FH Vorarlberg
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Analysing Crowd Flow in Skiing Areas by means of Simulation

Master Thesis

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Abstract

Skiing is one of the most popular winter sports in the world and especially in the alps. As the skiers enjoy their time on the slopes the most annoying thing that could happen is long waiting times at a lift. Unfortunately, because of climate changes, this happens more regularly because smaller skiing areas at lower altitudes have to close and the number of good skiing days decreases as well. This leads to a increase in the number of skiers in the skiing areas which inevitably leads to longer waiting times and dissatisfied skiers. To prevent this from happening, the carriers of the skiing areas have to manage the skiers flow and distribution and what better way to analyse the current situation and possible changes then by simulating the whole area.

A simulation has the advantage of being flexible with regards to time as well as configuration. Be it simulating a skiing day and look into detail of the behaviour of a single skier and how it moves in the area by simulating in real time or setting the focus to the whole area and find out when and where queues are forming throughout the whole day by speeding up the time and simulate the day in only seconds, everything is possible. Even simulating a scenario where some part of the area is closed and the skiers can not take specific lifts due to some technical error or some slopes because of to less snow. By simulating and analysing all these scenarios not only does the experts of the skiing area gain valuable statistical information about the area but can also simulate changes to the system like a crowd flow control or an increase or decrease in capacity of a lift. The simulation built in context with this work for the skiing area of Mellau shows all those applications but can also be used as a basis for further improvements of the skiing area or be expanded to other areas like Damüls. The simulation was implemented using the Anylogic simulation environment and the statistical evaluation was also performed in this program.

Kurzfassung

Skifahren ist eine der beliebtesten Wintersportarten weltweit und speziell in den Alpen. Während Skifahrer und Skifahrerinnen ihre Zeit auf den Pisten genießen, sind lange Wartezeiten an einem Lift sehr ärgerlich. Leider kommt dies aufgrund des Klimawandels vermehrt vor, da kleinere Skigebiete in niedrigeren Lagen schließen müssen und auch die Zahl der guten Skitage abnimmt. Dies führt dazu, dass die Zahl der Skifahrer und Skifahrerinnen in den Skigebieten zunimmt, was unweigerlich zu längeren Wartezeiten führt. Um dies zu verhindern, müssen die Betreiber der Skigebiete die Verteilung der Wintersportler und Wintersportlerinnen steuern. Dafür werden Informationen über die aktuelle Situation und mögliche Änderungen benötigt. Die beste Möglichkeit bietet dabei eine Simulation des gesamten Gebietses. Die Simulation hat den Vorteil, sowohl zeitlich als auch in der Konfiguration flexibel zu sein. Es kann sowohl ein Skitag im Detail simuliert werden und das Verhalten eines einzelnen Skifahrers und einer einzelnen Skifahrerin und seine bzw. ihre Bewegungen im Skigebiet untersucht werden, indem man in Echtzeit simuliert. Es kann aber auch der Fokus auf das gesamte Skigebiet gelegt werden, um herauszufinden, wann und wo sich über den ganzen Tag hinweg Warteschlangen bilden, indem man die Zeit beschleunigt und den Tag in nur wenigen Sekunden simuliert. Alles ist möglich. Sogar die Simulation eines Szenarios, in dem ein Teil des Gebietes geschlossen ist und die Skifahrer und Skifahrerinnen bestimmte Lifte aufgrund eines technischen Fehlers oder einige Pisten aufgrund von Schneemangel nicht benutzen können. Durch die Simulation und Analyse aller Szenarien erhalten die Experten und Expertinnen des Skigebietes nicht nur wertvolle statistische Informationen über das Gebiet, sondern können auch Änderungen am System simulieren, wie z. B. eine Steuerung der Besucherströme oder eine Erhöhung oder Verringerung der Kapazität eines Liftes. Die im Rahmen dieser Arbeit erstellte Simulation für das Skigebiet Mellau zeigt all diese Anwendungen, kann aber auch als Grundlage für weitere Verbesserungen des Skigebietes verwendet oder auf andere Gebiete wie Damüls ausgeweitet bzw. übertragen werden. Die Simulation wurde mithilfe der Simulationsumgebung Anylogic implementiert und auch die statistische Evaluation wurde in diesem Programm durchgeführt.

Acknowledgments

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Contents

1 Introduction

Each winter, many people are skiing in a lot of different skiing areas. However, because of climate changes problems with snow coverage in the lower area forces them to go to higher altitudes because the lower areas are closed. Also a decrease of skiing day in a season is happening. All of this leads to an increase of skiers in the opened areas every year. To keep up with the load, the skiing areas have to improve their effectiveness of running their lifts and distributing the skiers in the area. The goal being to keep the waiting time for every skier to a minimum to avoid unhappy customers. Sometimes even a shutdown of lifts because of technical issues or to less snow has to be managed. The carriers of the skiing areas are presented with all these obstacles and no tool for even analysing their area.

1.1 Motivation

To get an idea of how and when the skiers arrive in the system and are distributed in the skiing area, on possibility is to implement a simulation model. This is then used to track the skiers behaviour in the system as well as noticing potential weak points in the lift system. As a point of reference for modeling, a normal skiing day can be observed in the real area and compared to the results of the simulation. Furthermore, different incidents like a technical defect of a lift can cause a backlog on a different lift and an increase in the waiting time of skiers. As the lifts are exposed to weather and wind, sometimes they have to be closed because of to strong winds. All these scenarios can be investigated and evaluated in a simulation model of a skiing area. This gives the carrier a change to study the system and evaluate different circumstances.

1.2 Thesis objective and non objectives

This thesis aims to give a better understanding of the processes in a skiing area as well as the concepts of computer assisted simulating of such a system. Starting with the building of a model for simulating and than going into details of what is needed to build a model of a skiing area as well as how to define a scenario, simulate and evaluate it. Not an objective is to get a perfectly realistic simulation of the whole skiing area with every detailed aspect modeled.

1.3 Structure of the thesis

In Chapter 2, an introduction into computer simulation is made and the process of how to build such a model is explained. In the second part of the chapter, Chapter 2.4, an overview of related studies and relevant state of the art techniques is given. In Chapter 3 the needed data for modelling a skiing area is listed as well as where to find such data. Further, in Chapter 4 the process of how the model was built in the simulation software is described in detail. In Chapter 5 the definition of a scenario as a basis for experiments is made and the scenarios are described. Building upon this, in Chapter 6 the analysis of the executed scenarios is made and in Section 6.3 the results are discussed and an interpretation is made. Finally, in Chapter 7 the done work is once more summed up and the results are reflected.

2 Background and related work

In this chapter the state of the art and related works found on the subjects is presented. The goal is to make this work self-contained and present background information necessary for understanding the remainder of the thesis.

2.1 Introduction into computer simulation

A computer simulation is a program that approximates a real-world system by either running a step-by-step logic or continuously calculating mathematical abstractions of a real system. A system is defined to be a collection of entities acting and interacting together toward a goal [6, p.22]. The size of the system depends on the scope, but generally all relevant entities needed for reaching the goal have to be inside the scope of modeling and therefore modeled in the system. Normally, the simulation takes in some state of the real world at time t and then calculate the system's state at time t+1. After a defined number of steps for a event based simulation and at a specific point in time for a continuous simulation, the new state of the system is evaluated and can give insights into the complex behaviour of the real-world system. For example the carrier of the skiing area is interested in how many people are waiting at a specific lift at a specific time of day. This can be evaluated by simulating skiers and lifts in an area. The underlying assumptions about how the system works e.g. how long it takes a skier to drive down a slope, are in a form of mathematical or logical relationships, the *model of the system*. It is used to abstract the reality and gain an understanding of how the corresponding system behaves to then be implemented in a simulation. If the relationships are simple, mathematical equations can be used to obtain information on questions of interest. However, the real world is often too complex to allow realistic models to be evaluated analytically and therefore, simulation is necessary.

Possibly the biggest advantage of simulation is to divide complex systems into small, comprehensible parts, which together allow an analysis of the whole real-world system. Another reason to use simulation is the possibility to easily change operating conditions and circumstances and, therefore, run different scenarios in a relatively short time. The different outcomes can then be compared and it can be decided which scenario and operating conditions best meet the specified requirements. Furthermore, simulation allows to study long time frames in compressed time or alternatively to expand the time and study detailed workings.

On the other hand, simulation has some disadvantages as well. The biggest might be that a simulation model only produces estimates of a model's characteristics for a given set of input parameters. Therefore, multiple runs are required for each set of input parameters. Also the development of a simulation model takes a lot of time and resources as well as in depth knowledge of the system and the simulation framework. If the simulation is not a valid representation of the real-world, its results provide little use for analysing the actual system. This particular problem later comes up with the implementation of the skiing area.

Simulation is one of the most widely used operations-research and management-science techniques and is used in many different areas [6, p.2]. There are applications in the area of designing and analyzing manufacturing systems, determining requirements or protocols for communications networks and computer systems, designing and operating transportation system such as airports, ports and road systems to just name a view. [6]

2.1.1 Systems, models and simulation

A system, as described earlier, is defined as a collection of entities, e.g. people or machines, which act on their own but also interact with each other to accomplish a goal. For example, if the scope of a simulation is, to study the behaviour of a queue at a cashier in a supermarket, only the people waiting to pay need to be simulated. The system is only a portion of the whole supermarket. If, on the other hand, the purchase behavior and the path of the customers in the whole supermarket or possibly in a shopping center is to be analysed, then the system needs to be expanded.

The needed variables to describe the system in connection to the goal at a particular time is the state of a system. Considering the example form above, such variables are the number of customers and their time of arrival in the supermarket as well as the number of cashiers and if they are free or serving a customer. Once the scope of the system is defined, there are two types of system categories: discrete and continuous. In a discrete system the state variables change instantaneously at separated points in time. The queue at a cashier is an example of a discrete system since the state only changes when a customer leaves the queue or a new customer starts waiting. Between these events any amount of time can elapse. In a continuous system the state variables change continuously with respect to time. As an example for an airplane, moving through the air the variables like speed, altitude and position change continuously. Unfortunately, only few systems are truly discrete or continuous, most are a mixture of both. In the majority of systems, one type of time change is predominant and therefore, it can be classified into either discrete or continuous. [6, p.3]

How to study a system

There are different ways to study a system and Figure 2.1 shows the structure of the most common. Starting with the most basic question, if a model of the system is even necessary or if the actual system can be experimented on. If a model is needed there are two possibilities, either a physical model or a mathematical model and the mathematical model can than be divided into a analytical solution or a simulation.

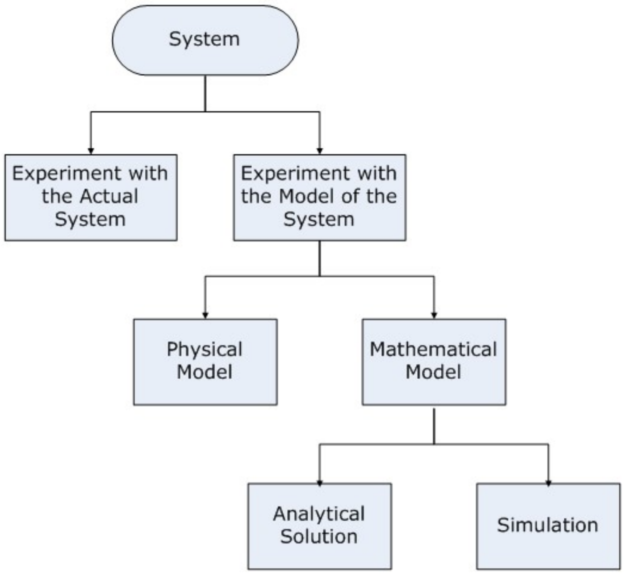


Figure 2.1: Ways to study a system [6]

Experiment with the actual system vs Experiment with a model of the system

If the real physical system can be easily altered, it is desirable to do so and let it operate under new conditions. In this case, there is no question about whether the insight is accurate or not. However, an experiment often disrupts the system and is very costly. For example, if a supermarket wants to close a cashier point to decrease the staff cost by decreasing the number of employees, it will result in long waiting times on the remaining cashier points. Or in another case a supermarket wants to increase the number of cashiers to test, if the waiting time decreases. This results not only in the need of more employees but also in building costs for the cashiers point. This can easily be avoided by simulating the cashiers and customers and then take or add a cashier to or from the simulation. Sometimes, the system does not even exists yet but there is a need to analyse and get insights on how to build it, e.g., a communication network. Therefore, it is often necessary to build a model as a representation of the system.

Physical model vs Mathematical model

A physical model is for example a car model in a wind tunnel or a cockpit, disconnected from the airplane to be used for training. These models are usually not interesting for operations research and systems analysis but more commonly used to study engineering. The bigger part of models are built as mathematical models, representing a system in terms of logical and quantitative relationships. These relationships, and also the variables, are changed to study how the model performs in simulation with different input values. If the model is valid, then it can be assumed, that the real system would react accordingly if the parameters are changed in the same way. [6, p.5]

Analytical solution vs Simulation

Once a mathematical model is build, it must be analysed to see how it can answer the questions of interest. If the model is simple, it is possible to get an exact, analytical solution. If a analytical solution to a mathematical model is available and can be solved efficiently, it is desirable to study the model in this way rather than via a simulation. However, many systems are highly complex because the mathematical models are to complex to solve analytically. In this case, the model needs a simulation.

