport directions.

Table 5-14: Detail: roll container turnover - Station S11 (Cityhub)

Detail: Roll container turnover - Station S11 (Cityhub)		
General - roll containers		
Average turnover time cityhub - cityhub	03:15:14	(hh:mm:ss)
Average turnover time distribution station - cityhub	01:06:06	(hh:mm:ss)
Roll container used at cityhub	445	#
Roll container stairway cityhub	360	#
Roll container used at distribution station	68	#

Diagram 5-11 shows the handling time for each arriving roll container (ordinate). Roll containers arriving at a later hour have a longer waiting time than those arriving earlier due to the process. On average, this results in an average turnaround time of 3:15:14 per roll container, with an increasing tendency the longer operating time is carried out.

At peak times there are a maximum of 112 roll containers (96 nested, 16 in use) on the distribution level in the distribution station. The maximum buffer area (nested) would amount to 20.90 m^2.

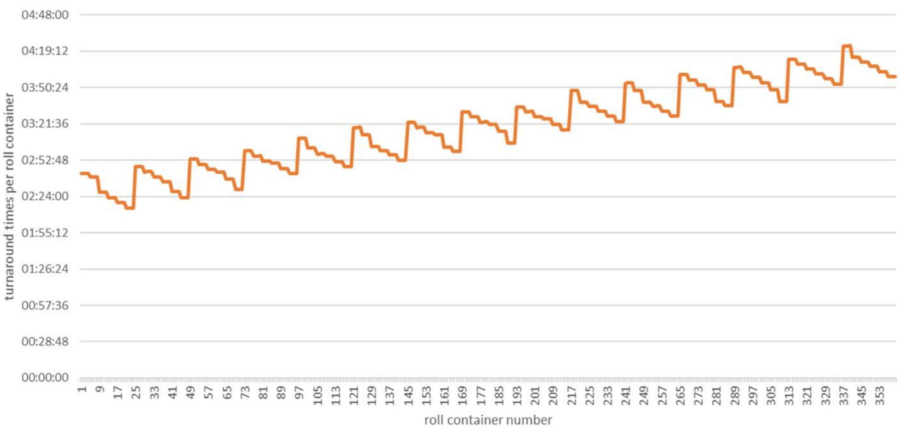


Diagram 5-11: Turnaround times per roll container from cityhub to cityhub, own display

- Example 1: Roll container no. 46 needs 02:24:00 to get from the cityhub and vice versa.
- Example 2: Roll Container No. 237 needs 03:21:36 to get from the cityhub and vice versa.

Compared to scenarios 2 and 3, the same cycle can be observed in principle. The main difference here is also the quantity and consequence of the more significant number of roll containers that have to be handled. Consequently, the later roll containers have a significantly longer waiting time than any of the previous scenarios.

5.2.4 Logistics staff – general

Logistics staff are classified into two categories. The first category is how long they have to work according to the shift schedule to be able to handle the transport capacities. The other category is effective working time. How long each worker is employed at his place of work. Both workers in the gondola level are in focus here. Since they represent the parameters relevant to the clock. In the primary mode of operation, the logistics staff is on average occupied with 60% to 70%. However, this value decreases in the course of the simulation, since both are exposed to longer waiting times due to the process. Thus, the worker from the cityhub has to wait until the first regular transport gondola arrives from the distribution station (waiting time on average 2x50 min, excluding any empty roll container gondolas). Diagram 5-12 illustrates the degree of utilisation of the respective workers in the individual stations, divided into three areas:

- 1st start-up Transport to the city
- 2nd start-up of empty container transport
- 3rd start-up transport from the city

In the first area, capacity utilisation must build up slowly, since all buffer positions must be filled at the beginning, capacity utilisation in this area is slightly high (average capacity utilisation between 50% and 60%).

In the second area, in addition to the regular roll containers, the handling of the empty containers must also be handled. This results in a renewed increase in capacity utilisation per worker (increase between 5% and 10% to up to 68%).

In the third area are all regular roll containers transported to the city. The convey from the city has begun. Due to the process-related waiting times between the last regular roll container from the cityhub and the first regular from the distribution station, the workload of the workers from the cityhub is decreasing (reduction of the workload in the cityhub by 5% to 10%). The workers from the distribution station start with the roll container transport from the city. Therefore, their utilisation decreases only slightly.

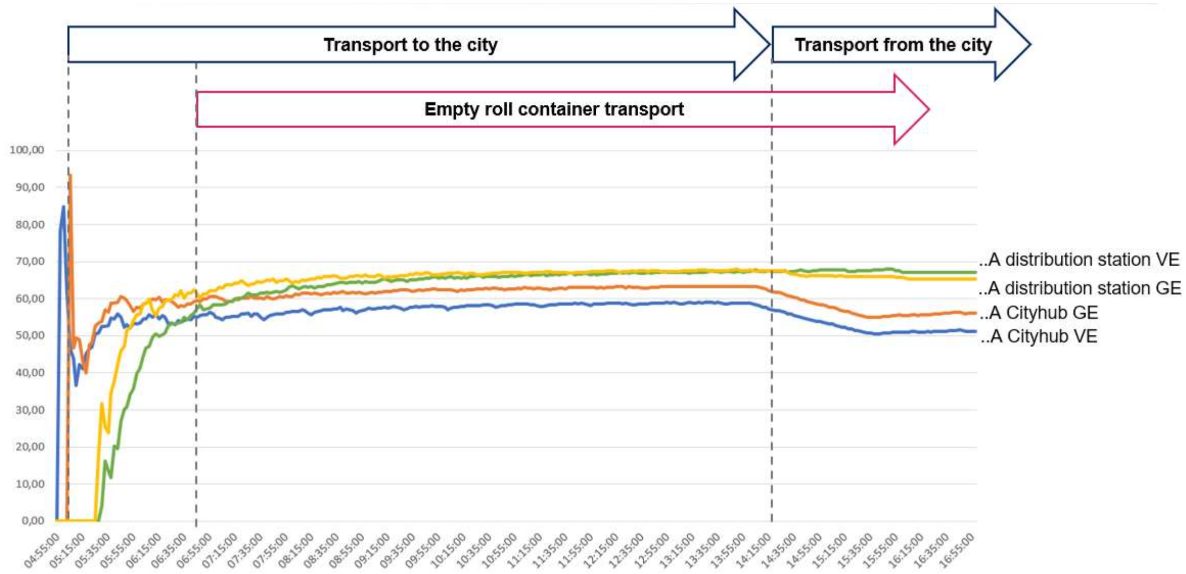


Diagram 5-12: Utilisation of workers over the work period (1-1), own representation

Compared to scenario 2, the workload is approximately the same, since the identical tasks have to be processed. However, logistics staff are employed during a more extended period and have to cover longer distances.
In Table 5-15, each worker is evaluated over the shift period, i.e. how busy he was over his work period.

Table 5-15: Worker load factor: SC 4: ECO Scenario 2025 1-1

Worker load factor: SC 4: ECO Scenario 2025 1-1		
General information		
Number of workers in the system	4	
1. CityHub		
distribution level		
1.1. Carrying	36.22	%
1.2. On the way to task	14.97	%
1.3. Working	51.19	%
1.4. Pause	48.81	%
1.5. Distance covered	14555.65	m
gondola level		
1.6. Carrying	42.42	%
1.7. On the way to task	13.31	%
1.8. Working	55.73	%
1.9. Pause	44.27	%
1.10. Distance covered	12758.00	m
2. Verteilerstation		
distribution level		
2.1. Carrying	46.79	%
2.2. On the way to task	20.67	%
2.3. Working	71.63	%
2.4. Pause	28.37	%
2.5. Distance covered	16993.19	m
gondola level		
2.6. Carrying	50.95	%
2.7. On the way to task	14.52	%
2.8. Working	65.47	%
2.9. Pause	34.53	%
2.10. Distance covered	13839.00	m

5.2.5 Cross-checking scenarios 4 and 5

The number of goods which has to be transfered makes it necessary to transport in a more extended period as it would be required in SC2 and SC3. Still, the process flow in this scenario is more or less identical. Differences can only be found in the slightly higher utilisation of the gondolas and the logistics staff, the longer shift times and the increased average handling time for roll containers from the cityhub.

The difference between SC 4 and SC 5 is the deployment of an additional worker per level and station. The same process and work steps are performed. Depending on the simulation, there is always an alpha and a beta worker. This means if a new task is received, one worker (alpha) starts first. If the workstation is released, and another order is still open, the second worker (beta) starts executing the task. Also, one of the workers may be completing a task while the other is pausing. It comes then to inconsistently long working times and distances. In addition to this, the alpha worker performs the quick tasks (such as unloading the nested roll containers) alone until the other worker has completed his task or reached the new task. In Diagram 5-13 these "dislocations" are recognisable as one worker is higher utilised than the other one at the same level (green line). In total, however, the same work tasks have been completed, and the workload has theoretically been halved by the other workers sitting in.

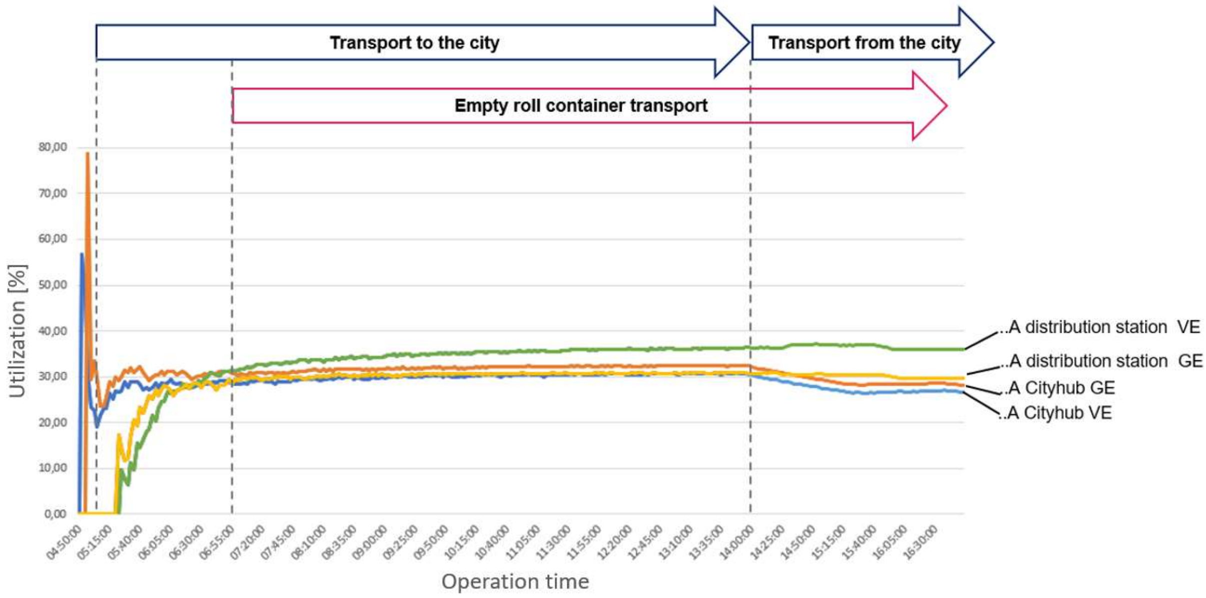


Diagram 5-13: Utilisation of workers over the work period (2-2), own representation

6 Summary and conclusion

In this summary, the strands and sub findings of the latter chapters will be brought together. On the base of these results the main statements of the thesis are then concluded.

6.1 Summary

To start off with the waiting times in the individual scenarios: Compared to the baseline scenario without the transport gondola, both scenario groups show an increased travel time in 2018 and 2025. However, due to the use of transport gondolas, passengers may be obliged to wait for a non-person gondola to pass through the station before entering the next passenger gondola. This leads to an extension of waiting time of almost 42 seconds — the interval between two sequential gondolas, since the transport gondola cycle must be awaited (worst-case scenario).

The passenger gondola load is identical in all scenarios, as the same number of passengers is transported over the same period. The capacity utilisation of the transport gondolas, on the other hand, rises by almost 3% from scenario 2018 to scenario 2025 because more goods are transported during a different, non-proportional period. Likewise, the utilisation of empty container gondolas increases by just under 6% in the scenario 2018 to 2025 for the same reason.

The utilisation of logistics staff is roughly the same (slightly higher) in Scenario 2018 1-1 and Scenario 2025 1-1. In scenarios 2018 2-2 and scenario 2025 2-2, capacity utilisation is virtually halved, as two workers are deployed in each scenario (virtually halved, as the program generates one alpha and one beta worker).

The last finding pertains to the throughput time of the roll containers and their required maximum buffer area. As described before, the cycle time is the time a roll container needs to get back from the from Cityhub and vice versa. Because more roll containers are transported to the distribution station than empty, nested roll containers can be carted off again, congestion occurs. Hence, the longer the system operates, the more roll containers will accumulate in the distribution station. The average lead time changes from scenario 2018 to scenario 2025 only by about 13 minutes, but it will be necessary to store 5 m^2 or about 26 more roll containers in the distribution station.

In summary, it can be said that higher utilisation of the gondolas or the workers can only be achieved with compromises in terms of waiting times of the persons or quantity of working hours of logistics staff. The limit for logistics staff is a gondola cycle of 5PG: 1TG every 42 seconds. If the cycle becomes shorter, the tasks for a worker can no longer be completed on time.

The most critical parameters are compared again in Table 6-1.

Table 6-1: Summary of the main parameters

Parameter	Basis	2018		2025	
	-	1-1	2-2	1-1	2-2
mean travel time	00:14:51	00:15:34		00:15:34	
waiting time change	-	+42 sec			
person gondola utilisation	9,0%	10,4%		10,4%	
transport gondola utilisation	-	24,5%		27,1%	
empty roll container gondola utilisation	-	21,3%		27,0%	
average logistics staff utilisation	-	58,3%	24,2%	61,0%	25,4%
maximum storage area (RC)	-	15,67 m^2 (nested)		20,90 m^2(nested)	
average turnover time (RC)	-	3:02:13		03:15:14	

To be able to predict how long the system can be operated with the settings of scenario 2025 1-1, certain assumptions are made:

- 25 Packages per Roll Container (RC)
- Limit 12h working day in Cityhub
- 1 logistics staff per level
- 5 passenger gondolas to 1 transport gondola
- Base scenario 2025
- Assumption +6% CEP market per year

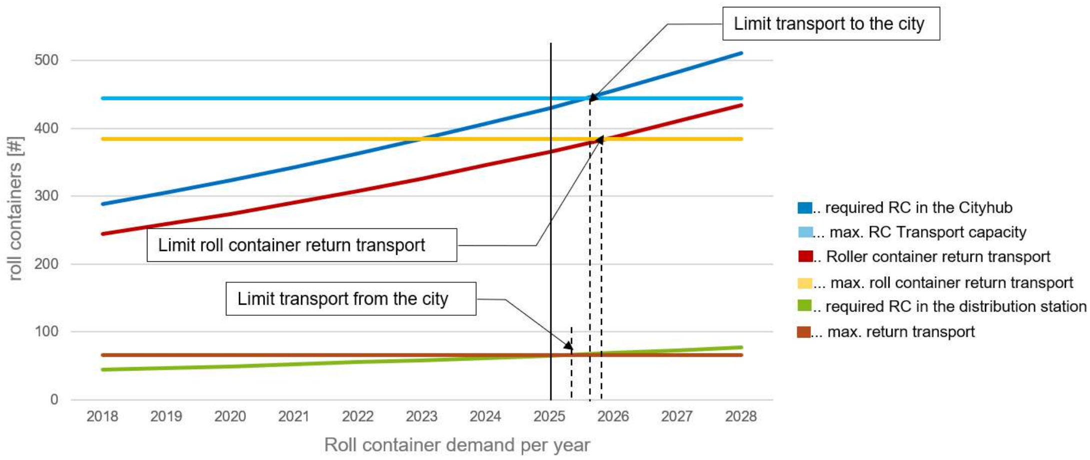


Diagram 6-1: Limits for further gondola use, own rep.