If a simulation is necessary, a decision is taken on what class of simulation model is desired:

- Static vs Dynamic Simulation Models
- Deterministic vs Stochastic Simulation Model
- Continuous vs Discrete Simulation Model

Static vs Dynamic simulation models

A static model is a representation of a system at a specific point in time whereas a dynamic simulation model represents a system as it evolves over time.

Deterministic vs Stochastic simulation models

A deterministic simulation model does not contain any probabilistic components which means, once the set of inputs and relationships in the model are specified, the output is determined which means it only changes, if the input or a relationship is changed. If the same parameters are set, the outcome is the same in every run of simulation. Most systems have at least some random input components and, therefore are stochastic simulation models. The results they produce have some randomness and must be treated as only an estimate of the truth. To get a more accurate estimation it is recommended to run the simulation multiple times.

Continuous vs Discrete simulation models

The decision whether to use a continuous or a discrete simulation model for a system depends on the specific objectives of the study. Many models can be either discrete or continuous. In a discrete model, the state variables only change at a countable number of points in time. Each time an event occurs the time is updated and the state variables are changed. In a continuous simulation there are infinite number of states and the state variables change in a continuous way, not abruptly from one state to another. [6]

2.1.2 Discrete event simulation

Descrete event simulation (DES) are modeled in such a way, that they evolve over time by a representation in which the state variables change instantaneously at specific points in time. These points in time are the ones at which an event occurs. A good example for a discrete event system is a service queue. It is implemented in the single server queue as illustrated in Figure 2.2.

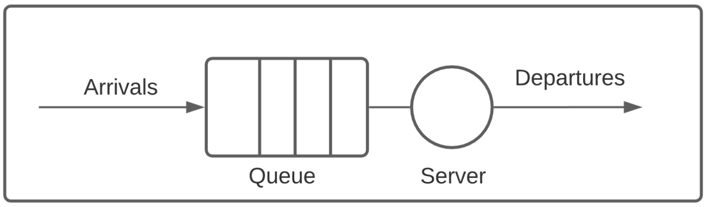


Figure 2.2: Single server queue model
[8]

Once an event occurs, it triggers some state change which is called an *Event Routine*. Event routines describe the dynamic behavior of the single server system. In Figure 2.2 there are three events:

1. *Arrivals:*

   Once a customer arrives at time t, the number in the queue is increased by one. If the server is empty then a load event is scheduled to occur immediately and the customer is being served. If the server is busy, the customer waits in the queue for the next event.

2. *Load:*

   When a load event occurs at time t, the number in the queue is decreased by one and the server is set to busy. This event only occurs after the arrive event in case the queue is empty or after a departure event and the queue is not empty. Simultaneously to the load event, an unload event is scheduled to occur at time $t + t_s$ where t_s is the expected serving time for the customer.

3. *Departure:*

   When a departure event occurs, the server is set to idle and a load event is scheduled if the queue is not empty. The customer than leaves the system.

To correctly simulate a systems dynamics and process the right events at the right time, there is a mechanism needed for saving and processing future events.

If a event is scheduled to occur in the future, it is added to the *Future event list (FEL)*. The event with the smallest, i.e. earliest, event time is called the *next event*. Once the simulation time reaches the event time of the next event, this event is triggered. Therefore, the simulation has to track the time in a measurement unit suitable for the system. The event list must be updated with every event. In discrete event simulation, opposed to continuous simulation, the time skips to the next event start time as the simulation proceeds. [2]

2.1.3 Agent-Based modeling and simulation

Agent-based modeling and simulation (ABMS) is an approach for modeling a system of autonomous, interacting agents. It is especially used in geographical systems like urban car simulation but is also noticeable in digital media to model massive crowds or fight scenes. The advances in computational power has made it possible for bigger and more complex ABMS systems to be developed. It can now be use for modeling agent behavior in the stock market for predicting sock values. It is also possible to predict the spread of epidemics or analysing the behavior of individual consumers in a shopping center. [7]

Agent-based modelling allows a developer to create individuals with an own set of unique characteristics and rules of behaviour. These individuals can than be placed within a realistic environment and the interactions can be observed. The ability to capture and understand individual behaviour over spatial and time scales gives an opportunity to understand the processes and drives that shape social systems. [3, p.58]

What is an agent?

There is no specific definition or protocol of what an agent or agent-based model is and every discipline has its own definition. Nevertheless, there is some consensus about different elements an agent should be comprised of.

- **Autonomy** All agents are autonomous which means that they act outside of the direct influence of an external control. The actions an agent takes are made by an independent decision-making process which is unique for every agent. This means no central controller controls multiple agents at the same time. The decision-making can be influenced by information the agent has and maybe shares with other agents or by interactions with the environment.

- **Heterogeneity** In an agent-based model the agents characteristics are heterogeneous, e.g. a human agent might be attributed an age, gender or job. There may be groups of agents such as buyers or sellers and the model may includes a number of different agents of each groups. Therefore, a system can include multiple similar agents from one group, however, each with independent characteristics and behaviors.

- **Active** The actions an agent takes during the simulation are commonly characterized into five models:

  Goal-directed - Agents are given goals which they are expected to attempt to achieve.

  Reactive or **perceptive** - Agents may have an awareness of their environment and the presence of other agents. Within this environment, agents interact, make use of and avoid environmental features and obstacles by taking actions accordingly.

  Rationality - Agents decisions are based on the rational choice paradigm which states, that individuals use their self-interests to make choices that will provide them with the greatest benefit.

  Interactive or communicative - Agents are able to interact with other agents and their environment in different ways.

  Mobility - Agents are able to move around in the modeled environment to pick up information and interact with other agents or perform actions.

- **Learning and adaption** If the implementation allows it, an agent can have the ability to learn and adapt. The current state of an agent can be depending on previous states and "memories". Hence, an agent can adjust its behaviour with reference to a form of memory or learning.

Advantages of agent-based modeling

With the mass of individual-level data describing the behaviour of single agents, new insights into the processes of individual agents e.g. a person are possible and with better computers, systems can be modeled as potentially infinitely many individual decisions. This makes agent-based modeling an obvious solution within which simulations can be created and ideas can be tested out. [5]

Crooks and Heppenstall [5] list several advantages of agent-based modeling compared to other simulation techniques. For example, the ability to capture emergent phenomena through bottom-up modeling, provide a natural environment for the study of different systems so that agents can move around and the ability to have unlimited numbers of parameters and rules. Furthermore, there are specific situations where agent-based modeling can be advantageous:

1. The interactions between agents can be complicated, nonlinear, discontinuous or discrete. Advantage of this is the possibility to describe the discontinuity of individual behaviour.

2. Designing and building a heterogeneous population of agents which can represent any type of unit if significant can be easily managed. This presents an opportunity to model agents with varying degrees of rationality in their decision making allowing a more complex identity of an agent.

Limitations of agent-based modeling

Because of the fact that agent-based modeling is popular in many different disciplines, there is no template or universally accepted way to design and build agent-based models. Without a central guidance it is hard to know how much detail to input into a model or what level of abstraction is best. Another drawback of agent-based modeling is that it needs a lot of data. A model can potentially contain millions of agents, each with its own and unique characteristics. This requires a lot of data not only for creating but also for the purpose of calibration and validation. Also the evaluation of the results is a big challenge, because without in depth knowledge of the processes of the system as well as knowledge of the real-world system, it is very hard to reproduce specific scenarios and outcomes. [3]

2.1.4 System dynamics

System dynamics (SD) is a type of continuous simulation. It is designed to improve policies or strategies in business, government and military. SD models look at systems at a more aggregate level. Most SD models are deterministic but it is possible for them to have random components. There are three key components to a system dynamics model: [6, p.708]

1. A *Stock* is an accumulation of a resource, e.g. a population of people or a inventory of products.
2. A *Flow* is a stream of a resource into or out of a stock with a valve that controls the rate of flow through the pipe.
3. An *Information Link* brings information from one stock to another or to a valve of a flow.

These components are used to build a system. The classic sd model is the *Lotka Volterra* shown in Figure 2.3, the model of predator and prey.

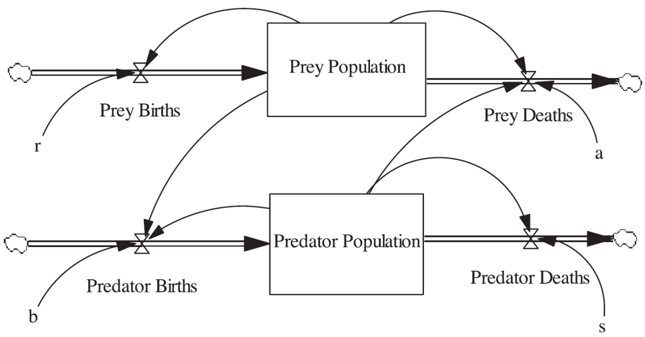


Figure 2.3: Lotka volterra model
[6, p.708]

The system consists of two populations, predators and prey, which interact with each other. The prey are passive and the predators depend on the prey as a source of food. Both populations start with a fixed number, if the number of predators is to big, the number of prey decreases to a minimum. As a result, the predators have less food and the number decreases with a delay to the number of prey. If the number of predators is low enough for the prey to recover the number rises and with a delay also the number of predators. This is theoretically a endless circle assuming the prey has enough food to survive and no external force influences the system. [9]

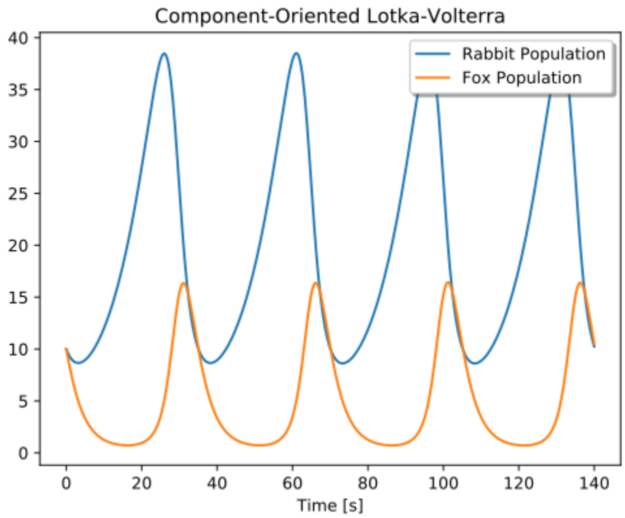


Figure 2.4: Predator and pray model
[9]

2.2 Building a simulation model

In the following chapter the process of building a model to simulate a real-world system is described. All steps, starting with the decision on what needs to be included, to the building process and the validation to giving a model credibility and be sure its doing what it is suppose to, are included.

2.2.1 Determining the level of model detail

Before the start of the development process the scope and detail level of a complex real-world system needs to be determined. It is rarely necessary to have a one-to-one correspondence between each element of the system and each element of the model. A too detailed model will often result in expensive models with regards to both computer power and programming resources which results in costly projects.

There are some guidelines for determining the level of detail required by a simulation model:

1. Define the specific issues to be investigated by the study and the measures of performance that will be used for evaluation. A great model for the wrong problem will never be used.

2. The entity moving through the simulation can vary from the entity moving through the corresponding system. For example, a large quantity of the same entities can be simulated as one single entity to enhance performance.

3. Use the knowledge of domain experts to determine the level of model detail. They often know which part needs to be modeled with more detail than other parts.

4. Start with a "moderately detailed" model and build up more details later.

5. Do not include more details than necessary to address the issues of interest.

6. Study the available data and determine what model detail is even possible with the available data.

7. Time and available money often constrain the amount of model detail

[6, p. 249f]

2.2.2 Validating a simulation model

Once the model is built, a very common problem is to try to determine whether a simulation model is an accurate representation of the real world system i.e. whether the model is valid or not. In the process of validating the simulation model, it is checked on its accuracy.

- Conceptually, if a simulation model is valid, it can be used to make decisions for the real world model.

- How easy or difficult it is to validate a model, depends on the complexity of the system and on whether a version of the system already exists and can be observed and compared to the simulation.

- A simulation model of a complex system can only be an approximation of the actual system. No system is ever completely valid in terms of accuracy to the real world. Often it is not necessary for the model to be as accurate as possible if it would make the model more complex and hard to understand.

- A simulation model should always be developed for a particular purpose. A model that is valid for one purpose might not be for another.

- The tests, used to validate a model, should include the way the decision makers will use it.

- Validation should be done before the system is complete and fully developed.