By mid-2026, the limits of transport towards the city will be reached, as will the limit for shipment from the city. Furthermore, the limit for the roll container return transport will be reached at the beginning of 2026. Anything that is transported beyond that can no longer be shipped into the city or would accumulate at the delivery station.

6.2 Conclusion

Basically, all the evaluated scenarios (SC2 to SC5) differ essentially only in terms of:

- Number of logistics staff deployed
- Quantity of transport material and resulting transport times

In this context, capacity utilisation is an essential factor. Utilisation potential can be found on the one hand in the logistics staff and on the other in the type of respective gondolas (passenger, transport and empty container gondolas). The simulations showed that the passenger gondolas were used to an average of just above 10% and the transport and empty container gondolas to just under 25%.

In the case of passenger gondolas, the high use of passenger gondolas has a slightly negative effect on the utilisation of the gondolas, but a positive effect on the average travel time of the passengers. In the case of transport and empty container gondolas, the respective transport route is decisive. Transport gondolas travel the longer distance unloaded (layout-related between S5 and S11). Empty container gondolas travel a longer distance loaded, but in a shorter period, while only two empty container gondolas are in use. If the number of transport gondolas was to be increased, their capacity utilisation would be reduced, as would the shift times of logistics staff. However, as the maximum possible throughput of roll containers would be increased, travel times of passengers would be extended, including longer waiting times.

Workers at the gondola level are a critical factor. They have great impact on the minimum distance between transport gondolas. When using a worker, this is a gondola distance of 42 seconds with a gondola cycle of 5:1 (i.e., every 6th gondola is a transport gondola, equivalent to 252 seconds). With shorter distances or cycles, one worker alone would not be able to handle four roll containers. Hence, in a 5:1 cycle, the logistics staff is generally used to 70 % of their capacity.

If, on the other hand, two workers are used per working level, the gondola cycle can indeed be reduced, while transport capacity for roll containers increases. Nonetheless, the degree of utilisation of the workers cut by one half. Logistics staff has more than 6 hours of idle time at 12 hours working time (capacity utilisation of just under 35%). Mid-2025, the system's capacity limits about roll container transport will be reached. The limit for the return shipments of rolling containers will attained at the beginning of 2026.

In summary, it can be said that higher utilisation of the gondolas or the workers can only be achieved with compromises in terms of waiting times of the persons or degree of employment of the workers. The limit for logistics staff is a gondola cycle of 5PG: 1TG every 42 seconds. If the cycle becomes shorter, the tasks for a worker can no longer be completed on time.

7 Appendix

7.1 Description simulation model

In the following chapters, only those methods and elements will be described which differ from the base model from the previous master thesis. Elements which have been inherted, can be found in the appendix of the master thesis of Dipl.- Ing. Simon Naderer - “Urban ropeway – material flow study of a ropeway system for the combining transport of people and goods” [Nad18]

7.1.1 All-embracing

7.1.1.1 Extension to a customizable rope speed

Table 7-1: Methods and elements in the distribution station (Part 1)

Methods – Rope speed definition

Characteristics - functions

The method “Change_Hour” and the generator “Generator_ChangeHour” have the task to change the rope speed during the day, every full hour. In the table file, “Tabelle_durationtime” are all the individual rope times (including acceleration and deacceleration) between two stations listed.

In the table file “Table_Hours” are the full hours of one day listed. The method is triggered by the generator and inserts the percentages into the table files for the target stations.

7.1.1.2 Extension to numbered transport gondolas

Table 7-2: Methods and elements in the distribution station (Part 2)

Methods – Nest time control

Characteristics - functions

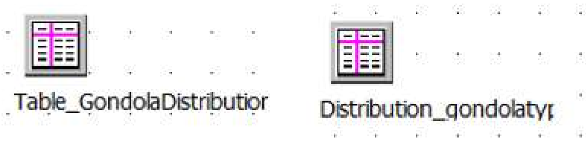
The method "Aktuelle_Nest_Nr_M" is activated if a load gondola pass. This trigger set the value "Aktuelle_Nest_Nr" to the current Nest_Nr of the gondola. The method "Reset_Aktuelle_Nest_Nr_M" set the value back to zero. This method is used to allow the worker to load the different gondola types within the correct loading cycle/limit.

Similar to that is the working principle of the method "Next_Nest_Nr_M" and "Gondola_Zyklus". These methods set the value "Next_Nest_Nr" to the Nest_Nr next transport gondola.

7.1.1.3 Adapting gondola creation

Table 7-3: Methods and elements in the distribution station (Part 3)

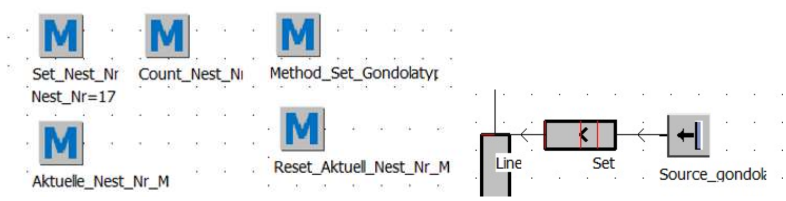
Table files – Gondola Distribution / Type



Characteristics - functions

The table file "Table_GondolaDistributor" contains the defined gondola distribution (e.g. 5 to 1; 6 to 1).
The table file "Distribution_gondolatype" contains the modification factor for any mathematical rounding errors. For an odd number of gondolas (e.g., 17.33), the value must be limited to a defined maximum (17).

Methods – Transport gondola numbering



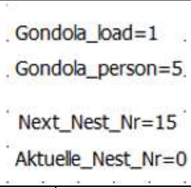
Characteristics - functions

The method “Count_Nest_Nr” is triggered when a gondola passes the sensor on the “Set”-line. It counts up and set the value “Nest_Nr”. Then, this number is set as the Nest_Nr of the passed gondola via the method “Set_Nest_Nr”.

The method “Aktuelle_Nest_Nr_M” is activated when a load gondola pass. The method “Reset_Aktuelle_Nest_Nr_M” set the value back to zero. This method is used to allow the worker to load the different gondola types with the correct transport unit.

The Method “Method_Set_Gondolatyp” set each type of a passing gondola according to the defined cycle in the table file “Table_GondolaDistributor”.

Variable – Gondola cycle



Characteristics - functions

The variable “Gondola_load” in combination with the variable “Gondola_person” define the gondola distribution.

The variable “Next_Nest_Nr” is set via the method “Count_Nest_Nr”.
The variable” Aktuelle_Nest_Nr” is set via the method “Aktuelle_Nest_Nr_M”

7.1.2 Cityhub

7.1.2.1 Worker in the cityhub on the gondola level

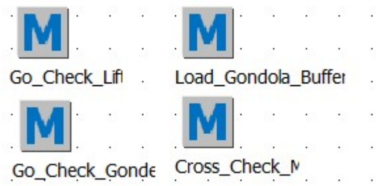
Table 7-4: Methods and elements in the Cityhub (Part 1)

Methods – Gondola load and unload

Characteristics - functions
The method „Gondola_In_M” is connected to the variable “IN”. It is activated when a load gondola passes the sensor. If the sensor is set, it represents the theoretical starting point of the active loading and unloading distance. The method "Gondola_Out_M" is set at the theoretical end, using another sensor. It resets the variable "IN" to zero.
Methods – Load, count

Characteristics - functions
The Method “In_M” is activated when the gondola is unloaded from the method “Method_Exit_Load”. The content is then unloaded to the element "Buffer_Exit_Load". To tell the worker how many elements (roll containers) are involved, the variable "In" is set. This is then retrieved by the worker and the lift elements.

Methods – Cross check functions



Characteristics - functions

The method “Go_Check_Lift” monitors whether the lift is in the gondola level and can, therefore, be loaded. If required, it return the contents of the buffer "Buffer_ZwLa_GE".

The method “Load_Gondola_Buffer” monitors whether the correct gondola (load or empty roll container) can be load and is in the designated area. (load/unload path)

The method “Go_Check_Gondel” and “Cross_Check_M” monitor the intermediate storage areas and elevator places. This prevents the intermediate storage areas from being overloaded and cross check if the roll container doesn’t block each other.

Methods – Backup locker

Characteristics - functions

The method “Unload_Secure” and “Lift_Lock” are backup methods which intercept individual cases such as odd-numbered or residual containers and forward or block them temporarily.

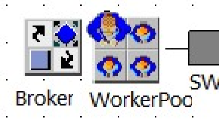
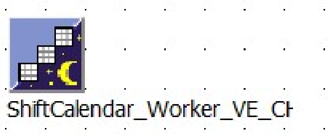
7.1.2.2 Extension the distribution level in the CityHub

Table 7-5: Methods and elements in the Cityhub (Part 2)

Methods – Store and Sort	
	
Characteristics - functions	
The method "Store_1" counts and releases defined "packs" of roll containers. In all scenarios, four roll containers are per pack collected and then brought into the system. The method “Sortierer” (“sorter”) sort the incoming elements which leave the system (roll container with the target number S5, roll container with the target number S11 and the nests) into the correct drain.	
Methods – empty leftovers	
	
Characteristics - functions	
Due to the random filling of the roll containers with variable content, it may happen that an uneven number of roll containers remains at the end. The method “Reste_leeren” (“empty leftovers“) compensates this and conveys them into the system.	
Methods – evaluation compensation of station 11 (and 5)	
	
Characteristics - functions	
Specific values are copied into the evaluation tables of the stations at the end of the simulation by the "EndSim" methods. This method compensates this access to station 11 (and station 5) and copies its values directly into the tables.	

7.1.2.3 Worker in the cityhub on the distribution level

Table 7-6: Methods and elements in the Cityhub (Part 3)

Methods – Worker	
	
Characteristics - functions	
The “Broker” object is the intermediary between the objects that request a service and the objects that deliver this service. This element delegates the workers to the various groups. The “WorkerPool” creates the logistic staff, and they remain in this object when there is no tasks to do. The “Worker” represents a working person who performs tasks.	
Methods – Shift calendar	
	
Characteristics - functions	
The shift calendar “ShiftCalendar_Worker_VE_CH” sets the shift times of the worker in the distribution level.	

7.1.2.4 Simulation model extended by the extension cityhub to lift

Table 7-7: Methods and elements in the Cityhub (Part 4)

Methods – Basic elevator control

Characteristics - functions

The method, “abladen_oben” (“unload_up”) discharges the elevator module at the upper end of the elevator section. It also checks if the elevator has been wholly emptied before it is released again.

As a counterpart acts the method "abladen_unten" (“unload_down”). It serves the same functions but is responsible for the lower level.

The stack file “Sensorliste” (“sensor list”) includes the four possible target stations:

- Gondola level unload
- Gondola level load
- Distribution level unload
- Distribution level load

all these positions represent a Buffer in which the elements from the elevator are loaded into when the elevator element triggers the individual sensor.

In the queue file “Fahrauftrag” (“transport order”) the lift orders are loaded, i.e. when there is a need for transport from the gondola level to the distributor level or vice versa.

The method “fahrzeugsteuerung” (“vehicle control “) operates the elevator. It adjusts the direction that the elevator has to move.

Methods – transfer elements in the elevator area

Characteristics - functions

The method "Umlagern_Lift" ("transfer_elevator") is used to transfer the transport elements (roll container and nests) to the transfer station. Due to the high complexity of the elevator load and unload procedure are more process station used, and this method combines and shifts the transport elements to the correct port.

The method "Go_Check_M" monitors the direct lift entrance "Buffer_Lift_Out" and Buffer _Exit_Lift" to avoid collisions.

Methods – Call the elevator

Characteristics - functions

The method "Lift_rufen_unten" ("Lift_call_bottom") and "Lift_rufen_oben "("Lift_call_top") call the elevator to the appropriate level by setting the specific number of the target stations in the queue file "Fahrauftrag" ("transport order").

Methods – Lift occupied

Characteristics - functions

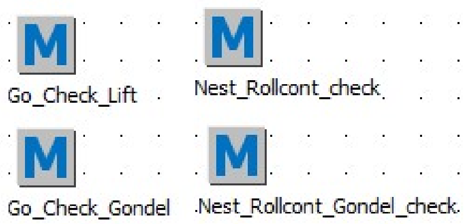
These methods set the elevator status on "occupied=true" or "occupied=false" depending if there is something per definition in the elevator path.

7.1.3 Distribution station

7.1.3.1 Worker in the distribution station on the gondola level

Table 7-8: Methods and elements in the Distribution station (Part 4)

Methods –



Characteristics - functions

The method "Go_Check_Lift" monitors the elevator. It crosschecks the incoming elements and the current content of the elevator element. If these numbers match, all elements have been loaded from the gondola into the elevator, the elevator can move to the distribution level.

The opposite of the previous method is "Go_Check_Gondel". The method compares the content of the elevator with the current content of the gondola buffer. When all elements of the elevator have been loaded, the operation is complete. This is used to meet the different priorities of the tasks.

The methods "Nest_Rollcont_check" and "Nest_Rollcont_Gondel_check" monitor the individual interim storage places to ensure that roll containers and nested roll containers do not get in each other's way and thus block each other.

7.1.3.2 Expand distribution level and worker in the distribution station

Table 7-9: Methods and elements in the Distribution station (Part 5)

Methods – Init and EndSim

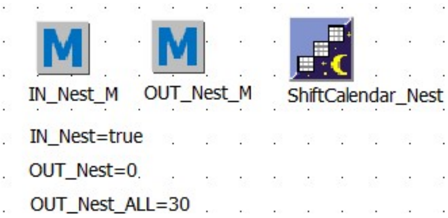
Characteristics - functions

The method "init" has a specific 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)

The method "EndSim" set the conditions when a simulation run is finished. The primary function is to copy the recorded data into corresponding table files.

Methods – general nest control



Characteristics - functions

The methods "In_Nest_M" and "OUT_Nest_M" together monitor the number of nests (nested, empty roll containers). The methods count the nests that are brought back to the cityhub. By definition, it must be ensured that sufficient roll container containers remain in the distribution unit to handle the returns. Therefore, the return transport stops as soon as the variable "Out_Nest_All" has reached a specific value.
The shift calendar used was added for documentation purposes and trials.

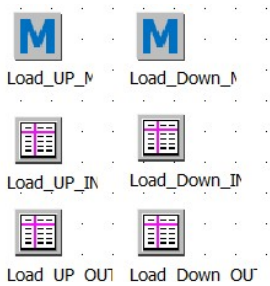
7.1.3.3 Expansion of an elevator in the Distribution station

Table 7-10: Methods and elements in the Distribution station (Part 6)

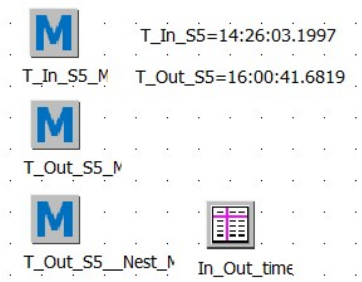
Methods – Elevator extension: a nested roll container	
	
Characteristics - functions	
The elevator was almost completely inherited from the one in the cityhub. However, the method “Umlagern_Lift_Nest” (“Relocate_Lift_Nest“) was extended accordingly for the return transport. This extension includes additional buffer space for the nested roll containers as well as corresponding transfer methods for releasing when these can be transported to the gondola level.	