[6, p.247]

2.2.3 Giving a model credibility

After the simulation model is validated, the manger and other key members of the project accept it as correct and therefore it has credibility. There are some points to help to establish credibility for a model:

- The manager has understood and agreed with the models assumptions
- The model has been validated and verified
- The manager is involved and agrees with the project
- The developers of the model have some reputation in the field

The process of building a model and developing a simulation is seamless and often start simultaneously. Once the model is finished and the simulation can be run, another important step is to actually perform the simulation and analyse the results. [6, p.248]

2.3 Simulation software

In this chapter, the most commonly used computer simulation software are presented. There are further programs like mathlab and simulink which are used to simulate physical and mathematical equations and systems.

2.3.1 Anylogic

Anylogic [1] is a multi method simulation development tool that supports different kind of methodologies such as agent-based, discrete event simulation and SD. It is used in various domains and different industries e.g. healthcare, retail, road traffic and aerospace, for simulating complex environments and systems. The model is developed using a graphical user interface and can be extended by implementing java code. This makes Anylogic very versatile, but on the other hand very complex.

[1] https://www.anylogic.com

2.3.2 NetLogo

NetLogo [2] is a multi-agent programmable modeling environment. For modeling complex systems evolving over time, Netlogo is best suited but also for simpler agent-based models. A model can consist of thousands of independent agents interacting with each other. This makes it a perfect tool to analyse and explore connections between micro-level behaviors of individuals and macro-level patterns, emerging from the interactions. [14]

2.3.3 Self implementation

Apart from using Anylogic or NetLogo, the model building and simulation can also be done by implementing a project in any programming language like Java or Python. However, the usage of a dedicated simulation software has the advantage of a built in graphical user interface and representation of the model and simulation. Also, the mentioned simulation software have some built in logic which can be used as modules and not everything has to be self implemented.

The reason why Anylogic was used to develop the ski area simulation is simply because it was part of a lecture series and already known. Also the development in Java made it easier than to learn a new programming language. No comparison between Anylogic and NetLogo was done.

[2] https://ccl.northwestern.edu/netlogo/

2.4 Related work

In this chapter the related papers around the topic of ski area simulation are linked and the key points are presented here. Starting with the two main papers, [10] and [1] which have a close relation to the work presented in this thesis. The further three papers, [12], [10] and [13] have some key points similar to this work.

2.4.1 Dynaski

In 2017 two researchers Alexis Poulhèsa and Paul Miriala of the university of Paris Est published an article about an agent-based model to simulate skiers in a skiing area [10]. In this publication they describe the process of developing such a system and why there is a need for such a tool. The research showed that the number of skiers and skiing days in the last years has been stable, but the number of days in the year where a consistent snow level for skiing can be maintained are decreasing because of climate change. Therefore, the number of skiers per day increase and if the skiing area stays the same, congestion will increase as the areas are overloaded. As a result the skiers experience will be less enjoyable. To keep skiing attractive and fulfill the needs of the customers, the skiing areas have to make their ski lifts and slopes more efficient. This is mostly done by improving the infrastructure and build faster and bigger lifts. However, this is a big investment and the improvement of flow and financial profits mostly relies on the experience of professionals and not on a actual model or simulation. Seen as an urban transportation network, the skiing area is an integrated system which means that every change in the infrastructure of the system will have an impact on the skiing area as a whole. Compared to an urban network, the number of agents in a skiing area is more limited and the behaviour of the agents is more predictable. With a simulation of the skiing area as well as the skiers behaviour it is possible to analyse the impact of a change in the system to the other parts. For example, if the capacity of a lift is increased because there is a long waiting time on busy days, there might be a even longer waiting time at another lift because of the change. Furthermore, such a system can be taken to evaluate the most suitable change in the infrastructure or in the case of a new area the model can help to design the infrastructure.

Structure of the model

The model described in the paper is based on a connected and oriented graph consisting of a set of slopes and a set of ski lifts. Both are only unidirectional and at each intersection is a decision node.

The slopes are divided into categories depending on there difficulty level. Each has a specific length as well as some features like snow cover or sun exposure.

The ski lifts are used by the skiers to get back up after a run on the slope. They are modeled in such a way that the capacity per hour is divided into the capacity of each gondola and the frequency and speed.

The skiers get directly to the first ski lift and the incoming point is saved for each skier as starting point which the skier later returns to at the end of the day. The model in the paper aggregates the skiers into groups to simplify the simulation. The groups have a ski level according to which they decide what slopes they take. The behaviour of the skier groups is influenced by two levels: firstly, the skiers overall perspective is to explore the area and diversify their path as much as possible. Summits in a skiing area can be taken as intermediate destination for a skier so the group decide on one summit as their destination and calculate a path toward it. After reaching this intermediate destination they decide on a new target and follow this new path. The second level is a local preference of choice of the available slopes and ski lifts. The group always prefer slopes they did not already skied and if possible consistent with their skiing level.

Queue model

The waiting time at a ski lift is, according to the paper, one of the most viewed indicators to evaluate a ski area. Their model takes the waiting time for all the available ski lifts into account to define which direction the group is going.

This waiting time is calculated by the number of arriving skiers, the gondola capacity and the frequency of the lifts arrival rate. If a group fits into one gondola, they wait until they can go together. This selfish behaviour influences the waiting time.

Returning to the origin point

By the time the lifts close, each group has to be at the point where they started. Therefore, they need to anticipate the time to get back to where they start before the lifts are closing. This is implemented by restricting the choice a group has at each choosing point after a specific time of day.

The focus of the paper is more on the individual behaviour of the skiers than on the global view of the whole area. The skiers or agents, combined together to groups, have an autonomous decision making process depending on there earlier path. The decision on the path taken by the skiers in the system by this author is based on probabilities and it is focused on the spreading and analysing the global system.

2.4.2 Queues in ski resort graphs

In the paper [1], a flow graph of a skiing area is presented. It describes a ski resort as a connected oriented graph, similar to [10], where the axis i.e slopes and lifts are specific in regards to there properties and influence the behavior of the skier. To simulate the behaviour of the skiers in a ski area, it is necessary to model the number of skiers arriving as well as their diffusion on the ski runs. As the access to some parts of the ski area is dependent on specific lifts, the load increase in the network is not homogeneous. This leads to congestion of the lifts at the bottom at the start of the day and only after some time a steady state arises when the skiers are distributed over the whole area. However, with the simulation it is possible to follow the change in waiting time at every lift during the day and also follow the skiers flow. With this information it is possible to adjust the rates and speeds of the different ski lifts and then measure the impact during the simulation.

The distribution of skiers over the skiing area is dependent on the weather situation because the decision which slopes are taken is different for a sunny day compared to a day with snow or fog.

Sunny and warm	Sunny and cold	Rain	Snow
- blue = 0.27	- blue = 0.09	- blue = 0.27	- blue = 0.23
- red = 0.42	- red = 0.36	- red = 0.44	- red = 0.46
- black = 0.23	- black = 0.25	- black = 0.21	- black = 0.21
- yellow = 0.08	- yellow = 0.25	- yellow = 0.08	- yellow = 0.10

The colors are based on the European ski slope colors:

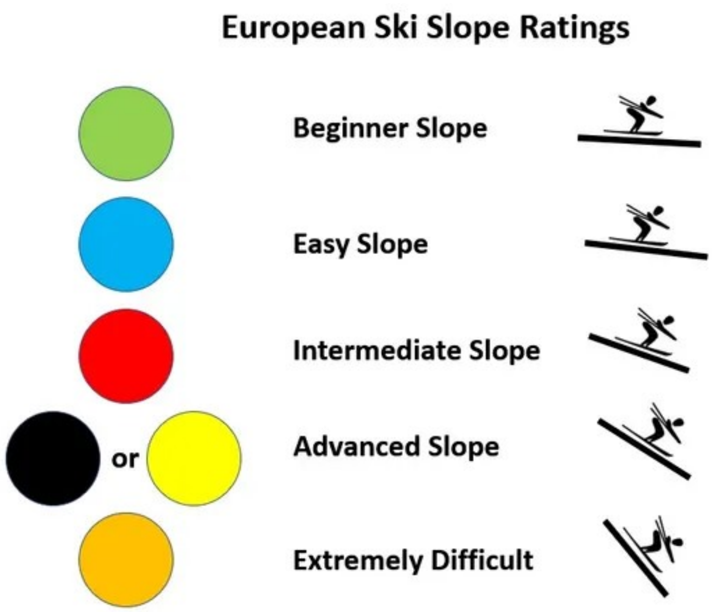


Figure 2.5: Slope colors [4]

The results of the simulation are the waiting times at each ski lift over the course of a simulation day. Theses values can be used to analyse the potential global impact of a local choice in the graph for example a change of flow rate or a failure of a lift.

2.4.3 Predicting snow height in ski resorts using an agent-based simulation

In [12] a system named Juste-Neige that predicts the snow height on the ski runs of a resort is presented. Through an agent-based simulation software it aims to reduce the production cost of artificial snow and, in consequence to reduce the water and energy consumption. There are some points in the skiing area where the snow height is measured. Based on the meteorological factors and the usage of the ski slopes, the software provides a map with the predicted snow heights for several days. With this information, the management can then decide on where to put the available machines to produce artificial snow. Based on three measurements a result is produced. The first of three simulation steps is to spatial interpolate unknown points based on the available data. With the measured snow heights, a prediction is made for all other points of interest mainly the ski runs. The second step of simulation is to analyse the influence of the weather on the snow height in the particular area. Finally, the third step of simulation is to analyse the impact of the skiers on the snow by an agent-based model of the movements of the individual skiers in the skiing area.

2.4.4 Modelling skier behaviour for planing and management

Some of the authors of the the paper Dynaski [10] also analysed the behaviour of the skiers in the ski area. The behavioral patterns change in the course of a ski day and can be modeled into three big phases - Skiing period, lunch break and return to the resort. The paper focuses on analysing the skiers behaviour in the event of a change in the system such as a closure of a slope or lift. Furthermore, the management can react to a shortage of snow or skiers based on the information of the simulation and some interpretation. The data for building a model was gathered by surveys and analysing the GPS data from a app, which tracks the movement of individual skiers in the skiing area. [11]

2.4.5 Optimization of ski resort layout

In [13] the author describes the process of building a model to optimize the layout of lifts and slopes. It aims to get the best lift speed or a most efficient system regarding time or costs while still being safe for the customers. It starts by building a full factorial design for one chairlift and one slope. The factorial design hereby measures the system response of every possible combination of input variables and levels. The insight are analyzed to provide information about the main effect as well as the interaction effect of a change in a variable. If more variables are investigated, a full factorial design becomes too expensive and time-consuming to run and a partial factorial design is used. It produces similar results with fewer experiments. Applying this system on a ski area shows, how the parameters of a ski resort layout affects the overall capacity of the resort and therefore the waiting time of the skiers, which is one of the biggest influences on satisfaction.

3 Data sources and modelling

In this chapter the data sources for building a model and a simulation is described. The data, necessary for building the parts of a model including the slope model and the skier as well as the data to put into a simulation like the number of skiers arriving per hour and over the course of a full day. Based on this information, a model can be created that facilitates the simulation process.

3.1 Data source - information of skiing area

The main data sources are the interactive map *skimap* [1] and the online system for skiing tickets *skiline* [2] as well as the authors experience of skiing and working as a skiing instructor in the area.

For the modelling of the ski area, especially for the lift and slope layout, the information given in the interactive map, see Figure 3.1, was used.

[1] https://winter.intermaps.com/damuels_mellau_faschina
[2] https://www.skiline.cc

Figure 3.1: Interactive map

This map was created and released by the carriers of the ski area in cooperation with the company *intermaps* [3]. The map includes all slopes as well as the lifts and points of interest like restaurants, camera points and junctions. Also included is information about the lift, like the starting and ending height as well as the length, the capacity per hour and the capacity per gondola. All this information is incorporated into building the model of the skiing area. Information regarding the slopes includes the difficulty level and whether it is currently opened or not. The open or closed state can be useful for simulating special scenarios which are explained later on in Chapter 5. Some important information was not contained in the map, e.g., the time it takes a gondola

[3]https://www.intermaps.com/en/

to travel from the bottom of a lift to the top. This information was gathered from the statistic of the lift pass provided by *Skiline*. Skiline provides a service for customers to put in a ski pass number and see the statistics of their skiing days. It gives a detailed insight on the path a skier took trough the skiing area and, hence, the time it takes to get from the bottom station of a lift to the top station, i.e., the time it takes a gondola to travel from the bottom to the top.

Figure 3.2 shows, that it takes a skier in the Mellaubahn about 7 minutes and 20 seconds to get to the top. It can also be seen that the day starts at the bottom of the skiing area with a ride on the Mellaubahn and continues with the Rossstelle and so on. If hovered over the lift rides, it shows how long the ride takes from the bottom to the top and if hovered over the downhill, it tells the skier how long it took to get to the next lift. This includes the time spend on the slope skiing and waiting in a queue at the lift until the card was next scanned at a terminal.

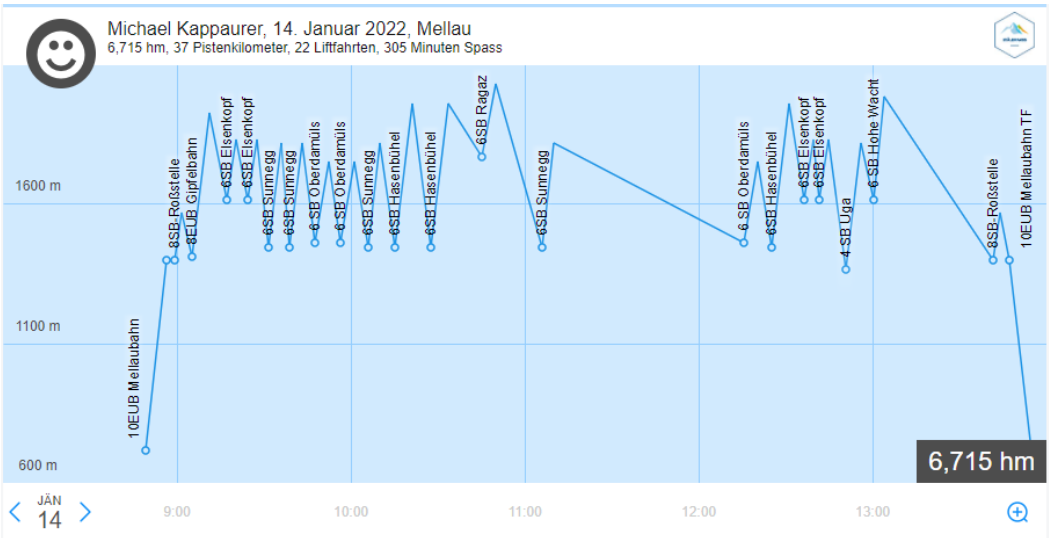


Figure 3.2: Skiline skiing day

3.2 Building a model

All of the information described in the previous section is only useful in a representation, that a developer can use to build a model and a simulation with. Therefore, a data model needs to be designed that includes all relevant data. For the current state of the simulation, the relevant data concern the lifts, slopes and skiers. The points of interest, e.g., restaurants and camera points, are not modeled.

3.2.1 Gathering information

Starting with the overall layout, a list of all lifts is made. They are then chained together with connections and the slopes are added. This is all the information needed to describe the skiing area.

Lifts

The most important information about the lifts is the size and type of the gondolas. The starting and ending height as well as the length in meters and the travel time from the bottom to the top is also needed for the model. Table 3.1 gives an overview of all lifts in Mellau.

Name	Gondelbahn Mellau	Sesselbahn Rossstelle	Sesselbahn Wildgunten	Sesselbahn Suttis	Gondelbahn Gipfelbahn
Size of unit	10	8	6	6	8
Type of unit	gondola	chairlift	chairlift	chairlift	gondola
Hourly rate	3100	3400	2400	2214	2400
Starting height (m)	710	1400	1465	1420	1412
Ending height (m)	1395	1570	1750	1750	1924
Length (m)	2080	628	1210	1150	600
Time to travel	7 min 20 sec	2 min 20 sec	5 min	5 min	6 min

Table 3.1: Lifts in Mellau

Slopes

The information about the slopes concerns the start and end point as well as the length and the color of difficulty. The levels of difficulty used here is as followed:

blue = easy red = medium black = hard

Name	Rossstelle links	Rossstelle rechts	Moos	Moos Wildgunten	Wildgunten
Number	21	22	23c	24	25
Start point	Rossstelle	Rossstelle	Rossstelle	Rossstelle	Wildgunten
End point	Rossstelle	Rossstelle	Gipfelbahn	Wildgunten	Wildgunten
Length	700	700	700	600	2200
Color	red	blue	red	blue	red

Name	Achtergraben	Nüggl	Schnimösle	Fis-Rennstrecke	Funpark Nühof
Number	26	27	28	29	30
Start point	Slope 25	Slope 25	Slope 25	Wildgunten	Slope 29
End point	Wildgunten	Rossstelle	Rossstelle	Wildgunten	Slope 25
Length	700	1200	1200	2200	800
Color	blue	blue	blue	red	blue

Name	Rotenberg	Steilhang Suttis	Steilhang Seele	Vordersuttis	Dorfabfahrt	Route 7
Number	31	32	33	34	35	7
Start point	Slope 25	Suttis	Suttis	Slope 33	Slope 33	Wildgunten
End point	Slope 33	Slope 33	Suttis	Slope 33	Mellaubahn	Slope 33
Length	1100	800	1200	250	4800	450
Color	blue	black	black	black	red	black

Table 3.2: Slopes in Mellau

Connections

Connection link lifts together. They are not necessarily slopes to drive on but can also be part of a slope to walk to the next lift. These connections are often not explicitly listed in the map as slopes. For example, there is no specific slope between the top of the Mellaubahn and the bottom of the Rossstelle, but nevertheless skiers can go back and forth between them. Important for these connections is not only the length, but also if it is uphill or downhill. This influences how fast the skiers are traveling along the particular connection.

Name	Length	Downhill or Uphill
Mellaubahn - Rossstelle	50	Uphill
Rossstelle - Mellaubahn	50	Downhill
Rossstelle - Gipfelbahn	200	Uphill
Gipfelbahn - Rossstelle	200	Downhill
Wildgunten - Suttis	50	Uphill
Suttis - Wildgunten	50	Downhill

Table 3.3: Connections in Mellau

3.2.2 Enritching model with context

After all information is gathered and listed, the context is added by connecting the lifts with connections and slopes. The result is a model with the lifts and the connections as illustrated in Figure 3.3. It shows where a skier can travel without using a specific slope. A more detailed model, containing all lifts, slopes and connections is shown in Figure 3.4.

These models can then be implemented into a software like Anylogic to simulate the system.

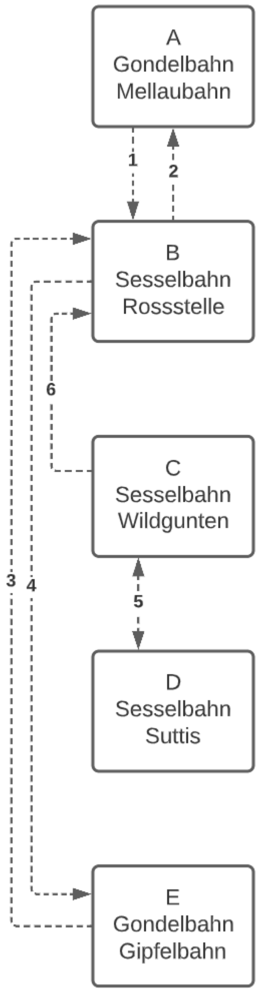


Figure 3.3: Model of the lifts

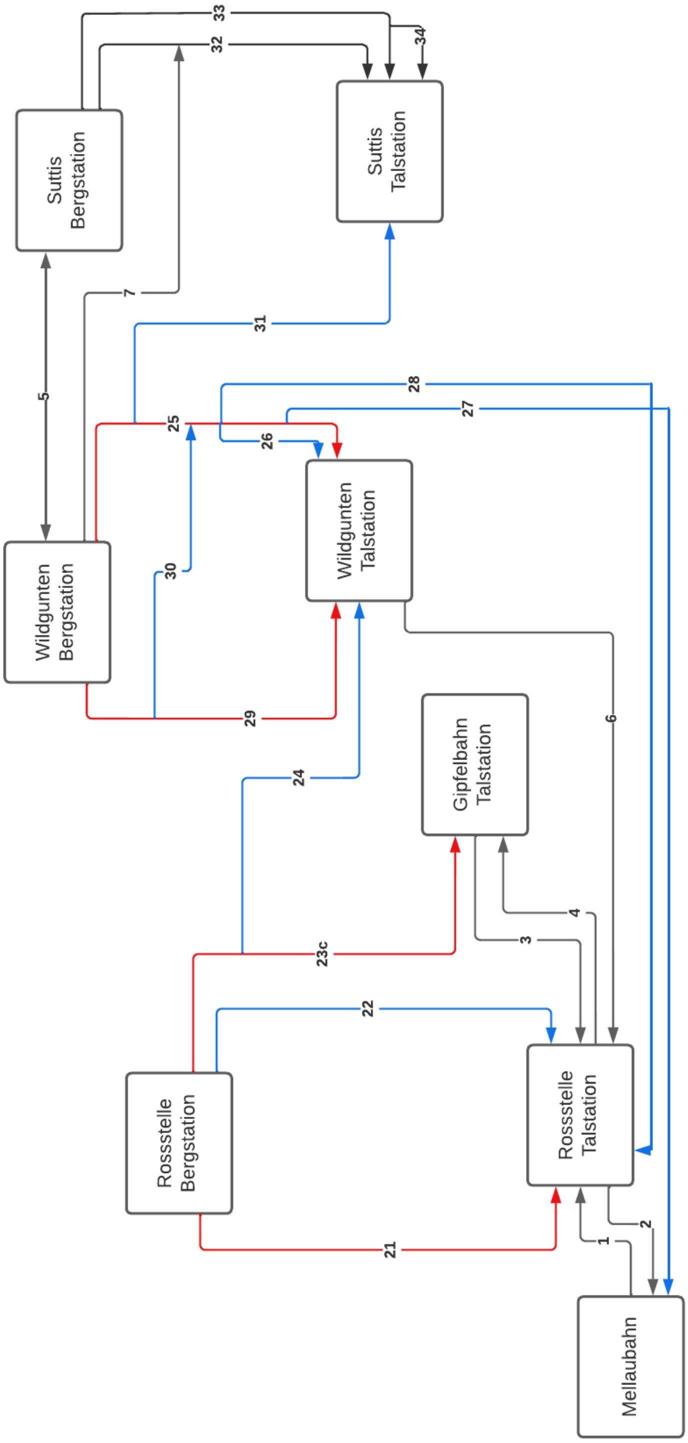


Figure 3.4: Lift plan with slopes and connections

4 Ski area simulation

In this chapter, the development of the simulation model, including combining the lifts, slopes and connections into one model, is described. This simulation model is the basis for developing and simulating scenarios defined in Chapter 5. This step is done in the simulation software Anylogic. First the single components are described here and then, at the end of this chapter, the full model is presented.

4.1 Lift model

Starting with the ski lifts, Figure 4.1 shows how they are modeled as a pickup and dropoff model with two different queues.

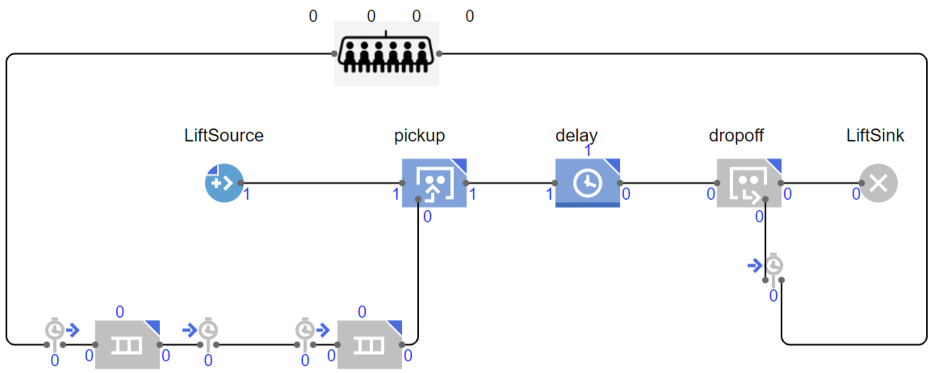


Figure 4.1: Simulation model of the ski lift

The guests arrive at the lift and wait in the first queue until a place in the second queue is available and they can move up. The first queue has an unlimited capacity, while the second is limited to the capacity of the gondola. This second queue represents the on-boarding onto the lift, where skiers are no longer waiting in line an are not yet riding the lift. For every entering and exiting skier in the queues, a counter is updated to keep track of the current sizes of the queues. The queuing strategy used is first in, first out (FIFO).

The gondolas are generated in the lift source and pass through the pickup and dropoff, according to the hourly rate of the lift and the size of the gondola. For example, for the transportation rate of the Mellaubahn the interactive map states 3100 people per hour with a gondola size of 10 people. Accordingly, there are 310 gondolas per hour and an inter arrival time of 11.6 seconds. On *pickup* all skiers in the second queue are taken. Depending on how many people are in the first queue, the second queue is filled with as much skiers as possible. The skiers are then taken to the top of the lift and dropped of. The time it takes for the lift to arrive at the top is extracted from the information of skiline. For example it takes the Mellaubahn 7 minutes and 20 seconds to reach the top. At the dropoff the skiers are passed on to the slopes and the gondolas return to the bottom, which is modeled as the lift sink. Figure 4.2 shows the flow of the gondolas can be seen again in more detail.

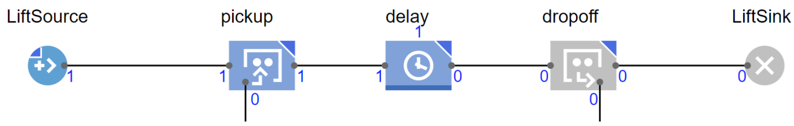


Figure 4.2: Lift model - gondola flow

Figure 4.3 shows the three components of the first queue (i) the time measure start block (ii) the queue and (iii) the time measure end block.