7.1.3.4 Implement evaluation methods for the simulation model

Table 7-11: Methods and elements in the Distribution station (Part 7)

Methods – Load level transfer times	
	
Characteristics - functions	
The methods "Load_UP_M" and "Load_Down_M" have been added in order to be able to distinguish the individual packages between system boundary and simulation boundary and to monitor the actual path between gondola and distribution level. They store each load element in the respective table files, depending on whether they arrive (UP_IN) or depart (Down_OUT) at the level.	

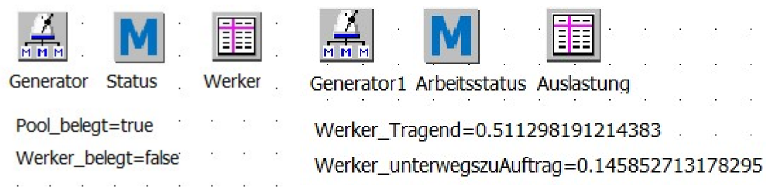
Methods – Gondola arrival and departure times



Characteristics - functions

When triggered, the methods above save the corresponding roll container number, gondola number and the current simulation time in a table file. In this way, it can be monitored when which roll container arrives in which gondola and also when. The same elements can be found in the city hub and the distribution station. Thus, the transport route and the time required can be mapped and compared for each roll container.

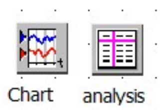
Methods – Worker statistics



Characteristics - functions

The methods "Status" and “Arbeitsstatus” ("Work status") monitor one worker per level. For this purpose, the status of the worker is tapped via the element "Generator" at certain times and entered in the corresponding table file. Since there is a difference between operating time and generation time of the workers, the working status of each worker can be recorded at his actual operating period. The different valuables are created to get a real-time, visual control, used during the testing verification phase.

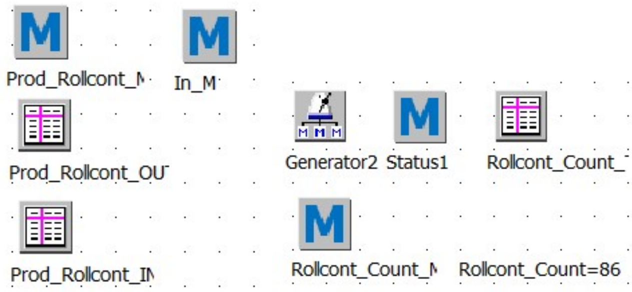
Methods – Fill status of the intermediate storage



Characteristics - functions

In general, a "chart" element can be used to visualise the data generated by an element(buffer). In this case, the element monitors and documents the fill status of the intermediate storage "ZWS".

Methods – Roll container departure and arrival times



Characteristics - functions

The methods "Prod_Rollcont_M" and "In_M" have been added in order to be able to distinguish the individual roll container between the system boundary and simulation boundary and to monitor the actual path between cityhub to the distribution level and vice-versa. They store each roll container in the respective table files, depending on whether they arrive or depart at the station.

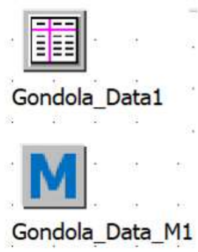
The method “Status1” and “Rollcont_Count_M” are used in the distribution station to monitor the time-specific current amount of roll containers in the distribution station.

Methods – Timecheck

Characteristics - functions

The "Timecheck" method was used at the beginning of the implementation process at the one-sided generation of the gondolas. The distances between the gondolas, and especially between the first and last gondola, were recorded in order to optimise the generation times and thus the distances.

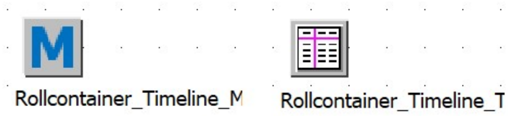
Methods – Person gondola occupation monitoring



Characteristics - functions

The "Gondola_Data_M1" method is called via a "Generator" at periodic intervals. The current simulation time and the current load of a passenger gondola, as well as its load, are entered into the table file “Gondola_data1”. This also happens identically for a defined transport gondola and an empty container gondola.

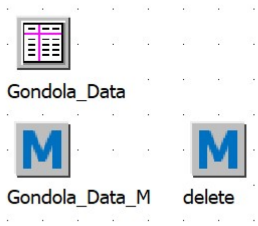
Methods – Roll container monitoring



Characteristics - functions

These methods are used to examine the path of the roll container in more detail. The method "Rollcontainer_Timeline_M" is called periodically called by a "generator" and the current position and the simulation time are entered into the table file “Rollcontainer_Timeline_T”. Thus, the exact path and time of the roll containers can be tracked.

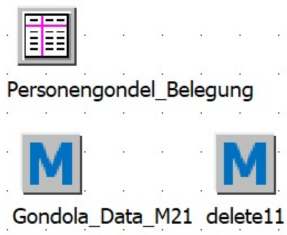
Methods – gondola utilisation times



Characteristics - functions

The method "Gondola_Data" is started during the simulation and writes the simulation time and for each gondola and their absolute utilisation, and their relative empty utilisation into the table file “Gondola_Data”. With the method "delete1" this table can be reset if necessary.

Methods – Person gondola occupation

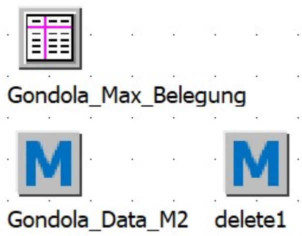


Characteristics - functions

The method “Gondola_Data_M21” is used to record the loading of defined passenger gondolas. Thus, their occupancy can be documented over the simulation period in the table file “Personengondel_Belegung” (“Passenger gondola_occupancy”).

With the method "delete11" this table can be reset if needed.

Methods – general nest control

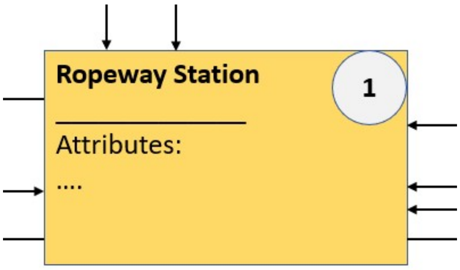


Characteristics - functions

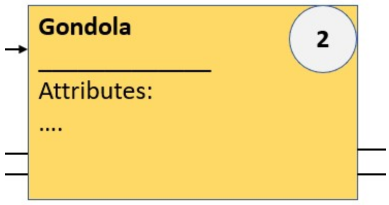
The method “Gondola_Data_M2” is periodically activated at the end of the Simulation time. It stores all the maximum occupation of each gondola in the table file “Gondola_Max_Belegung” (“Gondola_Max_occupation”).

7.2 Data Model

Table 7-12: Data model

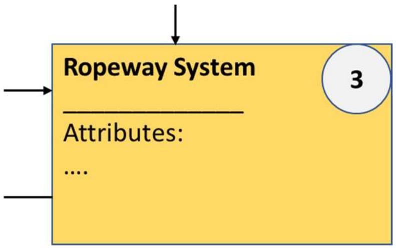
<table>
<tr><th colspan="2">Class: Ropeway System (Class Nr.1)</th></tr>
<tr><td colspan="2">
</td></tr>
<tr><th>Attributes</th><th>Relations</th></tr>
<tr><td>I. $: ID cable car station: string
II. Designation: string
III. Position: string
IV. Type: string
V. Length of gondola circulation/pass: real
VI. I: Capacity Entry area Passenger transport: integer
VII. I: capacity exit area passenger transport: integer
VIII. I: Capacity loading area Freight transport: integer
IX. I: Capacity unloading goods transport: integer
X. I: lead time station persons: time
XI. I: lead time station goods: time
XII. O: utilisation of passenger transport (capacity): real
XIII. O: utilisation of goods transport
XIV. (Capacity): real
XV. O: utilisation of roll container transport (capacity): real</td><td>• *control* from Timetable
The timetable controls the ropeway system. It determines at what time people or goods enter the system.
• *supplies* by Entrance
Interface for the persons to enter the System (Source of Persons).
• *supplies* Exit
From the Station persons leave the system via the Exit. Station supplies the Exit with persons.
• *supplies* by Cityhub:
From the Ropeway station goods leave the system via the cityhub, supplies the cityhub with goods.
• *possess* Cityhub:
Cityhub is may is embedded in the Ropeway station
• *possess* Pick-up station:
A Ropeway station may possess a Pick-up station depending on the network structure where people pick-up their goods.
• *Supplies by* Distribution unit:
A Distribution unit supplies the Ropeway station with roll container.
• *Connect to* Ropeway system</td></tr>
</table>

Class: Ropeway System (Class Nr.2)



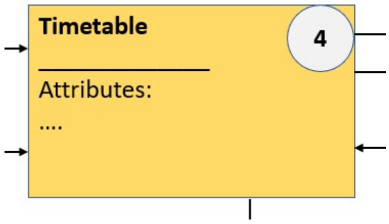
Attributes	Relations
I. $: ID gondola: string II. Type: string III. Nest_No: integer IV. I: Funding capacity persons: integer V. I: Production capacity goods - Rollcontainer: integer	• *control* from Timetable Specifies the creation times and distances as well as the number of gondolas. • *use* Ropeway System move on the track the Ropeway system dictates. • *travels through* Ropeway station: Gondolas pass through Ropeway station; enter or exit persons - load or unload goods. • *transport* Persons: Gondolas transport persons. • *transport* Roll container: Gondolas transport goods via Roll container

Class: Ropeway System (Class Nr.3)	



Attributes	Relations
I. $: ID cable car system: string II. Maintenance intervals / availability: real III. Number of gondolas: integer IV. Acceleration-deceleration: real V. Conveying speed rope: real VI. Cycle time: time VII. O: Throughput rate of passenger transport: real VIII. O: throughput rate Cargo transport: real IX. O: lead time passenger transportation: time X. O: lead time Cargo transport: time XI. O: Occupancy passenger gondolas: real XII. O: utilisation of cargo gondolas: real	• *control* from Timetable The timetable controls the ropeway system. It determines at what time the system is active and with which rope speed is currently being driven • *connect* to Ropeway Station There are stations in the system. They allow persons or roll container to enter or leave the ropeway system. • *use* by Gondola The gondolas are attached to the cable (Ropeway system) when travelling between stations. They transport persons and roll container.

Class: Ropeway System (Class Nr.4)



Attributes

I. **Operating times**

II. $: ID timetable: string

III. Conveying speed rope: real

IV. rope speed: speed via time

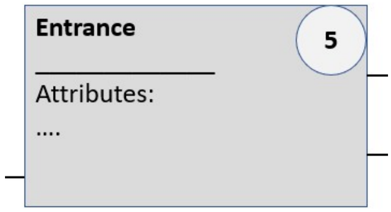
V. Operating time cable car (start-end): time

VI. Date/day of the week: date

Relations

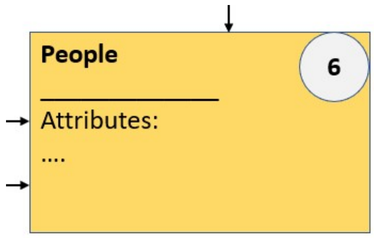
- *control* Gondola:
  The Timetable operates the Gondola relating to operating hours.
- *control Ropeway s*tation:
  The Timetable operates the Station relating to operating hours.
- *control* Ropeway system:
  The timetable controls the ropeway system. It determines at what time the system is active and with which rope speed is currently being driven
- *affect* by customer
  Customer affects the timetable, depending on their habits.
  (Source and Drain for Goods)
- *affect* by City hub
  Cityhub affects the timetable, depending on their transport requirements, opening and process times.
- *affect* by Entrance
  Interface for the persons to enter the System (Source of Persons).
- *control* Logistic staff
  The timetable control, whenever a shift of the logistic staff starts or ends at every station during the operating time

Class: Ropeway System (Class Nr.5)



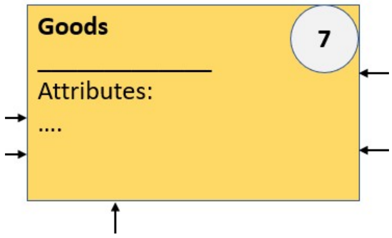
Attributes	Relations
I. Source: Persons II. $: ID-Source Persons: string III. SP: Start-Destination-Quantities Distribution Passenger Transport: table	• *affect* Timetable: The number of persons entering the system via the interface Entrance to the environment affects the Timetable (operating hours of the system). • *supplies* Station: Via the Entrance persons come to the Station. • *generate* Persons: Entrance is the source of Persons. Entrance generates Persons.

Class: Ropeway System (Class Nr.6)



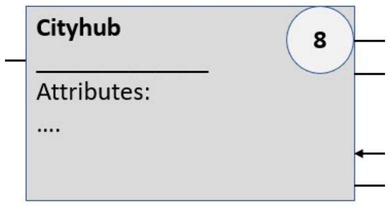
Attributes	Relations
I. $: ID person: string II. Destination station: integer	• *generate* by Entrance: Entrance is the source of Persons. Entrance generates Persons. • *delete* by Exit: The exit is the drain of Persons. Entrance deletes Persons. • *transport by* Persons: Gondolas transport persons.

Class: Ropeway System (Class Nr.7)



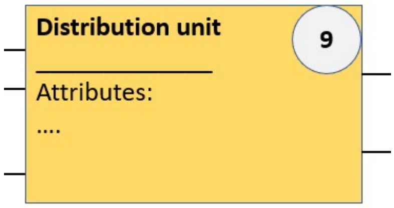
Attributes	Relations
I. $: ID goods: string II. Destination station: integer	• *store* by Warehouse: The warehouse stores goods from the system • *require* by Distribution unit: Distribution unit requires goods • *require* by Cityhub: Cityhub requires goods • *require* by Costumer: customer needs the goods or gives them up for further transport • *transport* by Roll container Goods are transported in Roll containers

Class: Ropeway System (Class Nr.8)	

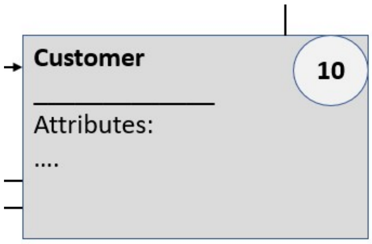


Attributes	Relations
I. **Source-drain: goods** II. **Source-drain: roll container** III. $: ID City Hub: string IV. Designation: string V. Position: string VI. Processing time goods delivery VII. Processing time goods pickup VIII. Capacity roll container: integer IX. SP: Start-Finish Quantities Distribution Goods Delivery: table	• *affect* Timetable: The number of goods entering the system via the city hub affects the Timetable of the ropeway system. • *supplies* Ropeway station: The city hub supplies the Ropeway station with goods. • *require* Goods: City hub is the source of Goods. (Source and Drain of goods) • *possess* Warehouse: A city hub possesses a Warehouse where the incoming/ outgoing Roll container and are stored/ buffered. • *possess* Ropeway Station A Ropeway Station possesses a Cityhub to transport Rollcontainer and goods into the city. • *require* Logistic staff Logistic staff move/transport the roll container (full or nested) within the station

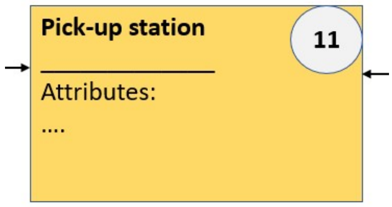
Class: Ropeway System (Class Nr.9)



Attributes	Relations
I. Source: roll container II. $: ID vehicle: string III. Designation: string IV. Type: string V. Capacity loading volume: real VI. Delivery time - Availability: time VII. Capacity roll container: integer VIII. I: number: integer IX. O: utilisation vehicle fleet: real	• *require* Goods: The Distribution unit transports goods to the final customers. • *require* Roll container Required roll containers for the transport of incoming goods • *supplies* Customer: Distribution unit delivers goods from the Ropeway station to Customer (shops, private persons). • *supplies* Ropeway station: Distribution unit delivers goods from shops, private persons to Ropeway stations of the ropeway system (return deliveries, goods to destinations outside the city). • *possess* Warehouse: A Distribution unit possesses a Warehouse where the incoming/ outgoing Roll container and goods are stored/ buffered. • *require* Logistic staff Logistic staff move/transport the roll container (full or nested) within the station

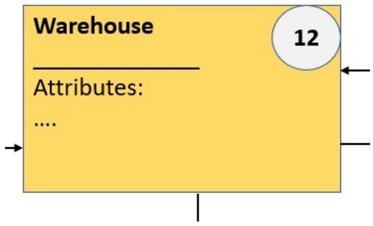
Class: Ropeway System (Class Nr.10)	
	
Attributes	**Relations**
I. Source-drain: goods II. $: ID customer/business: string III. SP: Start-destination quantities Distribution Goods pickup: table	• *affect* Timetable: The demand for goods affects the Timetable (operating hours). • *require* Goods: Customer (shops, private person) need Goods. • *supplies* by Distribution unit Distribution unit delivers goods from the Ropeway station to Customer (shops, private persons). • *picks up* Pick-up station: Customers may pick-up their goods at Pick-up stations located along with the ropeway system, depending on network structure.