The time-measure blocks at the entrance of the queues, which can be seen in Figure 4.3, as well as the exit of the dropoff are used to keep track on how long a skier is waiting in line and how long it takes to reach the drop off at the top. The incoming block (clock symbol) notes the time of arrival for each skier and once the skier is registered in the outgoing time-measure block the difference is added to the according parameter of the skier. Therefore, each skier keeps track on how long he or she spent skiing, waiting and going up in a lift.

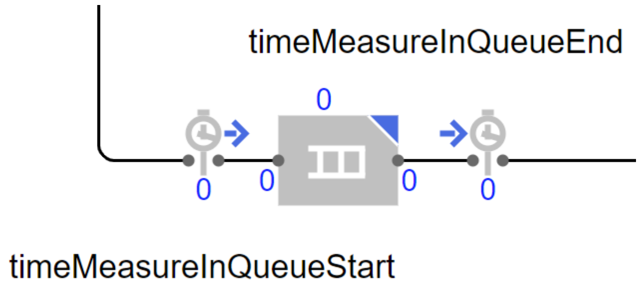


Figure 4.3: Time measure of queue

Lift schedule

All lifts have the same opening hours from 8 a.m. until 4 p.m. Once open, the flow rate is calculated as described before. This schedule is only for changing the opening hour or potentially change the flow rate e.g. to save energy if less people are waiting. If a value is set to 0 for example between 12 a.m and 1 p.m, no gondolas would flow in between this times. In the standard scenarios however, the rate of the gondolas is always the same throughout the day.

Start	End	Flow Rate
8:00	9:00	1
9:00	10:00	1
10:00	11:00	1
11:00	12:00	1
12:00	13:00	1
13:00	14:00	1
14:00	15:00	1
15:00	16:00	1

Table 4.1: Lift schedule

Lift parameters

- Capacity - capacity of the gondolas
- Delay time
- scheduleLift - Lift schedule value for the current simulation time
- Open - state on whether the lift is running or not
- In - number of skiers who arrived at the specific lift
- InQueue - number of skiers waiting in the queue
- InLift - number of skiers riding on the lift
- Out - number of skiers who left the specific lift

4.2 Gondola model

The gondolas of the lift are modeled as well but as they only need one parameter, which is the size and a symbol for the graphical simulation, it is a very simple model as can be seen in Figure 4.4.

Figure 4.4: Gondola model

4.3 Slope model

Figure 4.5 shows the model of a single slope. Together with the lifts, the slopes are the main elements of the model.

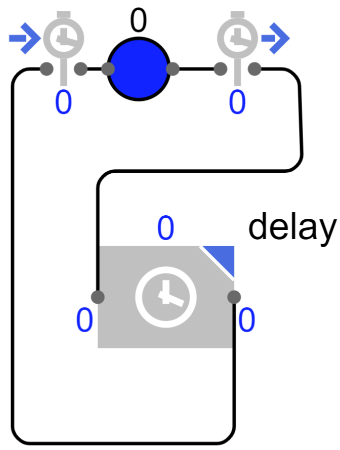


Figure 4.5: Single slope model

The driving of a skier on a slope is modeled as a delay where the delay time depends on the length of the slope and the skiing level, i.e., the ability of the skier, of the single agent representing the skier. The model of the slope has a length in meters and the skier has a speed in meters per second. Using these values, the delay time is calculated. For statistical calculations, the time it takes each skier to ski down a slope is tracked. Since the time is calculated by dividing the length of the slope and the skiers speed, which is fixed, the time it takes each skier is a value of a list of fixed times. For example, if a slope is 100 meters long and the speed of a beginner skier with a skill level of 1 is 3 meters per second than it takes 33 seconds to get from the top to the bottom of the slope. As the skill level increases, the speed increases as well and a professional skier with a skill level of 5 and a speed of 15 meters per second only takes 6.6 seconds for a 100 meter long slope. For every slope a skier takes, the time is measured in the same way as for the time spent waiting in a queue or on the lift. Using these values, the ratio on how much time is spend skiing compared to the time waiting in line and riding on a lift back up is calculated.

Once the skier leaves the system either by leaving at the bottom of the skiing area or, in this particular skiing area, at the top to Damüls, the agent i.e. the skier is deleted.

Slope parameters

- Difficulty - blue, red or black
- Length in meter
- Multiplicator - for slopes going uphill and therefore take longer
- Open - state on whether the slope is opened or not

4.4 Skier model

The skier has only three parameters (i) the skiing level, (ii) the average speed and (iii) the starting point. The speed depends on the skiing level, which is distributed exponentially between 1 and 6. Class 1 are the very beginners and class 6 the advanced. This is adapted in the simulation by changing the mean speed according to the level of the skier. The skiing level multiplied by three is the speed in meters per second. It would be possible to just use the speed, but since the distribution of the skiing level can be changed at the start of the simulation, it is easier to model it in this way. The starting point is added when a skier enters the simulation. There are two entry points into the system - one in Mellau at the bottom and one at the Gipfelbahn, where skiers can enter from the area of Damüls. The rate of how many skiers are entering the system is defined by the global rate, which can be altered at the start of each simulation. For the evaluation, the system keeps track of each skier the spent time for each skier. the resulting parameters are shown below.

Skier parameters

- skiing level
- average speed
- starting point
- total skiing time
- total waiting time
- total lift time
- total meters of skiing

4.5 Decision making

If a skier reaches a point, where multiple options are available, i.e., at a junction where a slope splits, there is a probability table with different probabilities. Figure 4.6 illustrates that the skier can take three different slopes after ascending to the top of the Rossstelle.

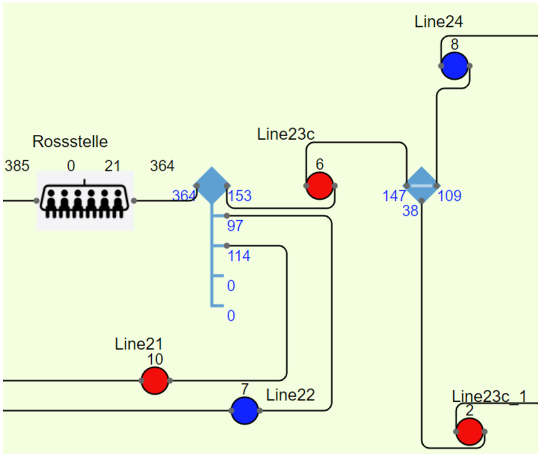


Figure 4.6: Decision making - select output

The first outgoing line from the spilt, which 153 skiers passed so fare, is the slope number 23c. It parts again at half way into 23c and 24 which end at the bottom of the Gipfelbahn or the Wildgunten respectively. The second and third outgoing lines are the slopes with the numbers 21 and 22, which both lead back to the entrance of the Rossstelle. 97 and 114 skiers toke those slopes. The probabilities of this specific example are:

Probability taking slope 23c

Standard value = 0.4

If Wildgunten or Gipfelbahn is not running - value = 0.1

If Wildgunten and Gipfelbahn are not running - value = 0

If simulation time is bigger than 420 - value = 0

Probability taking slope 22
Standard value = 0.3
If simulation time is bigger than 420 - value = 0.5

Probability taking slope 21
Standard value = 0.3
If simulation time is bigger than 420 - value = 0.5

The first probability for taking slope 23c depends on the state of the two following lifts. If one of them is not running, the ration decreases and more skiers go to the other slopes. If both lifts are not running, no skiers take this slope since they would get stuck at the bottom of one of the lifts. The reason for the value change after a specific point in time is due to the fact that otherwise the skiers would not leave the skiing area at the closing hours. The simulation time starts at 8 a.m. therefore after 420 minutes at 3 p.m. the skiers start to leave the skiing area as it closes at 4 p.m. If the waiting time at the end of the day is still very long, it is possible for some skiers to still be in the area after 4 p.m.

4.6 Implemented simulation model

Figure 4.7 shows the resulting model that combines all components into one complex system. The ski area is modeled from left to right starting with the source, i.e. the entry point for skiers, where a specific number of skiers arrive at each hour. At the top of the lift Mellaubahn is a decision point where the skier can decide where to go. They can either take the next lift, Rossstelle, up to the slopes or walk to the next lift, the Gipfelbahn, which leads to the skiing area of Damüls. A second source is added here, that allows skiers from Damüls to get to the area of Mellau. It is also possible to return back to the bottom of Mellaubahn, however the probability for this during the day is very low. After the lift Rossstelle is another decision point at the start of the slopes. The skiers can take several slopes with different difficulty levels and different directions. Once at the bottom of the slope the skier takes the next lift back up or leaves the skiing area.

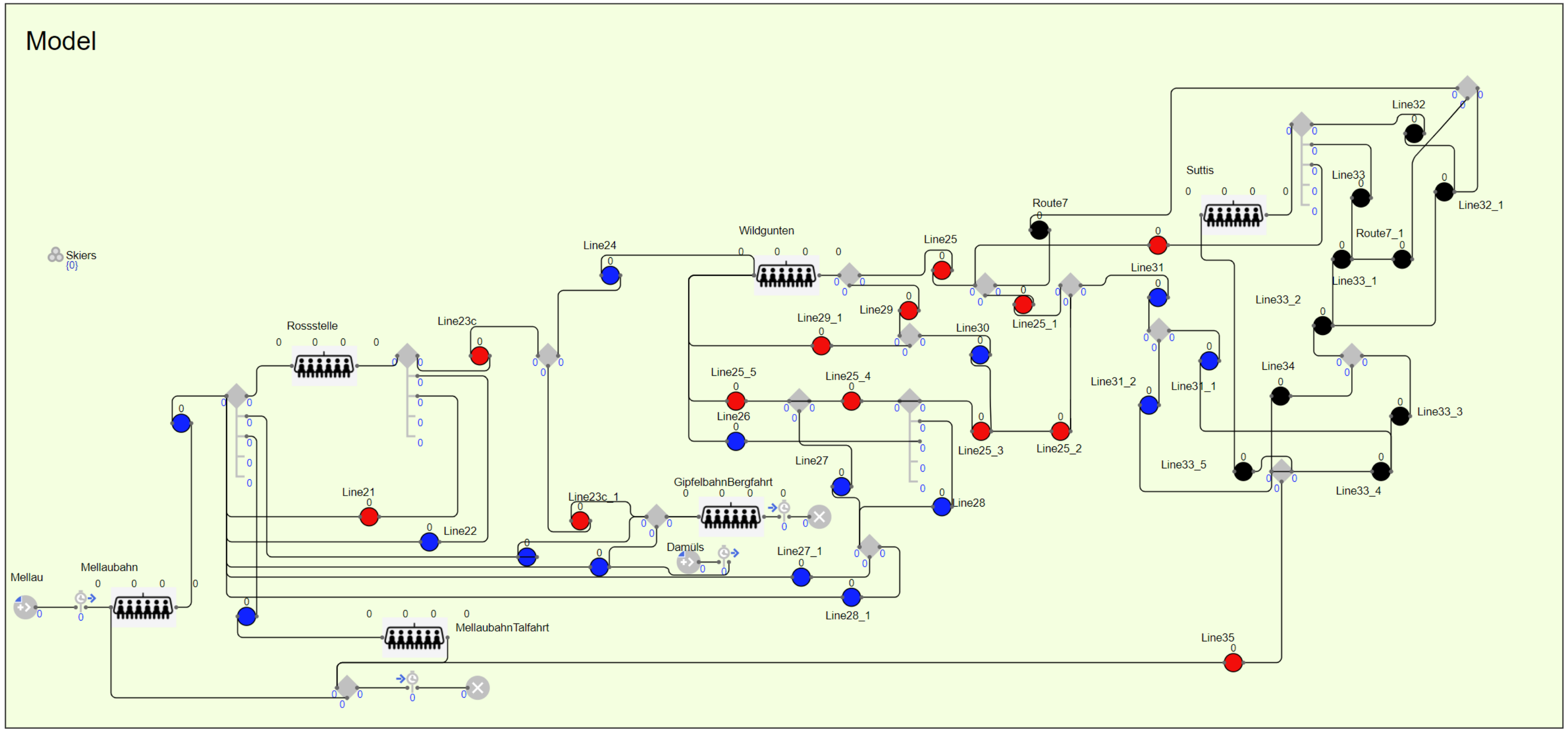


Figure 4.7: Simulation model of the skiing area

4.7 Visualisation of the model on the map

For making the simulation model easier and comprehensible, a visualisation of where the lifts and slopes are located on a map, can be added to the simulation. This is only for visualisation reasons and is not necessary for the simulation and evaluation.

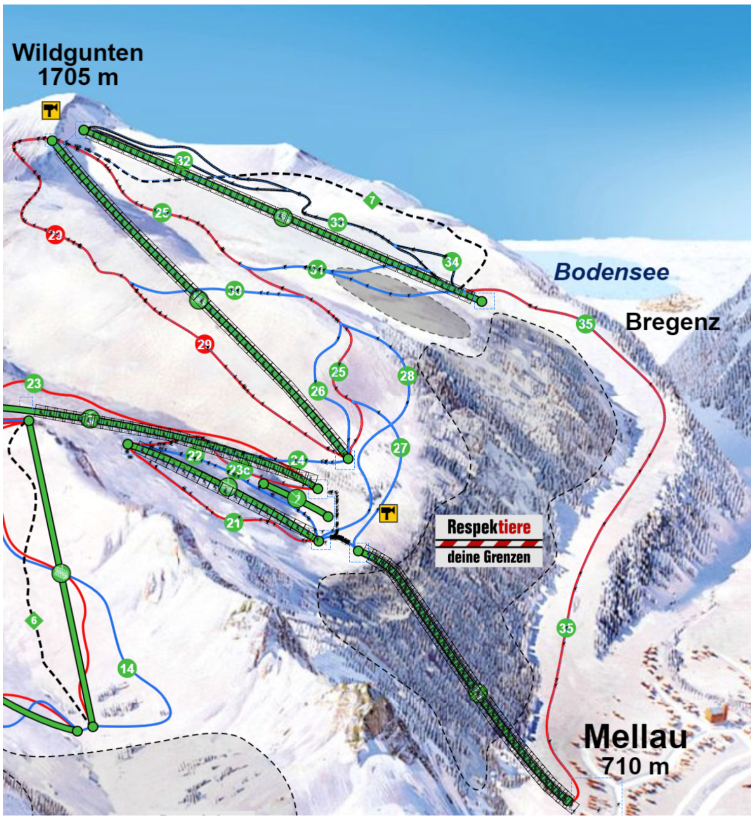


Figure 4.8: Simulation model with map

The slopes are visualized as paths for the skiers. Each slope has a specific path on which the skiers appear when they are in the delay state of a particular slope. Depending on the speed and the length of a slope, a skier takes a certain amount of time on a slope. This is also graphically animated. Also the lifts are animated as gondolas traveling on the according paths.

5 Scenarios

Defining scenarios is the basis for the evaluation of the implemented simulation model. This chapter outlines the definition and detailed description for each evaluated scenario. The simplest scenario is a normal skiing day where all lifts are opened. More complex scenarios include either technical defects of lifts or facilities shutting down because of harsh weather conditions. Finally, some scenarios are specified where additional information is provided to the skier by means of information boards.

5.1 Normal skiing day with different configurations

The following scenario is the standard case that occurs in the current state of the skiing area and in day to day business. There will be changes in the configuration regarding the running of lifts as well as ski slopes, but the basic process of the skiers arriving at a certain rate and traveling trough the system does not change.

In the fist configuration all the ski lifts are functional and running throughout the day without interruptions. Also all slopes are opened. The first parameter, which can be changed, is the basic load. This is the number of skiers arriving at the bottom of the skiing area to go skiing as well as the number of skiers arriving from the skiing area of Damüls. The actual load is then calculated by taking the current value from the arrival rate schedule, see Table 5.1, multiplied by the basic load. This number of skiers is added to the system every minute.

For example if the basic load is one, one skier is added every minute from 8 to 9 o'clock and three skiers are added every minute from 9 to 10 o'clock and so on according to the schedule. This sums up to 600 skiers for the Mellaubahn. The same applies to the rate at the Gipfelbahn. If the basic load is two, than 600 more skiers are added which results in 1200 skiers per day. With each value increase, 600 more skiers are added to the system. It is expected that on a very busy skiing day about 6000 to 7000 people are arriving at the skiing area. Therefore, the basic load can be scaled up to 10 where 6000 skiers arrive in Mellau and 1300 at the Gipfelbahn, distributed over the day.

Arrival rate schedule

As the skiers arrive throughout the day, there needs to be some control on when they arrive. Most of the people arrive in the morning when the skiing areas are opening but there are also skiers arriving only for the afternoon. In Table 5.1a the ratio on when skiers arrive is listed.

Analogously, for the arriving skiers from Damüls, there is a schedule Table 5.1b. Due to the layout of the skiing area the rate starts later, since the skiers need to take other lifts to get to this entry point.

The schedule values are based on personal experience and knowledge about the skiing area.

Start	End	Value
8:00	9:00	1
9:00	10:00	3
10:00	11:00	3
11:00	12:00	1
12:00	13:00	1
13:00	14:00	1
14:00	15:00	0
15:00	16:00	0

(a) Mellau

Start	End	Value
8:00	9:00	0
9:00	10:00	0
10:00	11:00	1
11:00	12:00	1
12:00	13:00	1
13:00	14:00	1
14:00	15:00	0
15:00	16:00	0

(b) Damüls

Table 5.1: Arriving rate schedules

Skill level

The skiing level is distributed exponentially to represent a realistic crowd, so more slower skiers are in the system. It can, however, be adapted by changing the exponen tial distribution to only range from 3 to 6 by changing the floor of the distribution. This leads to a system with more advanced skiers, e.g., due to bad weather conditions, or during the off season, where no tourist are in the area.

There are many further parameters which influencing the simulation. For the scenarios in this work these are the important one. More options in parameters and how they influence the outcome of the simulation is explained in the evaluation chapter 6 and outlook section 6.4.

5.2 Technical defect of lifts

It would be ideal for the carrier of the skiing area to have the system working perfectly at all times and no difficulties arise with the lifts or the slopes. This, unfortunately, is not really realistic. Often it is interesting to see how a system behaves when unforeseen circumstances arise. These not ideal behaviour could lead to long waiting times and therefore to dissatisfaction of the skiers. In these situations it is necessary to have alternatives, which can be identified and tested using simulation.

In the following scenarios different lifts are out of order for the whole day due to a technical defect. However, the first lift, the Mellaubahn, bringing the skiers into the skiing area, has to be operational to even consider opening the whole skiing area. Therefore, this lift is always working. Because of the nature of the skiing area, it is very difficult to go to another lift other than the Rossstelle, after entering through the Mellaubahn. For this reason, it is not meaningful to simulate a dysfunction of this lift, simply because the people at the bottom can not go anywhere else. As a result, the only lifts that can malfunction are Gipfelbahn, Wildgunten and Suttis. If the Wildgunten is not running the Suttis can not be operational, since the skiers depend on the ride up the Wildgunten to get there.

The final scenarios are as follows:

- On a not to busy day (load = 6) the lift Wildgunten and therefore also Suttis are not running. The simulation is used to analyze how the skiers and their distribution of waiting, skiing and lift time changes.
- On a very busy day (load = 9) the lift Suttis is not running. This should have a significant impact and an increase in load on the other lifts should be noticeable.

5.3 Weather related shutdown of specific lifts

The most impact on the skiing area a technical defect has, is if it happens on startup of the lift and as a result, the lift is not running through the whole day. Even if the lift is running initially, a shut down during the day has still a big impact on the overall capacity of the lifts. It sometimes happens, that a bad weather period starts in the middle of the day and forces a lift to shut down. This often happens in Mellau with the Gipfelbahn, as it is exposed to strong winds. For this reason, in this scenario the Gipfelbahn shuts down at 12 o'clock and the skiers have to stay in Mellau rather than going to Damüls. The parameters set for this scenario are as follows: Basic load is set to 3, reason being that on bad weather days, there are less people skiing. The minimal skiing level is set to 3 because the real beginners often do not visit skiing areas on bad weather days. With this scenario no big waiting times should occur, because the load is low and the three remaining lifts should be able to handle it.

5.4 Special scenarios

The previous scenarios can occur in the current real world system of the skiing area of Mellau. The following special scenarios however, some changes to the current state is needed as additional information is presented to the visiting skiers. For example a way to present the skiers, driving on a slope, the number of waiting skiers waiting at the bottom of a lift. This can either be done by means of a digital panel on the slopes or with a mobile app, where a skier can check the current situation of the whole skiing area.

Information about the the waiting skiers at a lift

As the decision making at each junction is based on probabilities, slightly changing single values can have a significant impact on the entire system. To analyse such impacts, a scenario was built in which the skiers are given some information about the waiting skiers at a specific lift if they drive on a slope which leads to it. As a result, if the number of waiting skiers is to high, a part of the notified skiers decide to go to a different lift. This is modeled by changing the probability at this junction.

For example, if at the Rossstelle are more than 200 people waiting, the probability that skiers drive to the Gipfelbahn increases. The same applies if more than 200 people are waiting at the Wildgunten, and, as a result, more people drive to the Suttis and back to the Rosstelle. This should result in more even distribution of skiers in the skiing area.

5.5 Open simulation

The open simulation gives the user of the simulation model the possibility to experiment with a custom set of parameter. It is, for example, possible to only simulate very advanced skiers by putting the distribution floor of the skiing level to 4 or the other way around to only simulate beginners. Also the starting of ski courses can be simulated by adding a specific amount of skiers to the system at the Rossstelle at 10 a.m. This is a commonly occurring scenario during holidays and it is interesting to see how the system would behave in such a situation.

5.6 Starting a scenario

In Figure 5.1 the starting screen of a simulation is shown. Here the user can set the parameters like basic load and skill level. The default values are set to the once defined in the corresponding scenario.

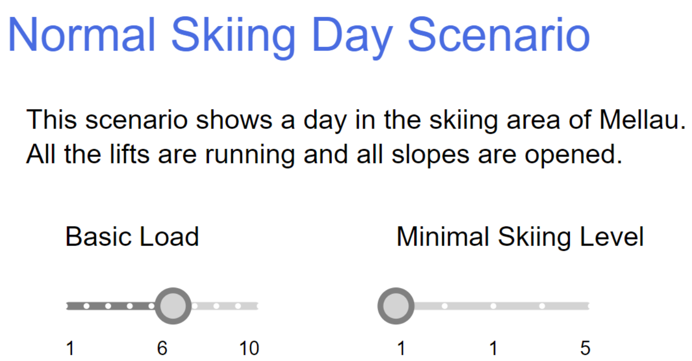


Figure 5.1: Normal skiing day scenario

After all parameters are set, the simulation is started. The skiers arrive at specific locations with the defined arrival rate, and start their path trough the skiing area and ski throughout the day. They can leave the system at two different points: once at the starting position or by leaving the simulated area with a connection lift to Damüls. Once the skiing day is finished and the simulation time reaches 4 p.m. the simulation is stopped.

6 Evaluation, analysis and interpretation

In this chapter the conducted experiments and there outcome are evaluated. Starting with the scenarios, there results are shown primarily in the statistics. There are more possible statistical insights but the most important once are included here. Subsequently, theses results are summed up and the findings of the interview with the experts of the skiing area Mellau are presented.

There are five main charts in the following evaluations. The fist one is the pie chart, e.g. Figure 6.1a, which shows the distribution of the time spent by all the skiers in the area over the whole day split into the three parts *lift time, waiting time and skiing time*. The next is the line chart, e.g. Figure 6.1b which shows the current number of skiers in the skiing area over the course of the day. On the x-axis is the time of day in minutes and on the y-axis is the number of skiers. Next, there is the collection of pie charts, e.g. Figure 6.2 which shows the distribution of the time skiers of different skiing levels spend over the day. The next chart is again a line chart, e.g. Figure 6.3b which shows the number of waiting skiers at each lift over the day. On the x-axis is the time of day in minutes and on the y-axis the number of skiers at each lift. Last but not least the line chart, e.g. Figure 6.4 which shows the workload of the lifts. In brackets, the size of the gondolas of each lift is shown and the load is evaluated by the number of skiers in one gondola.

6.1 Outcome of the scenarios

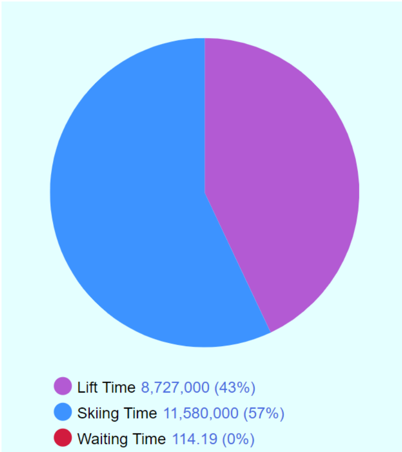
The previously defined scenarios are evaluated with a fixed set of parameters but due to the non deterministic nature the results are subject to randomness. Each scenario is done with different parameters to give some context on the defined scenarios and have something to compare them to.