Class: Ropeway System (Class Nr.11)



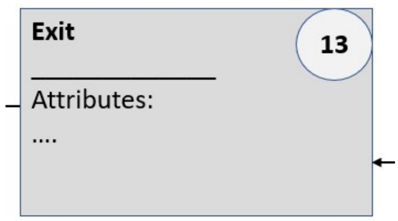
Attributes	Relations
I. $: ID pick-up station: string II. Designation: string III. Inventory content: integer IV. Processing time put away: time V. Processing time outsourcing: time VI. I: Capacity: integer VII. O: utilisation pick-up station: real	• *picks up* by Costumer: A Pick-up station stores Goods for Customers who want to pick-up their Goods directly from the ropeway system is an additional service. • *require* Goods: Customer (shops, private person) need Goods. • *possess* by Pick-up station: A Ropeway station may possess a Pick-up station depending on the network structure where people pick-up their goods.

Class: Ropeway System (Class Nr.12)

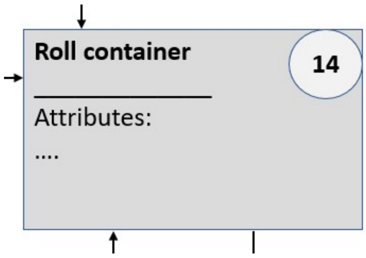


Attributes	Relations
I. $: ID warehouse: string II. Inventory content: integer III. Processing time put away: time IV. Processing time outsourcing: time V. I: Capacity: integer VI. O: utilisation warehouse (capacity): real	• *store* Goods: The Warehouse stores the incoming Goods (Returns). • *store* Roll container: The Warehouse stores the incoming Roll container (Returns, regular ones and nested, empty roll container). • *possess* by City hub: A city hub possesses a Warehouse where the incoming/ outgoing Roll container is stored/ buffered. • *possess* by Distribution unit: A Distribution unit possesses a Warehouse where the incoming/ outgoing Roll container and goods are stored/ buffered.

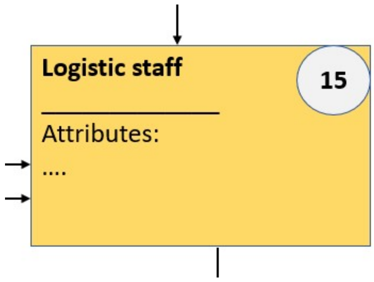
Class: Ropeway System (Class Nr.13)



Attributes	Relations
I. Drain: people II. $: ID drain people: string III. O: throughput rate people station	• *delete* Persons: The exit is the drain of Persons. Exit deletes Persons. • *supplies* by Exit From the Station, persons leave the system via the Exit. Station supplies the Exit with persons.

Class: Ropeway System (Class Nr.14)	
	
Attributes	**Relations**
I. $: ID roll container: string II. I: Capacity: integer III. SP: Target station: integer	• *store* by Warehouse: The Warehouse stores the incoming Roll container (Returns, regular ones and nested, empty roll container). • *transport* Goods: Goods are transported in Roll containers • *require* by Distribution unit: A Distribution unit requires roll containers for the transport of incoming goods. • *transport* by Gondola: Gondolas transport Roll container (full or empty and nested) • *handle* by Logistic staff: Logistic staff move/transport the roll container (full or empty and nested)

Class: Ropeway System (Class Nr.14)



Attributes	Relations
I. $: ID worker: string II. Capacity: integer III. O: statServicesTransportingPortion: real IV. O: statServicesEnRouteIdlePortion: real V. O: statServicesWaitingImpPortion: real	• *require* from Cityhub: • *require* from Distribution unit: A Distribution unit requires roll containers for the transport of incoming goods. • *handle* Roll container: Logistic staff move/transport the roll container (full or empty and nested) • *control* via Timetable The timetable control, whenever a shift starts or ends for each worker at every station

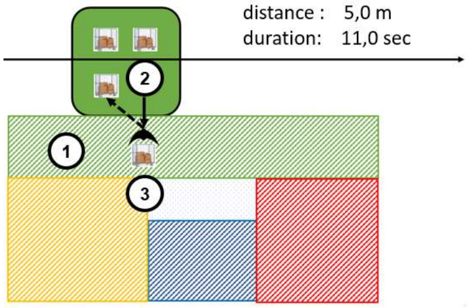
7.3 Work tasks

7.3.1 Tasks at the gondola level

Table 7-13: Work areas of the workers at the gondola level

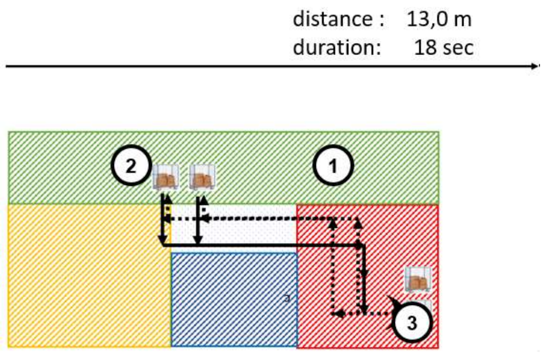
Worker - gondola level - gondola unloaded:

1. Go from the starting point to the gondola and enter it.
2. Unlock the roll container and leave the gondola.
3. Place the roll container in the loading and unloading buffer and secure (green zone).
4. Start the procedure for the next roll container again at 1.



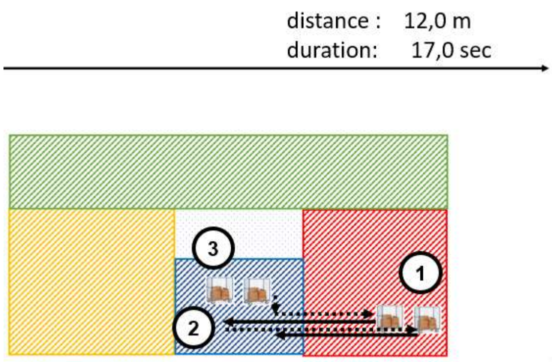
Workers - gondola level - prepare roll container containers for elevator transport

1. Walk from the starting point to the roll container.
2. Unlock the roll container and bring it to the buffer position.
3. Park the roll container in the buffer position and secure it (red zone).
4. Start the procedure for the next roll container again at 1.



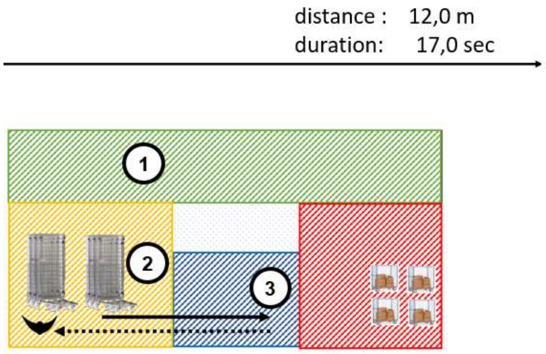
Worker - gondola level - lift loading or unloading

1. Walk from the starting point to the roll container.
2. Unlock the roll container and get into the lift.
3. Park the roll container in the lift and secure it (blue zone).
4. Start the procedure for the next roll container again from the 1st position.



Logistics staff - gondola level - load empty roll container into elevator

1. Walk from the starting point to the nested roll containers.
2. Unlock the nested roll containers and transport them in the elevator.
3. Place the nest in the elevator and secure it (blue zone).
4. Start the procedure for the next ones again at 1.

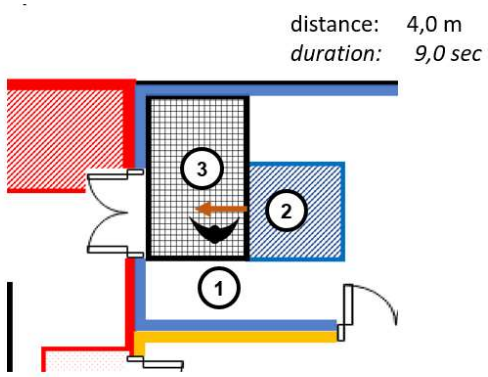


7.3.2 Tasks at the distribution level - distribution station

Table 7-14: Work areas of the workers at the distribution level (distribution station)

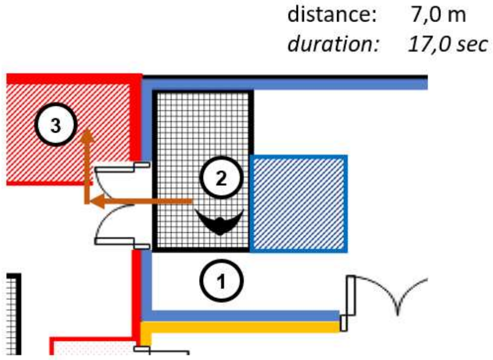
Distribution level (distribution station) - Unload roll containers

1. Walk from the starting point to the elevator and enter it.
2. Unlock the roll container and get out of the elevator.
3. Park the roll container in the buffer zone and secure.
4. Start the procedure for the next roll container again from the 1st position.



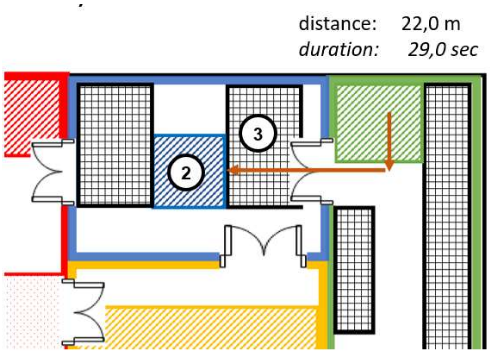
Distribution level (distribution station) - Loading roll containers

1. Go from the starting point to the roll container.
2. Unlock the roll container, park it in the buffer zone and secure it (red zone).
3. Start the procedure for the next roll container again from the 1st position.



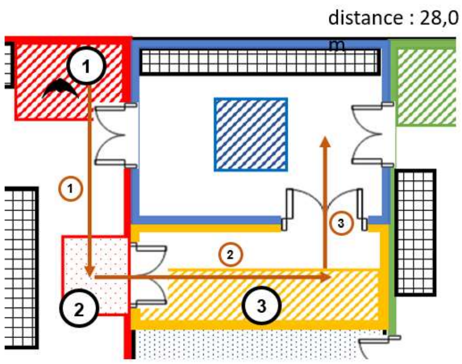
Distribution level (distribution station) - Load returns

1. Go from the starting point to the buffer zone for returns.
2. Unlock the roll container and drive to the lift.
3. Depending on the process:
    a) Park the roll container in the lift and secure it (blue zone).
    b) Place the roll container in the intermediate buffer.
4. Start the procedure for the next roll container again at 1.



Distribution level (distribution station) - nesting roll containers

1. Go from the starting point to the buffer zone for the empty roll containers (route 1).
2. Unlock the roll container containers and drive to the buffer location for nested roll container containers (route 2).
3. Park roll containers in the buffer zone, nest and secure (yellow zone).
4. Depending on the process:
    a) Return to the buffer zone for the empty roll containers, pick up the roll containers and bring them to nesting (section 2).
    b) Return to the starting point and unload the lift or pick up returns from there.
    c) Take up the empty roll container and bring to an intermediate buffer

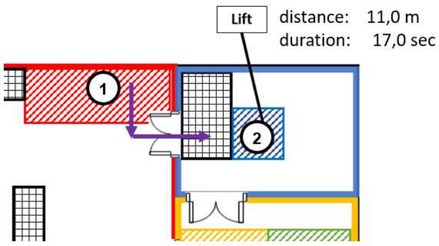


7.3.3 Tasks at the distribution level – cityhub

Table 7-15: Work areas of the workers at the distribution level (Cityhub)

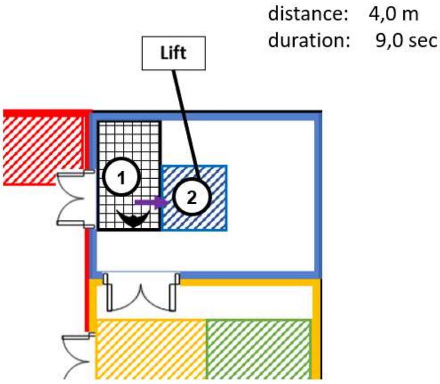
Distribution level (Cityhub) - Intermediate storage of roll containers

1. Go from the starting point to the buffer location for the roll container containers
2. Unlocking the roll container and placing it in the intermediate buffer
3. Place the roll container in the intermediate buffer and secure it.
4. Start the sequence for the next roll container again at 1.



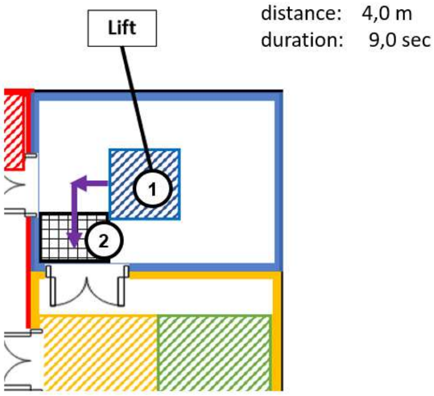
Distribution level (Cityhub) - Loading roll containers

1. Go from the starting point to the roll container.
2. Unlock the roll container, drive into the lift, park and secure (blue zone).
3. Start the procedure for the next roll container again at 1.



Distribution level(Cityhub) - Load returns

1. Go from the starting point to the lift and enter it.
2. Unlocking the roll container (or nest).
3. Move the roll container container/nest out of the lift and park and secure it in the intermediate buffer.
4. Start the sequence for the next roll container (nest) again at 1.



Distribution level (distribution station) - Load returns

1. Go from the starting point to the interim storage facility.

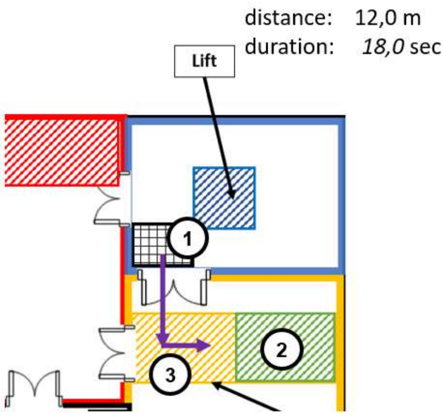
2. Unlocking the roll container (or nest).