6.1.1 Normal skiing day with different configurations

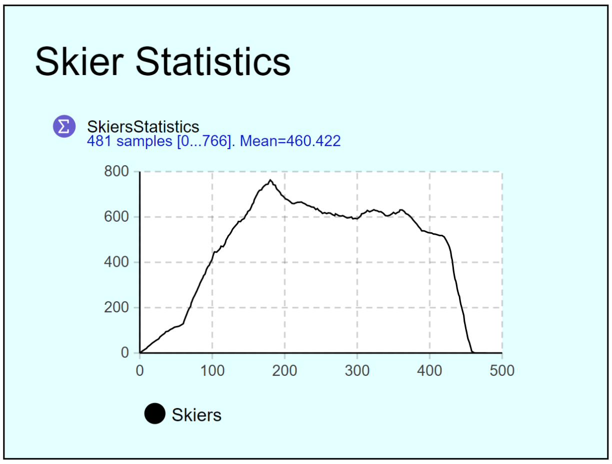
This section presents the simulation of a normal skiing day which was defined as a scenario in section 5.1. The only parameter that is changed in the upcoming evaluation is the general load i.e. the number of skiers arriving. The evaluation is based on statistics of the waiting time at the ski lifts as well as the time spent on a ski slope and in the lift. Furthermore, the workload of the lifts is analysed through extracting how full the gondolas of each lift are.

Load = 3 - low load

In Figure 6.1b the number of skiers in the skiing area over time is plotted. The x-axis shows the time since starting the simulation in minutes is shown and on the y-axis the number of skiers. The graph shows that at 8 a.m. no skiers are in the system and later, after about 180 minutes, so at 11 a.m., a peek is shown where the most skiers are in the system with a maximum of 766 skiers. They gradually leave the skiing area over time either to Damüls or back down to Mellau. At 3:30 p.m. most skiers have left because the lifts are closing.



(a) Time spend by skiers



(b) Skiers over time

Figure 6.1: Statistics of a normal skiing day with load 3

Figure 6.1a shows where skiers spend the time while being in the skiing area. In this scenario the load is very low and therefore there is no waiting time at all. The majority of time is spend skiing on the slopes with 57% and the rest so 43% is spend on the lifts.

Interestingly, but not unexpected, is the differences between slower and faster skiers. It is to be expected that good skiers spends less time on the slope and more time on the lifts but the difference is significant as Figure 6.2 shows. A beginner spends 62 % skiing and 38 % on the lift whereas an average skier spends 63 % on the lift and only 37 % skiing. More advanced skiers however only spend 22 % skiing.

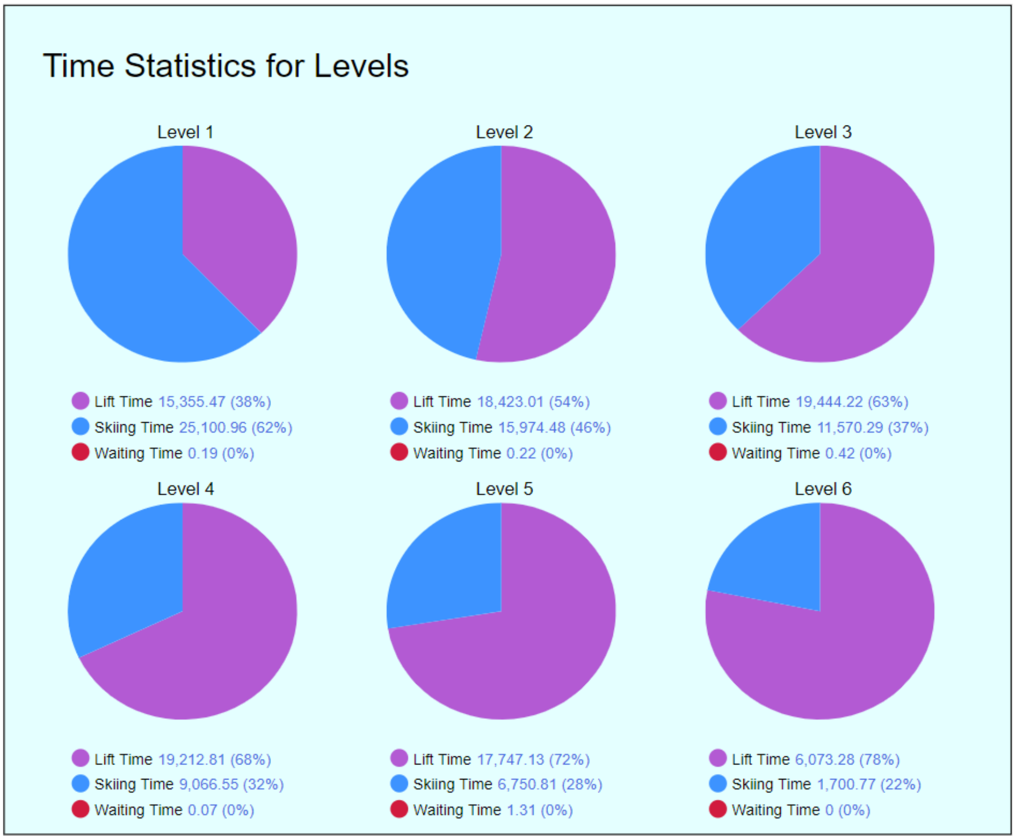
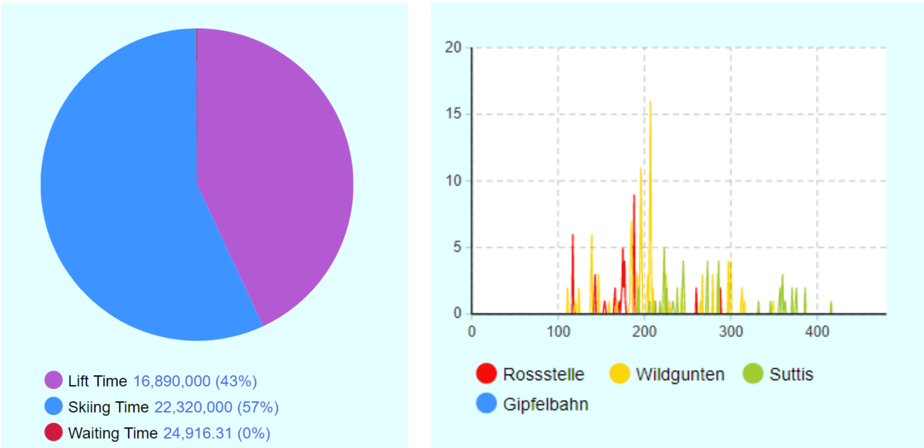


Figure 6.2: Normal skiing day - time spent in skiing area - separated by skiing levels

Load = 6 - medium load

Running the same experiment with a different load that adds 3600 skiers to the system throughout the day still is manageable by the skiing area without any waiting time at the lifts. The distribution shown in Figure 6.3a is about the same as before.

With this amount of skiers in the system, no queues are forming as can be seen in Figure 6.3b. This also shows in the workload in Figure 6.4 where none of the analysed lifts are at the maximal capacity.



(a) Time spend by skiers (b) Queue length over the day

Figure 6.3: Statistics of a normal skiing day with load 6

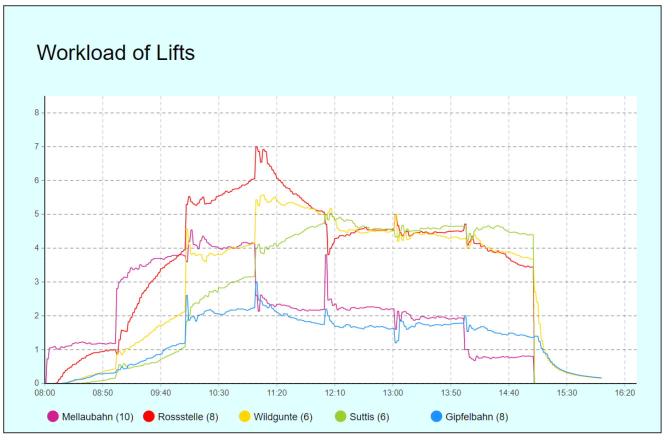
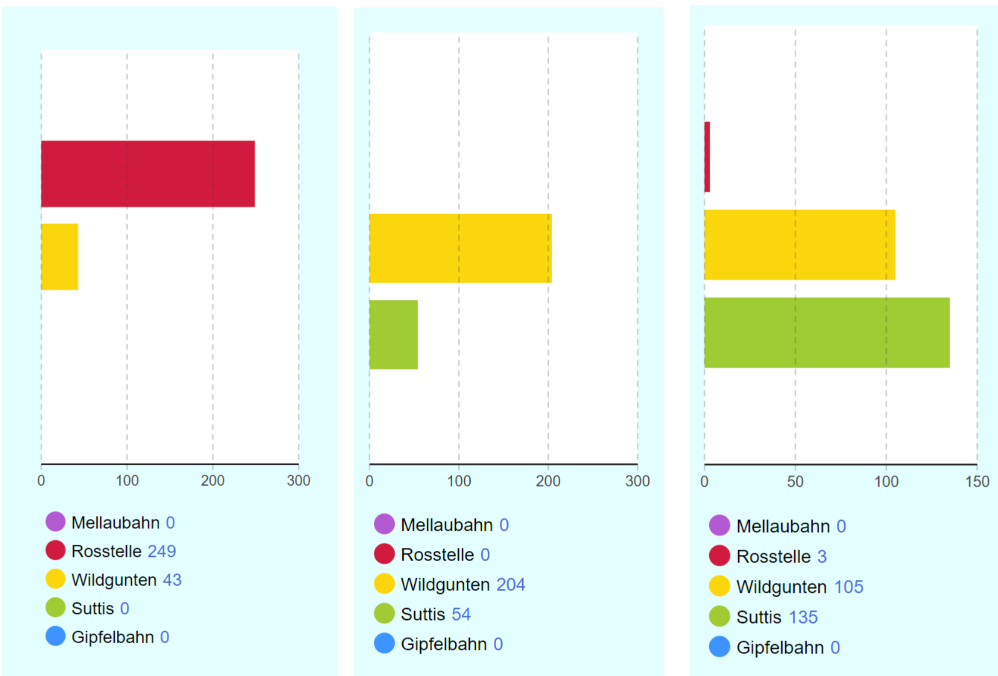


Figure 6.4: Normal skiing day - workload of the lifts

Load = 9 - high load

With more skiers, the system is getting more occupied and, therefore, queues are forming at the lifts. Starting at the Rossstelle, which is the lift most skiers take first, the crowding takes place in the morning and midday, whereas at the Wildgunten and Suttis the queues only build up in the afternoon. This can be observed in Figure 6.5 where the current length of the queue at each lift is shown at different times of the day. In the morning, when less skiers are skiing, no queue is building up.

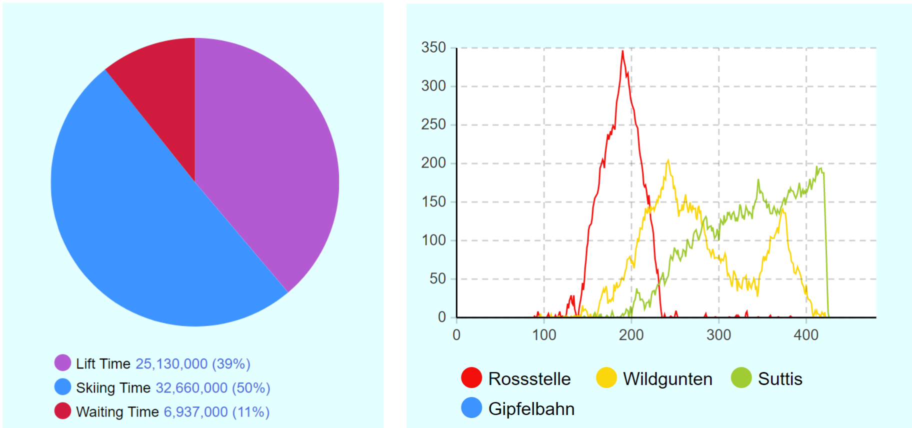


(a) Queues at 11 a.m. (b) Queues at 1 p.m. (c) Queues at 2 p.m.

Figure 6.5: Queue length at different day times

In Figure 6.6b the queue length over the whole day is shown. For the Rosstelle, the biggest load is after about 190 minutes from start of the simulation so at about 11 a.m., with a maximum queue length of 350. For the Wildgunten the busiest time is in the afternoon after about 250 minutes from start, so between 12 a.m. and 1 p.m., with a maximum queue length of 290. For the Suttis, most skiers only take this lift in the afternoon, which means that the time right before shutdown is when the peak of around 200 people occurs.

For the time distribution with a high load, the waiting time takes up 11 % and the skiing and lift time is at 50 % and 39 % respectively as Figure 6.6a shows.



(a) Time spend by skiers (b) Queue length over the day

Figure 6.6: Statistics of a normal skiing day with load 9

To put this into perspective, if the Rossstelle is running at optimal speed and every gondola is filled, it can transport up to 3400 skiers per hour. Therefore, the expected waiting time, if 350 skiers are waiting, is less than 10 minutes. Also the Wildgunten can take up to 2400 skiers per hour, which correlates to a maximum waiting time of about 5 minutes. This is confirmed by the statistics of the time end measurement of the Wildgunten in Figure 6.7

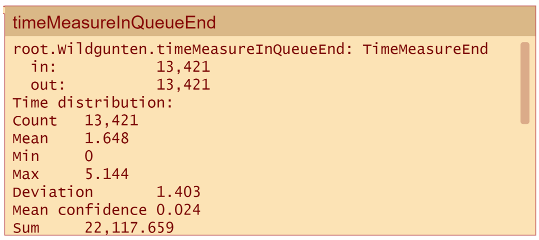


Figure 6.7: Normal skiing day - time measure end of Wildgunten

The statistics for the different skiing levels proofs to be even more interesting. Figure 6.8 shows that a beginner skier spends about 9 % waiting and 56 % skiing whereas a advanced skier spends 18 % waiting and only the same amount of time skiing.