3. Depending on the process:

    a) Pick up the roll container and bring it to the buffer location (green zone).

    b) Pick up nest and bring to buffer (yellow zone)

    c) Start the procedure for the next roll container (nest) again at 1.



7.4 Evaluated scenarios

7.4.1 Scenario 1: ECO Scenario 2018

As mentioned in the first chapter, all five simulation scenarios are performed with the same initial data from chapter 2. The first simulation scenario shows pure passenger transport within the ropeway system. This simulation serves as a reference scenario for the other four scenarios for combined ropeway use.

7.4.1.1 SC 1: boundary conditions - system parameters

Table 7-16 describes the ropeway specific input values for this simulation scenario:

Table 7-16: Boundary Conditions - System Parameters SC 1: ECO Scenario 2018

Boundary conditions - system parameters: Scenario 1: ECO Scenario 2018		
Network Structure		
city hubs	0	
distribution stations	0	
Station Layout		
station layout 1	Serial arrangement: person exit - person entry	
station throughput time with goods handling	-	sec
station throughput time without goods handling	44	sec
System Parameter		
operating time: Persons	Start 5:00 End 23:00	
operating time: Goods 1st cycle	Start - End -	-
operating time: Goods 2nd cycle	Start - End -	-
gondola cycle	42	sec
rope conveying speed	7,5	m/s
conveying speed rope (stations)	0,2	m/s
gondola acceleration	1	m/s²
gondola deceleration	1	m/s²
transport capacity passengers	35	per gondola
transport capacity roll container	-	per gondola
transport volume roll container	-	dm³
passenger gondolas on the system	104	gondola

7.4.2 SC 1: Evaluation

The following chapter analyses and evaluates the scenario. The most important points and results are briefly discussed.

7.4.2.1 Mean travel time - throughput – people

For the mean travel time and the daily throughput, the values in Table 7-17 results. The throughput figures at the stations show a high number of exits in the inner-city area and at the P&R facilities outside the city. Since probabilities, random numbers and percentages are used to simulate; these times can deviate slightly from different simulation runs even with the same simulation parameters. However, these deviations remain within limits and vary only slightly between simulations.

Table 7-17: Value table for average travel time - throughput for passenger transport

Station no.	MU type	Average throughput time	Throughput
Station 1	Person	00:19:58	2703
Station 2	Person	00:14:06	928
Station 3	Person	00:11:40	2729
Station 4	Person	00:12:38	3484
Station 5	Person	00:13:28	6166
Station 6	Person	00:13:45	4464
Station 7	Person	00:12:24	3277
Station 8	Person	00:13:52	3339
Station 9	Person	00:15:46	971
Station 10	Person	00:19:39	494
Station 11	Person	00:21:14	1915
			30480

The analysis of the mean travel time at the stations shows low travel times in the inner-city areas and an increase to the outer stations (Webling and Weinzödlbrücke) Diagram 7-1. The mean travel times (Average throughput time) also show the travel tendency. At the stations outside the city, the longer travel times with a decrease to the center can be seen because the people commute to the city early in the morning and tend to show short-distance tendencies in the center (the exact destination probabilities can be found in Table 3-7). It should also be mentioned that simulations are carried out with probabilities, random numbers and percentages. Therefore, even with the same simulation parameters, the times can deviate slightly between the later simulation scenarios (SC2-SC5). However, these deviations remain within limits and vary only slightly among each other and are therefore suitable for comparison.

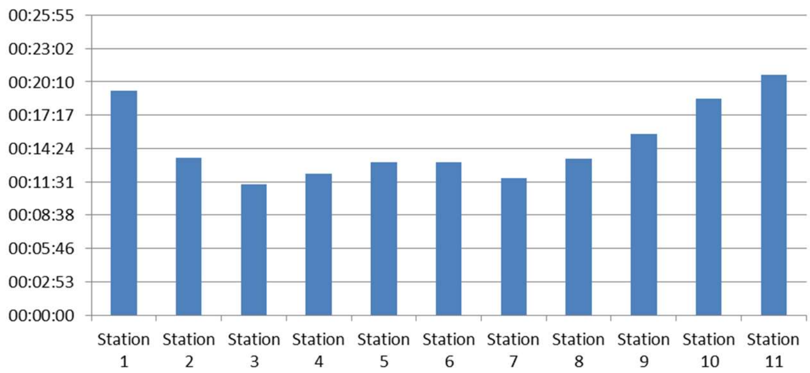


Diagram 7-1: Average travel time passenger transport, own representation [Nad18]

7.4.2.2 Detail: Number of persons - Station S11

The following Diagram 7-2 shows the arriving, waiting for persons for station S11 over the operating period. At the beginning of the steady increase, the early morning traffic and the start of work are due. The persons travel from outstations S1 and S11 to the center. The different times after work ensure that the number of people in the evening tends to flatten out. Compared to scenarios 2 and 3, there is a difference. However, this is due to the probability distribution of passenger destinations. (In each simulation run the persons are ranked (distributed) differently, so it can come to larger or smaller maximum values which in sum are identical to other scenarios).

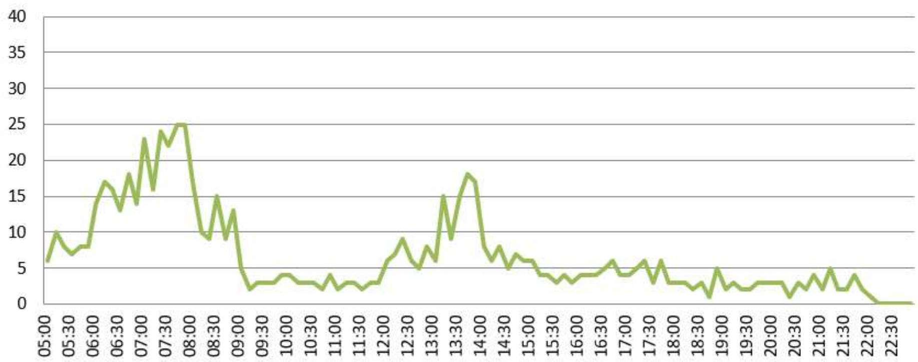


Diagram 7-2: Passenger volume in Cityhub over operating time, own representation [Nad18]

7.4.2.3 Detail: Number of persons - Station S5

Unlike the outstations, the more centrally located stations do not have to cope with peak traffic at the start of operations. However, there is a higher number of people in the waiting areas than in the outer stations over the entire operating period Diagram 7-3. The larger waiting groups tend to occur in the afternoon. (In each simulation run the persons are arranged (distributed) differently, so it can come to larger or smaller maximum values which in sum are identical to other scenarios).

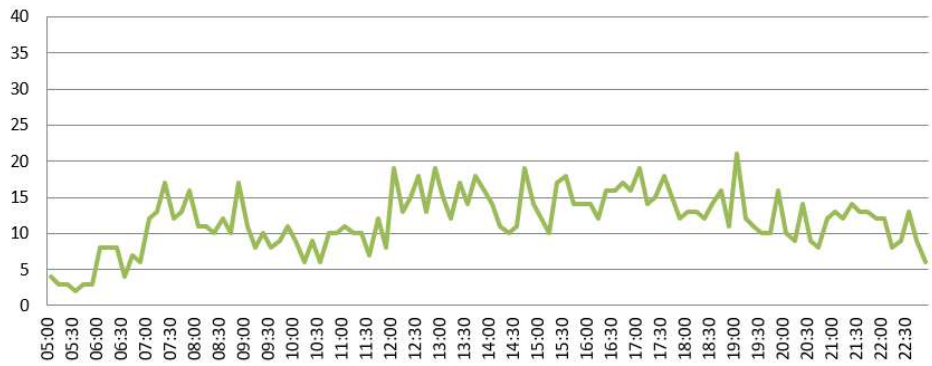


Diagram 7-3: Number of persons in distribution station over operating time [Nad18]

7.4.3 Scenario 2: ECO Scenario 2018 1-1

In the following subchapters, ECO Scenario 2: 2018 1-1 is evaluated in detail. Simulation scenario 2 is now extended by transport gondolas. This means that not all 104 gondolas are now available for passenger transport. 15 transport gondolas and 2 empty container gondolas are introduced.

7.4.3.1 SC 2: boundary conditions - system parameters

Table 7-18 describes the cable car-specific input values for this simulation scenario:

Table 7-18: Boundary Conditions - System Parameters SC 2: ECO Scenario 2018 1-1

Boundary conditions - system parameters: SC 2: ECO Scenario 2018 1-1		
Network Structure		
city hubs	1	
distribution stations	1	
Station Layout		
station layout 1	Serial arrangement: person exit - person entry	
station throughput time with goods handling	88	sec
station throughput time without goods handling	44	sec
System Parameter		
operating time: Persons	Start 5:00 End 23:00	
operating time: Goods 1st cycle	Start 04:55 End 11:00	into the city (CH to VS)
operating time: Goods 2nd cycle	Start 11:30 End 13:30	from the city (VS to CH)
gondola cycle	42	sec
rope conveying speed	7,5	m/s
conveying speed rope (stations)	0,2	m/s
gondola acceleration	1	m/s²
gondola deceleration	1	m/s²
transport capacity passengers	35	per gondola
transport capacity roll container	4	per gondola
transport volume roll container	550	dm³
passenger gondolas on the system	87	gondola
Transport gondolas in the system	15	gondola
Empty roll container transport gondolas in the system	2	gondola

Table 7-19 shows the target probabilities of individual persons for a particular station. These probabilities are identical for all scenarios and are charted in Chapter 3.2.5.

Table 7-19: Input parameter persons: SC 2: ECO Scenario 2018 1-1

Boundary conditions - input parameters: Scenario 2: ECO Scenario 2018 1-1		
Distribution of persons		
target probability matrix	charted in Table 3-7	%
number of persons	charted in Table 3-6	persons

Table 7-20 shows the parameters for Cargo transport. Specifically, the time at which the parcels are started to be transported to the respective station. The arrival of the respective individual packages is always assumed one hour in advance in order to have enough material in stock at the start of the operation to enable continuous work.

Table 7-20: Boundary conditions - input parameter goods: SC 2: ECO Scenario 2018 1-1

Boundary conditions - input parameters: Scenario 2: ECO Scenario 2018 1-1		
Total goods per station		
S11- cityhub south (Webling)	7200	#
S5 - Andreas Hofer Platz	1080	#
Distribution - Goods - into the city (CH to VS)		
S11 - Goods 1st cycle	Start 05:00 End 11:00	
S11 - Goods 2nd cycle	Start - End -	Not used for this scenario
Distribution of goods into the city (CH to VS)		
quantity of goods	see Table 7-21	
daytime curve	see Diagram 7-4	
Distribution - Goods - from the city (VS to CH)		
S5 - Goods 1st cycle	Start 11:30 End 13:30	
S5 - Goods 2nd cycle	Start - End -	Not used for this scenario
Goods distribution - from the city (VS to CH)		
quantity of goods	see Table 7-22	
daytime curve	see Diagram 7-5	

7.4.3.2 Time-variation curve goods - Cityhub

The assumed day curve for the individual arriving packages in the Cityhub was chosen in such a way that at the start of the shift at 05:00 the workers already have enough roll containers available to enable continuous working. The first arrival of the individual packages (%) is set at 04:00 and will be continued until 10:00 a.m., evenly distributed. The curve shows only at what time individual packages arrive and how many, it does not illustrate their further processing time or storage in the later system. The same percentage distribution was used as in scenarios 2 and 3; only the quantities were adjusted to 2025.

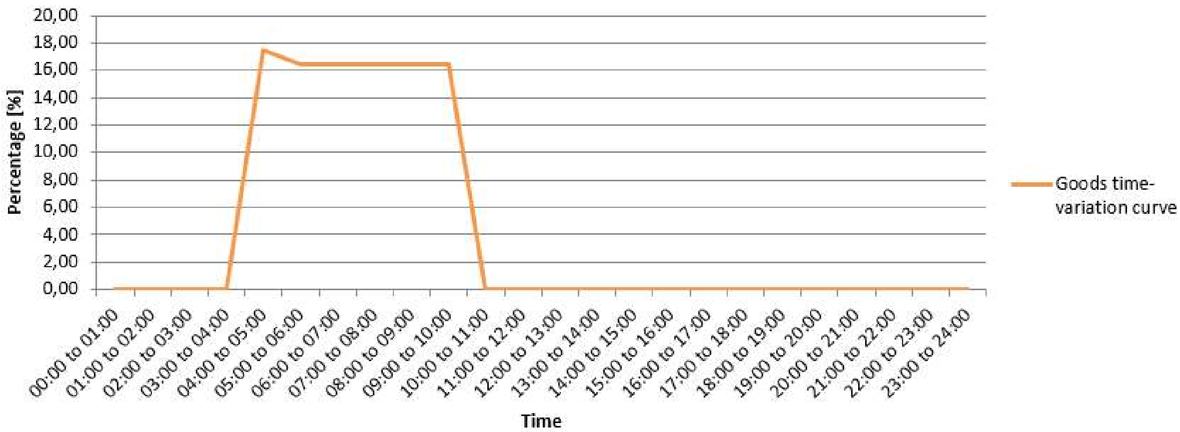


Diagram 7-4: Time-variation curve of the individual arriving packages in the cityhub

As a supplement to more accurate documentation, Table 7-21 shows how many individual packages (#) arrive in the system at that time (operating time [hh:mm:ss]). The number of incoming packages (quantity of goods) is then distributed evenly from the starting hour (operating time) to the 59th minute. However, it is started here to convey material one hour before the start of operation in order to have sufficient buffer material available at the start of the operation. The times can deviate strongly from the actual time of use.

Table 7-21: Distribution - Goods - in the city (CH to VS)

Goods distribution in the city (CH to VS): ECO scenario 2018 1-1	
operating time [hh:mm:ss]	quantity of goods
00:00:00	0
01:00:00	0
02:00:00	0
03:00:00	0
04:00:00	1260
05:00:00	1188
06:00:00	1188
07:00:00	1188
08:00:00	1188
09:00:00	1188
10:00:00	1188
11:00:00	0
12:00:00	0
13:00:00	0
14:00:00	0
15:00:00	0
16:00:00	0
17:00:00	0
18:00:00	0
19:00:00	0
20:00:00	0
21:00:00	0
22:00:00	0
23:00:00	0

7.4.3.3 Time-variation curve goods - Distribution station

Similar to the daily curve for the city hub, the arrival of the individual packages is also assumed in the distribution station one hour before the start of the return shipment (10:00-11:00). Here, too, the diagram shows only the arrival times and their quantity in percent. The later use or storage is not shown here.

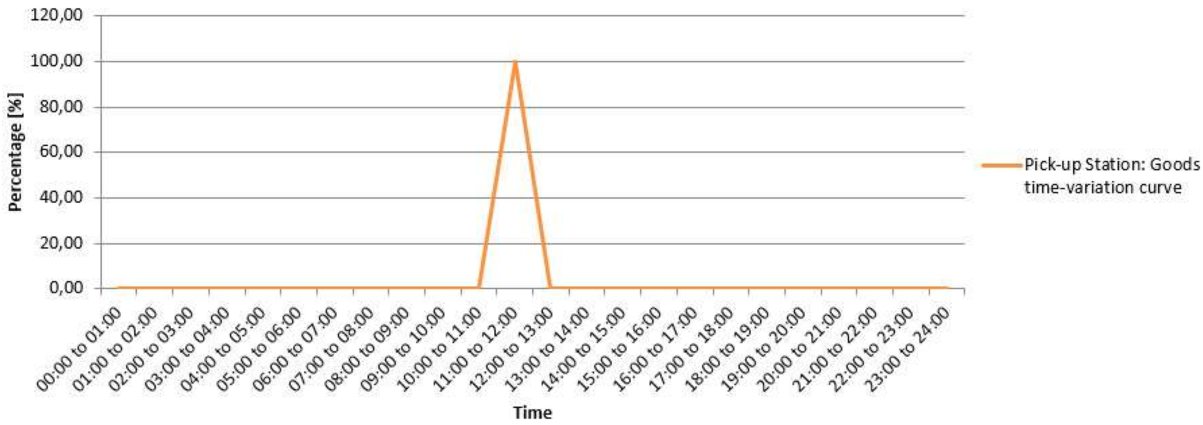


Diagram 7-5: Time-variation curve of the arriving packages in distribution stations

As in the previous table, Table 7-22 shows the respective quantity of goods at a specific operating time for the distribution station. It is only possible to start conveying individual packages from the city here when the last roll container has arrived from the cityhub. However, the table shows only the arrival times for the individual packages, one hour before the start of the operation. Here, too, the times may differ considerably from the actual time of use.

Table 7-22: Distribution - Goods - from the city (VS to CH)

Distribution of goods from the city (VS to CH): ECO scenario 2018 1-1	
operating time [hh:mm:ss]	quantity of goods
00:00:00	0
01:00:00	0
02:00:00	0
03:00:00	0
04:00:00	0
05:00:00	0
06:00:00	0
07:00:00	0
08:00:00	0
09:00:00	0
10:00:00	1080
11:00:00	0
12:00:00	0
13:00:00	0
14:00:00	0
15:00:00	0
16:00:00	0
17:00:00	0
18:00:00	0
19:00:00	0
20:00:00	0
21:00:00	0
22:00:00	0
23:00:00	0

7.4.3.4 SC 2: boundary conditions – workers

In the following Table 7-23, the general parameters of the workers in the system. The working times shown are shift times (including theoretical breaks).

Table 7-23: Boundary conditions - Workers: Scenario 2

Cityhub		
1st shift	Start 4:50 End 13:30	
2nd shift	Start - End -	Not used for this scenario
shift times	8:35	h
Distribution station		
1st shift	Start 5:20 End 12:45	
2nd shift	Start - End -	Not used for this scenario
shift times	7:25	h

7.4.3.5 SC 2: boundary conditions – nested roll container

Roll containers are transported from the cityhub to the city. There they are unloaded and processed. In order to prevent excessive accumulation of roll containers, they are combined into so-called "nests".
For their transport, transport gondolas are skipped (not filled) in the city hub. They are loaded with empty containers in the distribution station. (Empty container gondolas).

Table 7-24: Nests: Scenario 2: ECO Scenario 2018 1-1

Empty roll container gondolas		
Number of empty roll container gondolas	2	#
Empty container gondola numbers	3, 12	
Nests per empty container gondola	2	#
Roll container per Nest	12	#

The exact procedure for the return of the empty roll container can be found in chapter 4.5 on page 45.

7.4.4 SC 2: Evaluation

The following chapter analyses and evaluates the scenario. The most important points and results are briefly discussed.

7.4.4.1 Mean travel time - throughput – people

For the mean travel time and the daily throughput, the values in Table 7-25 results. The throughput figures at the stations show a high number of exits in the inner-city area and at the P&R facilities outside the city. Since probabilities, random numbers and percentages are used to simulate; these times can deviate slightly from different simulation runs even with the same simulation parameters. However, these deviations remain within limits and vary only slightly between simulations.

Table 7-25: Value table for average travel time - throughput for passenger transport

Station no.	MU type	Average throughput time	Throughput
Station 1	Person	00:20:08	2745
Station 2	Person	00:14:10	957
Station 3	Person	00:12:04	2741
Station 4	Person	00:12:53	3501
Station 5	Person	00:13:36	6269
Station 6	Person	00:13:44	4388
Station 7	Person	00:12:26	3196
Station 8	Person	00:14:08	3288
Station 9	Person	00:16:19	1024
Station 10	Person	00:19:19	510
Station 11	Person	00:21:32	1858
			30477

The analysis of the mean travel time at the stations shows short travel times in the inner-city areas and an increase to the outer stations (Webling and Weinzödlbrücke) Diagram 7-6. In comparison, pure passenger transport was shown (blue bars). The combined transport (yellow bars) shows an increase in average travel times by approx. 40 seconds per station. This combination corresponds approximately to a gondola cycle.

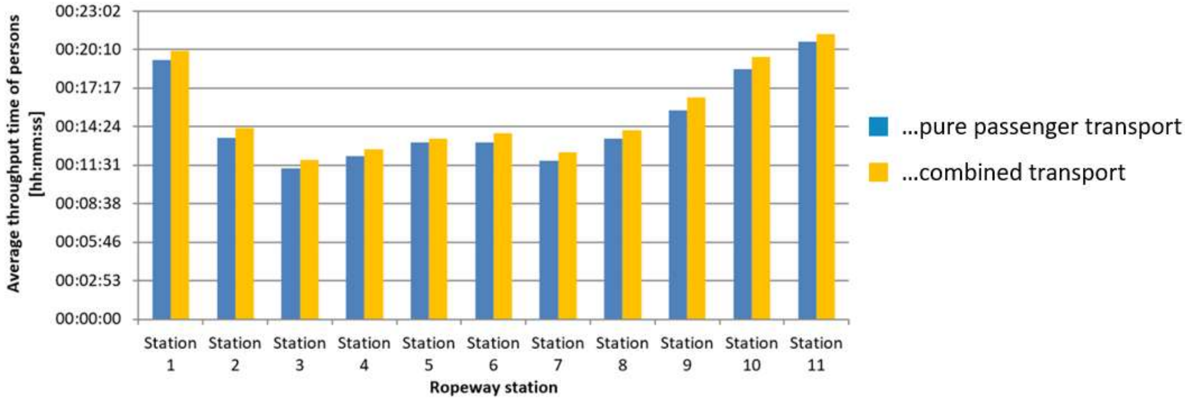


Diagram 7-6: Average travel time passenger transport, own rep. [Nad18]

7.4.4.2 Detail: Number of persons - Station S11

The following Diagram 7-7 shows the arriving, waiting for persons for station S11 over the operating period. At the beginning of the steady increase, the early morning traffic and the start of work are due. The persons travel from outstations S1 and S11 to the center. The different times after work ensure that the number of people in the evening tends to flatten out. (In each simulation run the persons are ranked (distributed) differently, so it can come to larger or smaller maximum values which in sum are identical to other scenarios).

Diagram 7-7: Passenger volume in Cityhub over operating time, own representation [Nad18]

7.4.4.3 Detail: Number of persons - Station S5

Unlike the outstations, the more centrally located stations do not have to cope with peak traffic at the start of operations. However, there is a higher number of people in the waiting areas than in the outer stations over the entire operating period Diagram 7-8. The larger waiting groups tend to occur in the afternoon.

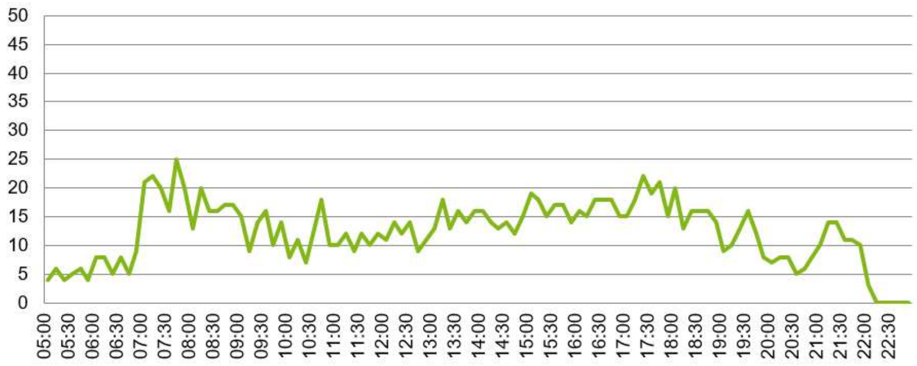


Diagram 7-8: Number of persons in distribution station over operating time[Nad18]

7.4.4.4 Detail: Gondola - waiting times

Diagram 7-9 shows the maximum occupancy of the individual gondolas over the entire operating period about the corresponding gondola numbers.
The waiting time per station in the various simulation runs a maximum of two gondola cycles (84 seconds), but in most runs, one gondola cycle (42 seconds) was the maximum waiting time increase. Diagram 7-10 shows the maximum content of each gondola during the simulation period. The gondolas in the lower part of the diagram (below 5 #) are the transport gondolas and the empty container gondolas. The gondolas that come directly after such transport or empty container gondola are all higher loaded and fully utilised, as people who are just passing through a non-passenger gondola have to wait for these to arrive.
The average passenger gondola occupancy is just under 18 persons.

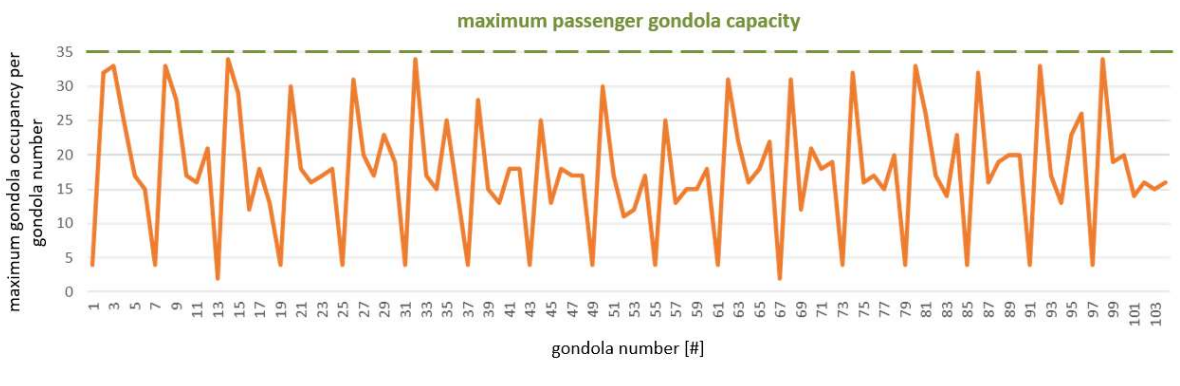


Diagram 7-9: Maximum occupancy per gondola, own display

In detail, the following diagram shows the direct and indirect following gondola (No. 32 and No. 33) after a non-person gondola (No. 31).

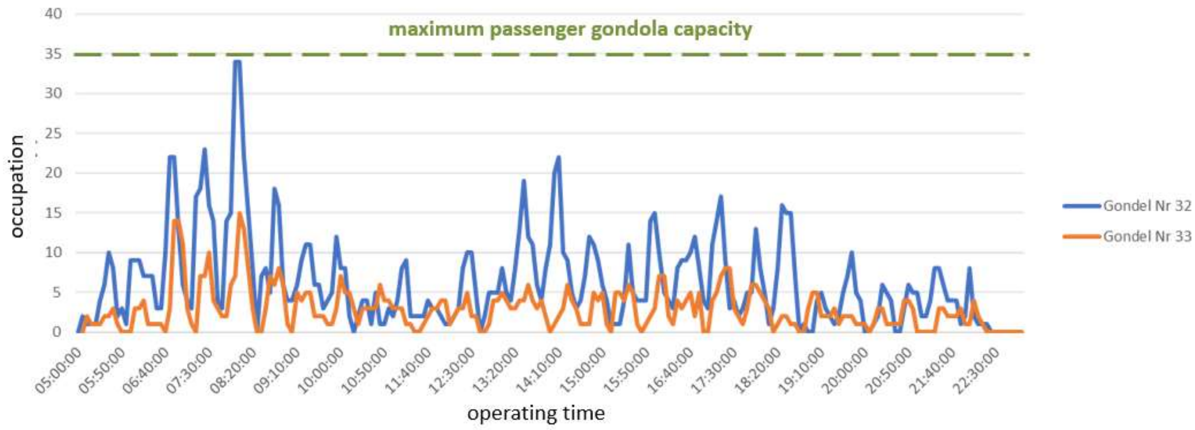


Diagram 7-10: Max. capacity of the direct and indirect following gondola of a transport gondola

The blue line shows the current content per operating time of the following gondola (No. 32) after a non-person gondola (No. 31). There is one peak, but it does not reach the maximum of the gondola capacity (35 persons per gondola). The orange line shows the gondola following directly (No. 33). This means that the gondola capacity is never more than 50% loaded during the simulation run. For this simulation run, it can be concluded that persons have to wait for an additional maximum of one gondola cycle (42 seconds).

7.4.4.5 Detail: Gondola - Capacity utilisation

In this scenario, too, the capacity utilisation of the gondola varies according to type and period of use:

- Passenger gondolas: 05:00 to 23:00
- Goods gondolas: 05:00 to 13:30
- Empty container gondolas: 06:45 to 12:45

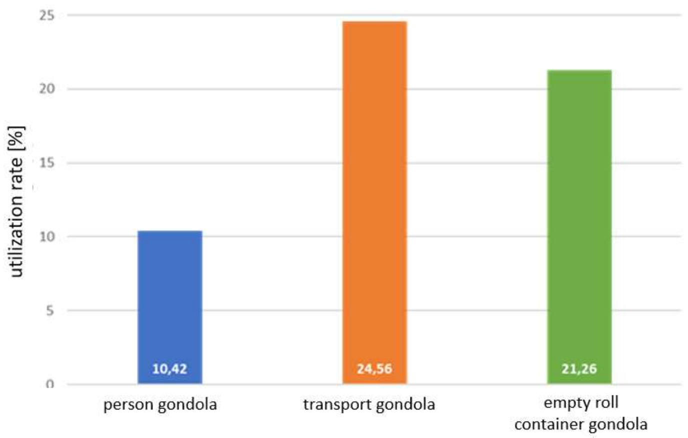


Diagram 7-11: Average gondola utilisation over the respective operating period

Passenger gondolas are the least used of all types (10.42%). The reason for this is the high number of passenger gondolas, which, however, has a positive effect on the waiting time.

For the transport gondolas, the respective transport route is decisive. Transport gondolas travel the longer distance unloaded (depending on the layout between S5 and S11), but the loaded distances are always fully loaded. They are, therefore, better utilised (24.56%).

Empty container gondolas travel a longer distance loaded, but over a shorter period. They are therefore used to roughly the same capacity as the transport gondolas (21.26%).

The following diagram shows the utilisation of passenger gondolas between two non-passenger gondolas. The direct following gondola (No. 1) to a non-person gondola is the one with the highest load factor in all cases (between 17% and 25%). The subsequent indirect gondolas rarely reach an average load of more than 10%.

Diagram 7-12 shows the utilisation of passenger gondolas between two non-passenger gondolas. The direct follow-up gondola (No. 1) to a non-person gondola is the one with the highest load factor in all cases (between 16% and 23%). The subsequent indirect gondolas then never reach an average occupancy rate of more than 10%.

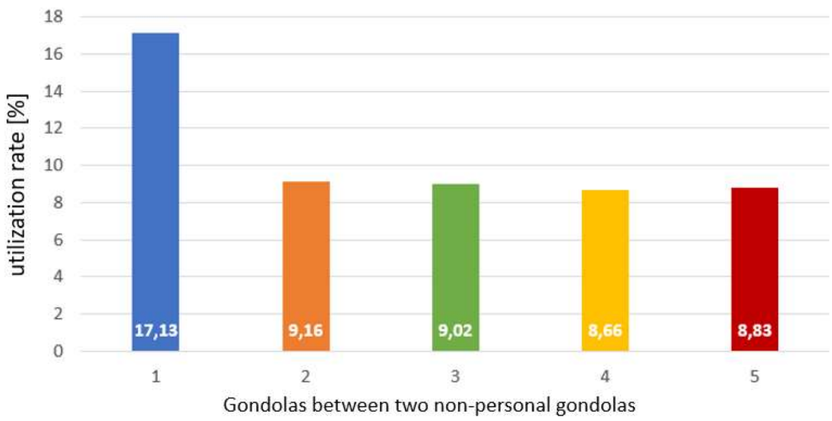


Diagram 7-12: Non-person gondola utilisation between two transport gondolas

7.4.4.6 Average lead time - throughput – goods

The average cycle time is used to calculate the time a packet (load) needs to travel from start station (station) to destination station (Table 7-26). Individual parcels from the cityhub take longer to load because the layout means that they can only be loaded and unloaded in one direction (see Figure 3-10: Station layout - 4b [Nad18]). Also, a certain number of gondolas are designed as empty container gondolas and therefore cannot be loaded with the regular return consignments. The times are identical to those from other scenarios, since only the quantity of transports changes, parameters such as transport route or gondola cycle remain the same.

Table 7-26: Value table average processing time - throughput

station	BE Typ	Average lead time	throughput
Andreas-Hofer-Platz	Load	1:04:59	1080
P&R Webling	Load	0:34:45	7200

7.4.4.7 Detail: Gondola times -staff general

Figure 7-1 shows how long gondolas require, on average between quality stations. As already explained above, loading and unloading are only carried out in one direction due to the layout.

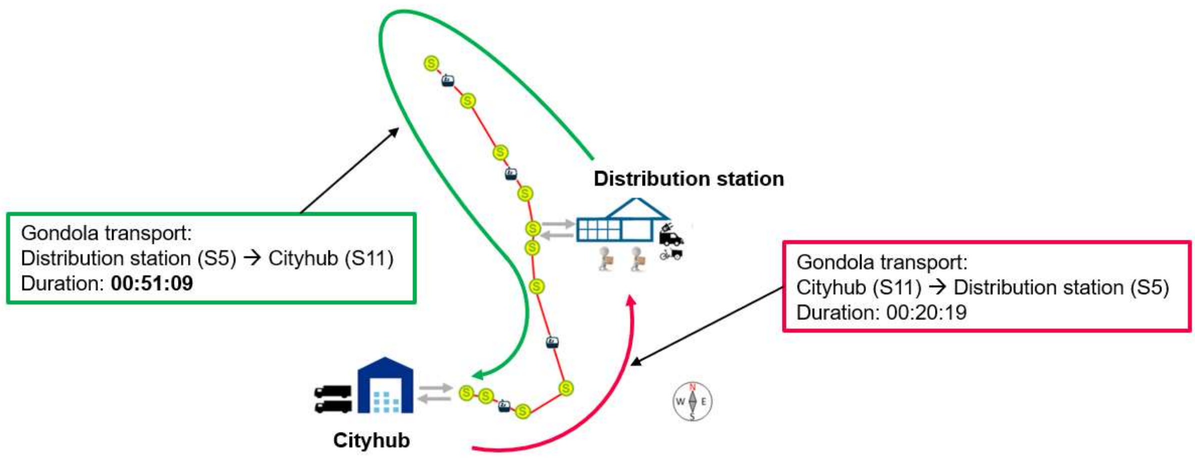


Figure 7-1: Transport times between cityhub and distribution station, own rep.

The figure above illustrates the transport times and distances in the respective transport direction.

Table 7-27: Transport times between individual stations of transport gondolas

definition	operating time	definition	operating time	time required
First transport gondola leaves Cityhub	05:05:51	First Cityhub transport gondola reaches distribution station	05:26:10	00:20:59
First transport gondola leaves distribution station	11:44:07	First transport gondola from distribution station reaches Cityhub	12:35:16	00:51:51
Last transport gondola leaves Cityhub	11:00:33	Last transport gondola of Cityhub reaches distribution station	11:20:52	00:20:59
Last transport gondola leaves distribution station	12:34:31	Last transport gondola of distribution station reaches Cityhub	13:25:40	00:51:51

Diagram 7-13 illustrates the time at which each key gondola leaves or arrives at the station. Depending on the choice of return gondolas, the necessary goods transport may already have been completed, but the accrued roll containers still have to be returned. This can lead to longer shift times.

7.4.4.8 Detail: Empty container gondola times - general

In order to return the roll containers from the distribution station, they are combined to so-called "nests", which are then loaded into empty container gondolas. Empty container gondola parameters can be found in Table 7-28.

Table 7-28: Transport times between individual stations of empty container gondolas

definition	operating time	definition	operating time	time required
First empty container gondola leaves the distribution station	06:44:01	First empty container gondola reaches Cityhub	07:35:10	00:51:51
Last empty container gondola leaves distribution station	12:13:39	Last empty container gondola reaches Cityhub	13:04:40	00:51:50

The average transport time for empty container gondolas is the same as for normal return gondolas due to their structure. Diagram 7-13 shows the most critical points in time. The simulation was designed so that the last gondola is a regular transport gondola and not an empty container gondola. Otherwise, there would be unintentionally long waiting times for the worker. Since the simulation calculates with random numbers, the number of individual packages in the roll containers varies, and different end times can occur. However, the latest possible time that was reached was assumed for the shift times (arrival of the last empty container gondola in the cityhub at 13:04:40).

The blue line shows the fill level of the buffers of the individual packages of the city hub; the orange line is enlarged and shows the fill level of the buffer in the distribution station. The corresponding numbers are assigned in Table 7-27 and Table 7-28.

1. First transport gondola leaves Cityhub
2. Last transport gondola of distribution station reaches Cityhub
3. First empty container gondola leaves the distribution station
4. Last empty container gondola reaches Cityhub

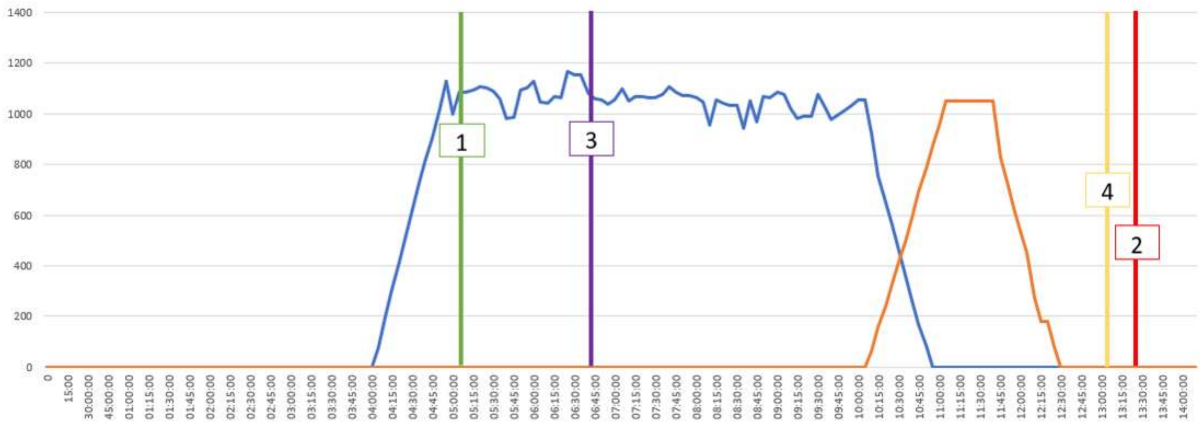


Diagram 7-13: Arrival and departure times of relevant gondolas via operating time, own display

7.4.4.9 Detail: Roll container turnover station S11

The rolling containers arriving at the distribution station are unloaded there and grouped into nests. This results in certain waiting times for the roll containers. Table 7-29 shows the average handling time of the respective transport directions.

Table 7-29: Detail: Roll container turnover - Station S11 (Cityhub)

Detail: Roll container turnover - Station S11 (Cityhub)		
General - roll containers		
Average handling time Cityhub - Cityhub	03:00:44	(hh:mm:ss)
Average handling time distribution station - Cityhub	01:06:06	(hh:mm:ss)
Roll container exit Cityhub	288	#
Roll container stairway Cityhub	220	#
Roll container departure Distribution station	43	#

Diagram 7-14 shows the handling time for each arriving roll container (ordinate). Roll containers arriving at a later hour have a longer waiting time than those arriving earlier due to the process. On average, this results in an average turnaround time of 3:00:44 per roll container, with an increasing tendency the longer work is carried out.

At peak times, there is a maximum of 84 roll containers (72 nested, 12 in use) on the distribution level in the distribution station (maximum buffer area (nested): 15.67 m²).

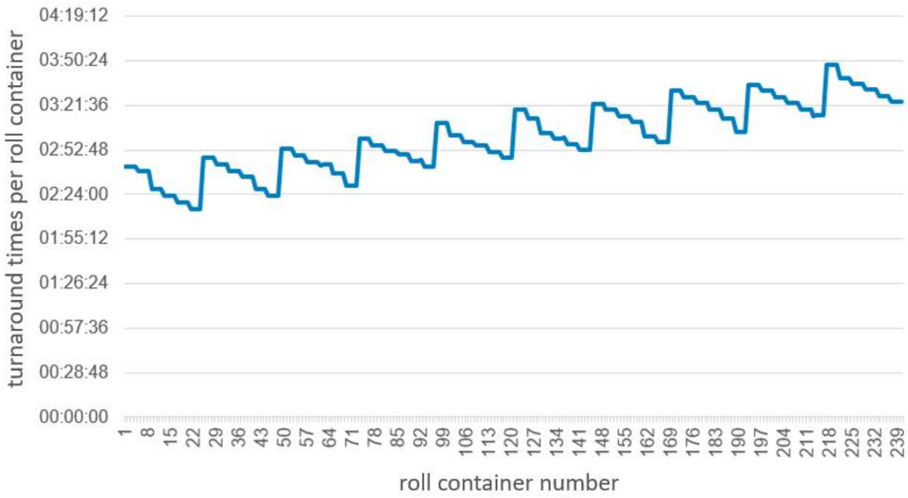


Diagram 7-14: Turnaround time per roll container from cityhub to city hub, own display

- Example 1: Roll container no. 49 needs 02:24:00 to get from the cityhub back to the city hub.
- Example 2: Roll Container No. 141 needs 02:52:48 to get back from the Cityhub to the Cityhub again

7.4.4.10 Logistics staff – general

Logistics staff are classified into two categories. The first is how long they have to work according to the shift schedule to be able to handle the transport capacities. The other category is effective working time. How long is each logistics staff busy at their place of work? Logistics staff at the gondola level are the focus here. As they represent the parameters relevant to the timing. In the primary mode of operation, the logistics staff is on average occupied with 60% to 70%. However, this value decreases in the course of the simulation, since both are exposed to longer waiting times due to the process. Thus, the logistics staff from the city hub must wait until the first regular transport gondola arrives from the distribution station (waiting time on average 2x50 min, excluding possible empty container gondolas). Diagram 7-15 illustrates the degree of utilisation of the respective workers in the individual stations, divided into three areas:

- 1st start-up Transport to the city
- 2nd start-up of empty container transport
- 3rd start-up transport from the city

In the first area, capacity utilisation must build up slowly, since all buffer positions must be filled at the beginning, capacity utilisation in this area is slightly high (average capacity utilisation between 50% and 60%).
In the second area, in addition to the regular roll containers, the handling of the empty containers must also be handled. This results in a renewed increase in capacity utilisation per worker (increase between 5% and 10% to just under 70%).
In the third area are all regular roll containers that are transported to the city. Transport from the city is started. Due to the process-related waiting times between the last regular roll container from the city hub and the first regular from the distribution station, the workload of the workers from the city hub is decreasing (reduction of the workload in the city hub by 5% to 10%). The workers from the distribution station start with the roll container transport from the city. Therefore, their utilisation decreases only slightly.

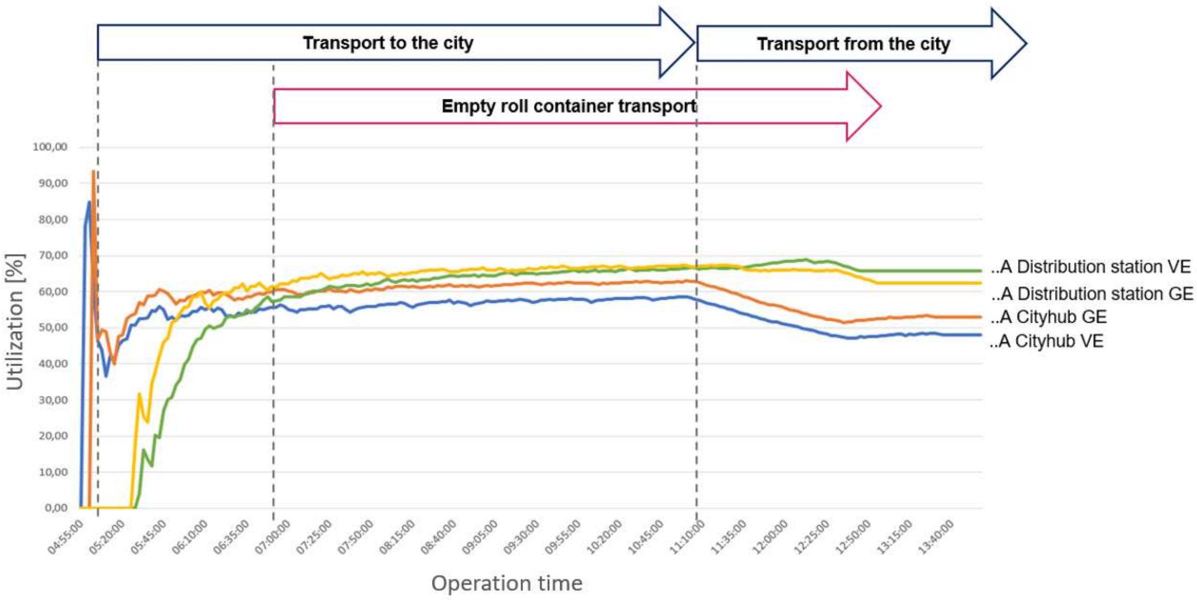


Diagram 7-15: Utilisation of workers over the work period (1-1), own representation

Table 7-30, each worker is evaluated over the shift period, i.e. how busy he was over his work period.

Table 7-30: Worker load factor: Scenario 2: ECO Scenario 2018 1-1

Worker load factor: Scenario 2: ECO Scenario 2018 1-1		
General information		
Number of workers in the system	4	
1. CityHub		
distribution level		
1.1. Carrying	34.01	%
1.2. On the way to task	14.03	%
1.3. Working	48.04	%
1.4. Pause	51.96	%
1.5. Distance covered	9798.44	m
gondola level		
1.6. Carrying	40.33	%
1.7. On the way to task	12.67	%
1.8. Working	52.99	%
1.9. Pause	47.01	%
1.10. Distance covered	8615.00	m
2. Verteilerstation		
distribution level		
1.1. Carrying	45.30	%
1.2. On the way to task	20.41	%
1.3. Working	65.71	%
1.4. Pause	34.29	%
1.5. Distance covered	11541.42	m
gondola level		
1.6. Carrying	48.65	%
1.7. On the way to task	13.86	%
1.8. Working	62.50	%
1.9. Pause	37.50	%
1.10. Distance covered	9302.70	m

7.4.4.11 Intermediate summary SC 2

In scenario 2, a combined simulation run is shown for the first time. It displays that the defined number of people can be transported without long waiting times. However, people who happen to arrive while a transport gondola is passing through may have to await this cycle. The critical factor in this simulation is the workflow of the worker at the gondola level in the city hub and the distribution station. This factor determines the maximum possible utilisation of the plant. In particular, the process of loading and unloading the gondola.

7.4.5 Scenario 3: ECO Scenario 2018 2-2

Simulation scenario 3 is now extended by one worker per level and station; all other parameters remain identical to scenario 2: ECO scenario 2018 1-1.

7.4.6 SC 3: Evaluation

The difference SC 2 between SC 3 is the deployment of an additional worker per level and station. The same process and work steps are performed. Depending on the simulation, there is always one alpha and one beta worker for several workers. This means that when a new task is received, i.e. in order to be fulfilled, a worker (alpha) starts first in order to fulfil it. If the workstation is then free, and another order is still open, the second (beta) worker starts executing the task. Also, one of the workers may be completing a task while the other is pausing. It comes then to differently long working times and distances. Recognisable. In addition to this, the Alpha worker performs the short tasks (such as unloading the nested roll containers) alone until the other worker has completed his task or reached the new task. In Diagram 7-16 these "dislocations" are recognisable as one worker is higher utilised than the other one at the same level (green line). In total, however, the same work tasks have been completed, and the workload has theoretically been halved by the other workers sitting in.

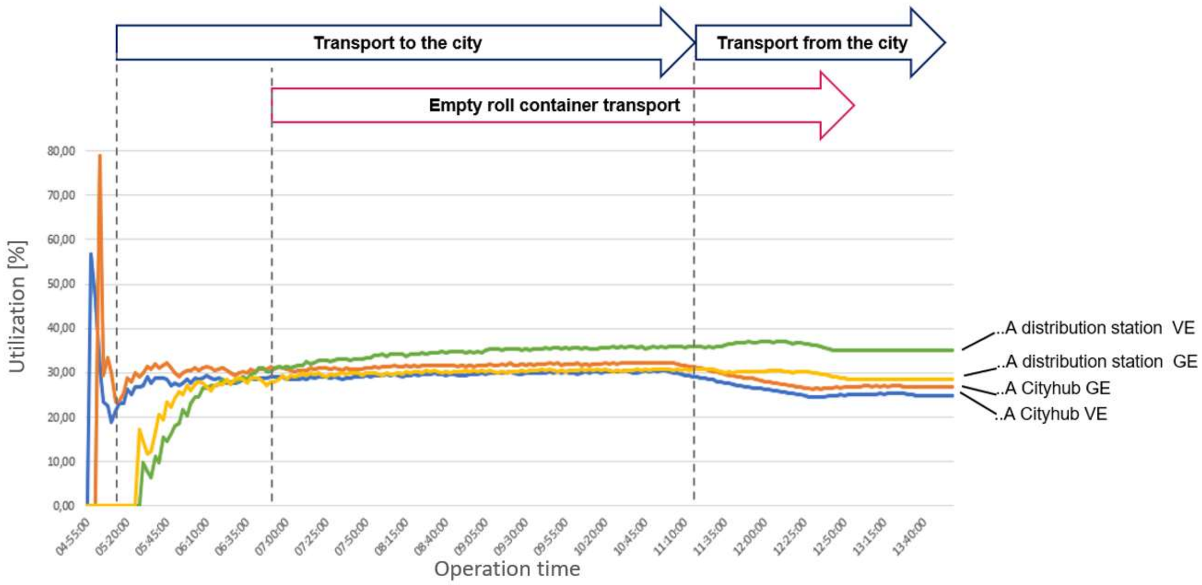


Diagram 7-16: Utilisation of workers over the work period (2-2), own representation

In Table 7-31 and Table 7-32, each worker is evaluated over the shift period, i.e. how utilised he was over his work period. In comparison to scenario 2, the working distance and the workload have almost halved (with small deviations that had to be made due to the adjustments in the simulation program (waiting times, waiting positions, ...) in order to make the use of several workers possible).

Table 7-31: Worker occupancy: Scenario 3: ECO Scenario 2018 2-2 (1)

Worker load factor: Scenario 2: ECO Scenario 2018 1-1 (1)		
General information		
Number of workers in the system	8	
1. CityHub		
Distribution level- worker 1		
1.1. Carrying	17.40	%
1.2. On the way to task	7.45	%
1.3. Working	24.85	%
1.4. Pause	75.15	%
1.5. Distance covered	5933.50	m
Distribution level- worker 2		
1.6. Carrying	17.17	%
1.7. On the way to task	6.24	%
1.8. Working	23.40	%
1.9. Pause	76.60	%
1.10. Distance covered	5939.74	m
Gondola level - worker 1		
1.1. Carrying	20.27	%
1.2. On the way to task	6.41	%
1.3. Working	26.68	%
1.4. Pause	73.32	%
1.5. Distance covered	4599.20	m
Gondola level - worker 2		
1.6. Carrying	20.34	%
1.7. On the way to task	5.99	%
1.8. Working	26.33	%
1.9. Pause	73.67	%
1.10. Distance covered	4444.96	m

Table 7-32: Worker occupancy: Scenario 3: ECO Scenario 2018 2-2 (2)

Worker load factor: Scenario 2: ECO Scenario 2018 1-1 (2)		
2. **Distribution station**		
Distribution level- worker 1		
2.1. Carrying	23.09	%
2.2. On the way to task	11.92	%
2.3. Working	37.06	%
2.4. Pause	62.94	%
2.5. Distance covered	7216.94	m
Distribution level- worker 2		
2.6. Carrying	23.09	%
2.7. On the way to task	11.92	%
2.8. Working	37.21	%
2.9. Pause	62.79	%
2.10. Distance covered	7362.95	m
Gondola level - worker 1		
2.1. Carrying	24.02	%
2.2. On the way to task	4.42	%
2.3. Working	28.43	%
2.4. Pause	71.57	%
2.5. Distance covered	3985.08	m
Gondola level - worker 2		
2.6. Carrying	24.75	%
2.7. On the way to task	3.73	%
2.8. Working	28.48	%
2.9. Pause	71.52	%
2.10. Distance covered	4021.42	m

7.4.6.1 Intermediate summary SC 3

Essentially, there are hardly any differences between scenario 2 and scenario 3 since almost all parameters remain the same. The scenarios differ only in the utilisation of logistics staff. These are only half of what is required over the entire operating period and also have to cover shorter distances.

The use of the additional workers does not influence the gondola utilisation system utilisation.

7.4.7 Scenario 5: ECO Scenario 2025 2-2

Simulation scenario 5 is now extended by one worker per level and station, all other parameters remain identical to scenario 4: ECO scenario 2025 1-1.

7.4.8 SC 5: Evaluation

The difference SC 4 between SC 5 is the deployment of an additional worker per level and station. The same process and work steps are performed. Depending on the simulation, there is always one alpha and one beta worker for several workers. This means that when a new task is received, i.e. in order to be fulfilled, a worker (alpha) starts first in order to fulfil it. If the workstation is then free, and another order is still open, the second (beta) worker starts executing the task. Also, one of the workers may be completing a task while the other is pausing. It comes then to differently long working times and distances. Recognisable. In addition to this, the Alpha worker performs the short tasks (such as unloading the nested roll containers) alone until the other worker has completed his task or reached the new task. In Diagram 7-17 these "dislocations" are recognisable as one worker is higher utilised than the other one at the same level (green line). In total, however, the same work tasks have been completed, and the workload has theoretically been halved by the other workers sitting in.

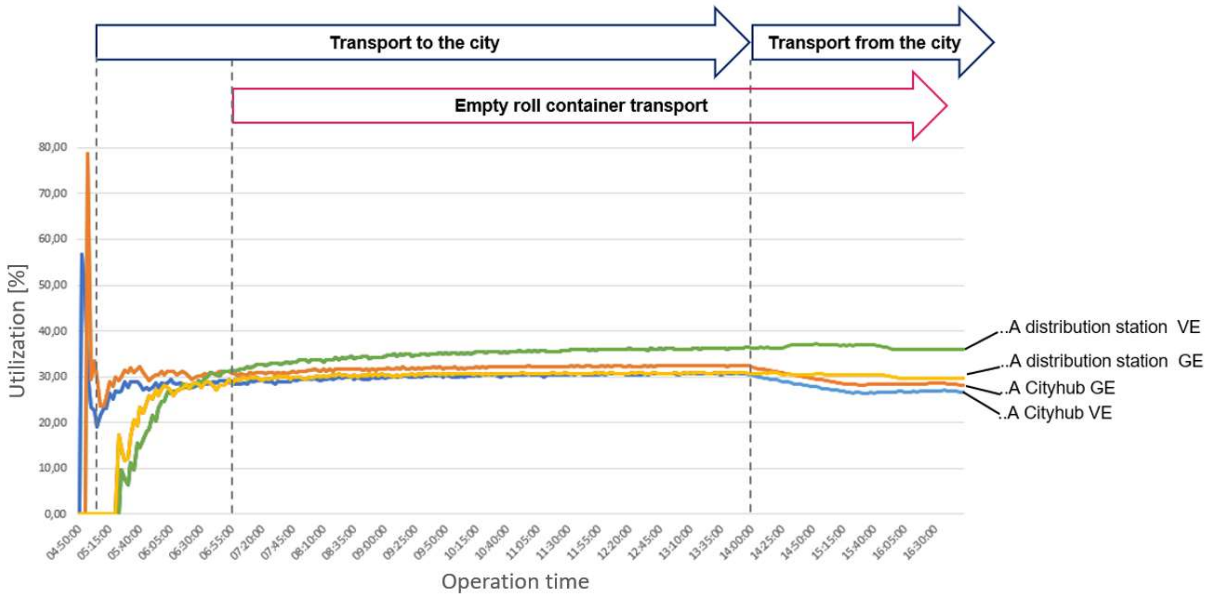


Diagram 7-17: Utilisation of workers over the work period (2-2), own representation

In Table 7-33 and Table 7-34, each worker is evaluated over the shift period, i.e. how utilised he was over his work period. In comparison to scenario 2, the working distance and the workload have almost halved (with small deviations that had to be made due to the adjustments in the simulation program (waiting times, waiting positions, ...) in order to make the use of several workers possible).

Table 7-33: Worker occupancy: Scenario 5: ECO Scenario 2025 2-2

Worker load factor: Scenario 5: ECO Scenario 2025 2-2 (1)		
General information		
Number of workers in the system	8	
1. CityHub		
Distribution level- worker 1		
1.1. Carrying	18.52	%
1.2. On the way to task	7.98	%
1.3. Working	26.50	%
1.4. Pause	73.50	%
1.5. Distance covered	8786.00	m
Distribution level- worker 2		
1.6. Carrying	18.20	%
1.7. On the way to task	6.61	%
1.8. Working	24.81	%
1.9. Pause	75.19	%
1.10. Distance covered	8771.44	m
Gondola level - worker 1		
1.1. Carrying	21.25	%
1.2. On the way to task	6.78	%
1.3. Working	28.03	%
1.4. Pause	71.97	%
1.5. Distance covered	6816.00	m
Gondola level - worker 2		
1.6. Carrying	21.29	%
1.7. On the way to task	6.34	%
1.8. Working	27.64	%
1.9. Pause	72.36	%
1.10. Distance covered	6597.60	m

Table 7-34: Worker occupancy: Scenario 5: ECO Scenario 2025 2-2 (2)

Worker load factor: Scenario 5: ECO Scenario 2025 2-2 (2)		
2. Distribution station		
Distribution level- worker 1		
2.1. Carrying	23.88	%
2.2. On the way to task	12.25	%
2.3. Working	38.24	%
2.4. Pause	61.76	%
2.5. Distance covered	10670.57	m
Distribution level- worker 2		
2.6. Carrying	23.04	%
2.7. On the way to task	13.15	%
2.8. Working	38.23	%
2.9. Pause	61.77	%
2.10. Distance covered	10894.29	m
Gondola level - worker 1		
2.1. Carrying	25.11	%
2.2. On the way to task	4.65	%
2.3. Working	29.76	%
2.4. Pause	70.24	%
2.5. Distance covered	5917.92	m
Gondola level - worker 2		
2.6. Carrying	25.84	%
2.7. On the way to task	3.89	%
2.8. Working	29.74	%
2.9. Pause	70.26	%
2.10. Distance covered	5954.34	m

7.4.8.1 Intermediate summary SC 5

In SC 5, one more worker is deployed per level and station. The transport quantity between SC 4 and SC 5 remains the same. Here, too, only the workload of the worker's changes, which is halved. The system and gondola utilisation have not changed compared to SC 4 because of the constant main parameters.

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7.6 Lists

7.6.1 List of figures

7.6.2 List of tables

7.6.3 List of diagrams

7.6.4 List of files

Master thesis report (*.pdf)

2019_06_25_Urban_Ropeway_paper_II_v9_ab	PDF document containing the written report

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

ropeway_model_S1_2018_x_15_ab	Plant Simulation file: Simulation model of the urban ropeway system for transport of people -Scenario 1
ropeway_model_S2_2018_X_1_1_V17_ab	Plant Simulation file: Simulation model of the urban ropeway system for the combining transport of people and goods - Scenario 2
ropeway_model_S2_2018_X_2_2_V17_ab	Plant Simulation file: Simulation model of the urban ropeway system for the combining transport of people and goods - Scenario 3
ropeway_model_S2_2025_X_1_1_V17_ab	Plant Simulation file: Simulation model of the urban ropeway system for the combining transport of people and goods - Scenario 4
ropeway_model_S2_2025_X_2_2_V17_ab	Plant Simulation file: Simulation model of the urban ropeway system for the combining transport of people and goods - Scenario 5

Input files (*.xlsx, *.xlsm)

Parameter_simulation_ropeway_v1_ab.xlsm	Excel file to generate the input files for the simulation model
Gueterbefoerderung_v2_Betriebszeit0500_2300_ab.xlsx Gueterbefoerderung_v3_Betriebszeit0500_2300_ab.xlsx	Excel file to configure the time-variation curve for goods transportation (v2 for 2018; v3 for 2025)
Personenbefoerderung_v2_Betriebszeit0500_2300_ab.xlsx	Excel file to configure the time-variation curve for passenger transportation
Ropeway_parameter_v2_ab.xlsx	Excel file to calculate basic input parameters

Analysis files (*.xlsx)
Evaluation files are saved for each scenario in a name-specific form (shown as an example for scenario 4).

1_Analysis_workload_2025_1_1_v1_ab	Excel file to analyse departure and arrival times, basic worker data and gondola occupation
1_Analysis_workload_buffer_2025_1_1_v1_ab	Excel file to analyse station buffer
2_Analysis_workload_gondola_report_2025_1_1_v1_ab	Excel file to analyse gondola utilization and output report
Gondelauslastung_Auswertung_2025_1_1_v1_ab	Excel file to calculate the gondola occupation
GondelüberZeit_Auslastung_2025_1_1_v1_ab	Excel file to calculate the gondola occupation according to the operating time
Rollcontainer_Auswertung_2025_1_1_v1_ab	Excel file to analyse basic roll container parameter
Szenario_3_ECO_Szenario_2025_1-1_Gantt_v1_ab	Excel file to define the working shifts via a Gantt chart
Werker_ArbeitüberZeit_2025_1_1_v1_ab	Excel file to plot the worker tasks over the operating time
Werker_ArbeitüberZeit_Auslastung_2025_1_1_v1_ab	Excel file to plot the worker utilization over the operating time
Gondelbelegung_über_Betriebszeit_2015_1-1	Excel file to plot the gondola utilization
Rollcontainerzeiten_v1_ab	Excel file to analyse the roll container time and numbers
UP_DOWN_Zeiten_S2_V1_ab	Excel file to analyse the Load travel times between stations and levels