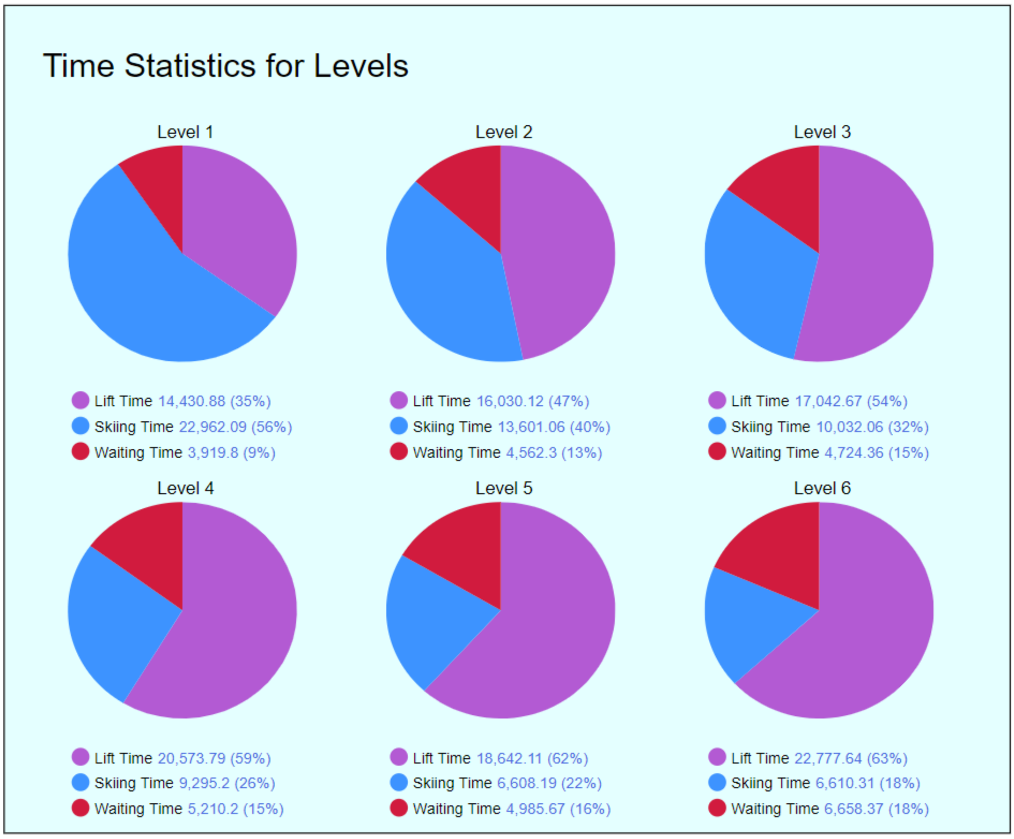


Figure 6.8: Normal skiing day - time spent in skiing area - separated by skiing levels

6.1.2 Technical defect of lifts

In this section the scenario is analysed if a lift, has a technical issue and does not run for the whole day as described in section 5.2. It is to be expected, that the waiting time at the remaining lifts increases since the same amount of skiers have to take less lifts and therefore the queues are longer. It is also to be expected that the skiing time decreases.

The chosen parameters are shown in Figure 6.9

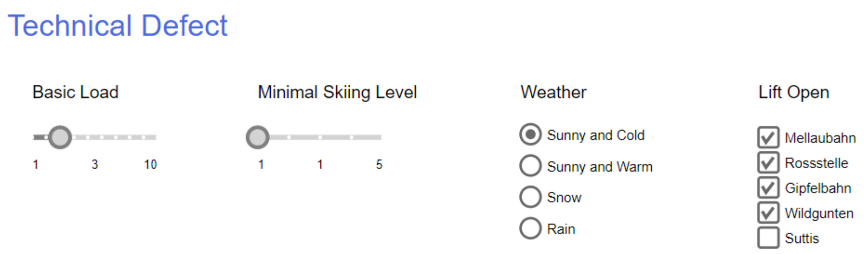


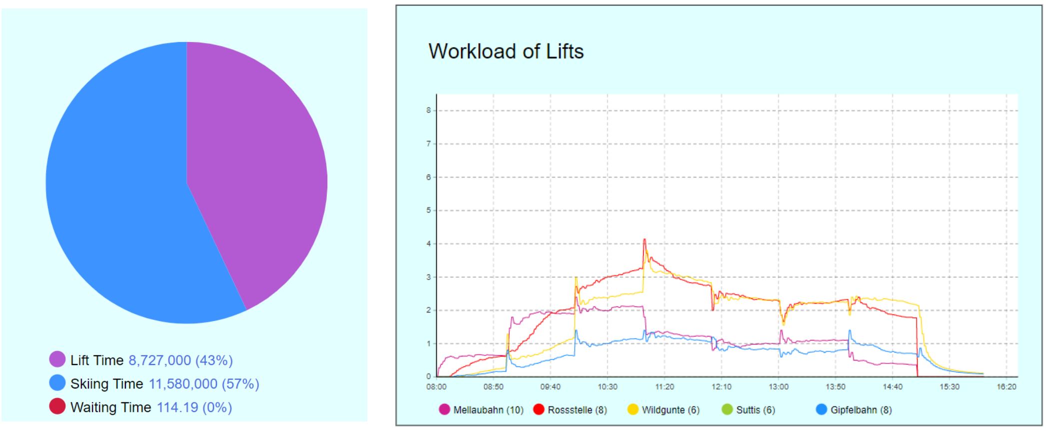
Figure 6.9: Technical defect of lifts - parameters

Suttis not running

The least effect on the whole system has a defect of the Suttis, since this lift handles the least amount of load anyway so the other lifts can take over very well. The simulation is done with different loads, starting with a minimum load of 3, followed by a medium load of 6 and a high load of 9.

Load = 3 - low load

With a low load, there are still no waiting times or queues form and the lift load is never at a significant high point. The evaluations of this scenarios are shown in Figure 6.10a and Figure 6.10b



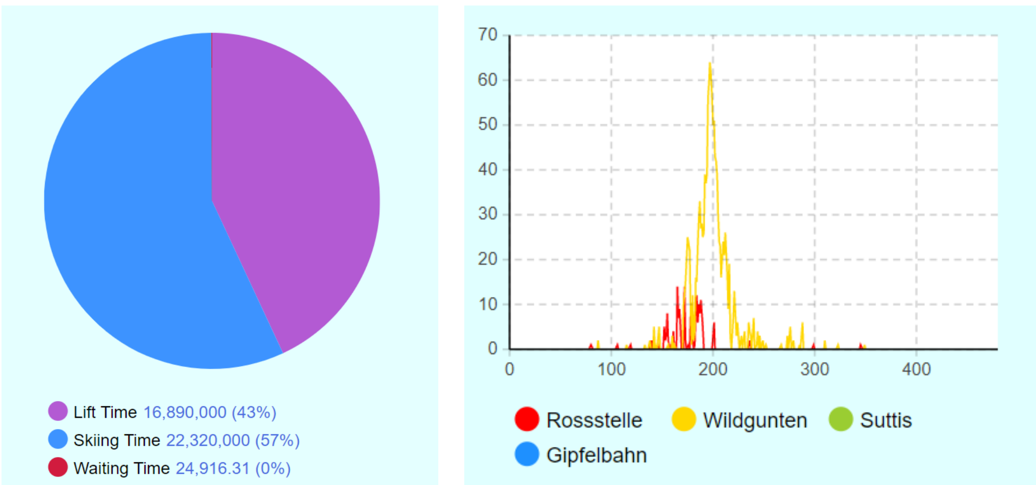
(a) Time spend by skiers

(b) Workload of the lifts

Figure 6.10: Statistics of a technical defect of lifts with load 3

Load = 6 - medium load

The same experiment was performed with a medium load. The outcome is as expected with some minor queues and some waiting time, but still not a high demand on the opened lifts. As indicated by Figure 6.11b, only the queue at the Wildgunten has a short period, when it is building up to about 60 skiers, but this results in no long waiting time.



(a) Time spend by skiers

(b) Queue length over the day

Figure 6.11: Statistics of a technical defect of lifts with load 6

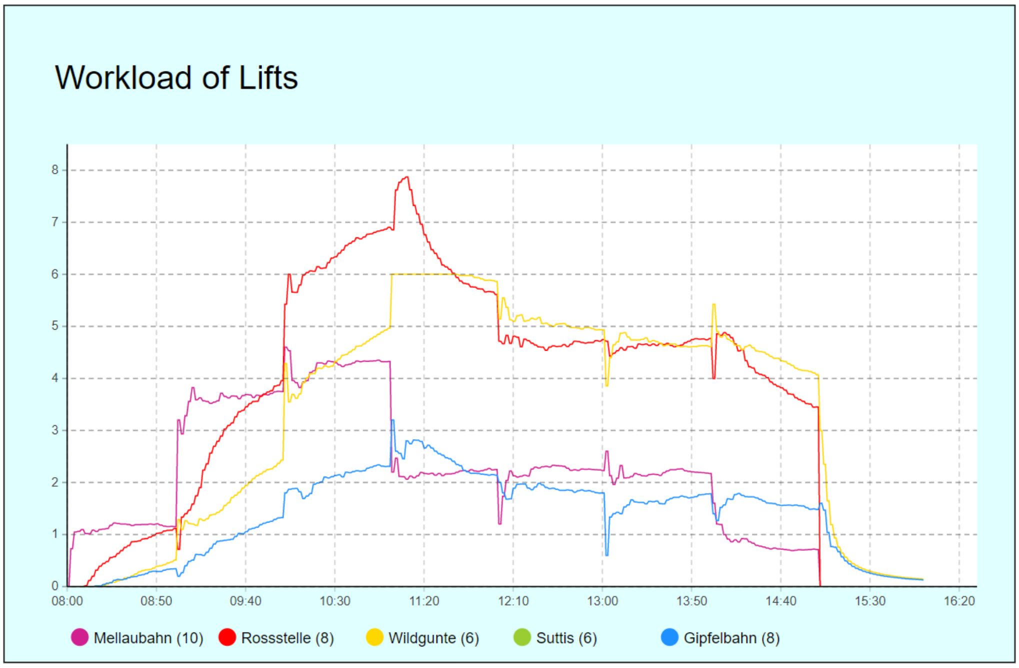
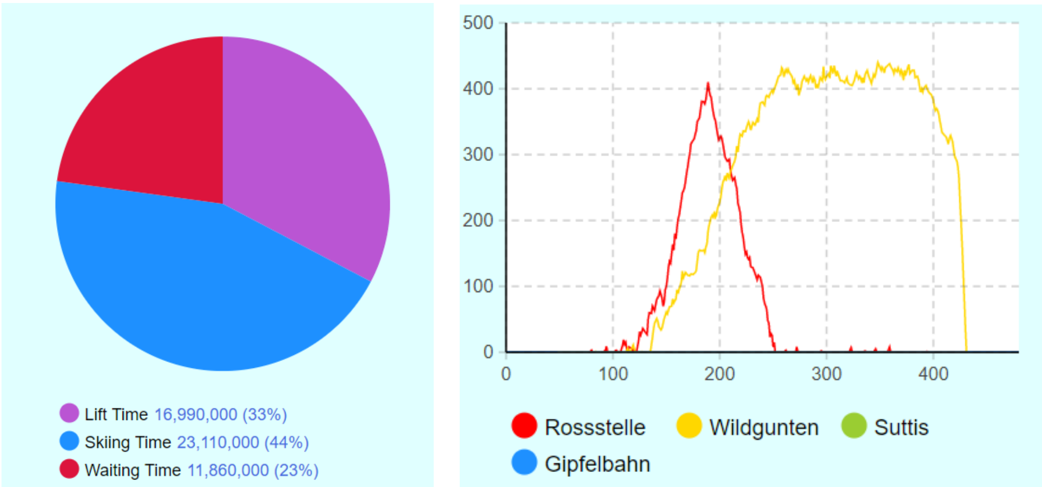


Figure 6.12: Technical defect of lifts - workload of the lifts

Load = 9 - high load

If the load is set to high, the increase is significant compared to the normal day scenario where all lifts are running. The waiting time is at 23 %, see Figure 6.13a, compared to the 13 % of the previous scenario. Also the queue length of the Wildgunten went up and stayed on a high value throughout the whole afternoon as indicated in Figure 6.13b, where skiers normally take the Suttis.



(a) Time spend by skiers

(b) Queue length over the day

Figure 6.13: Statistics of a technical defect of lifts with load 9

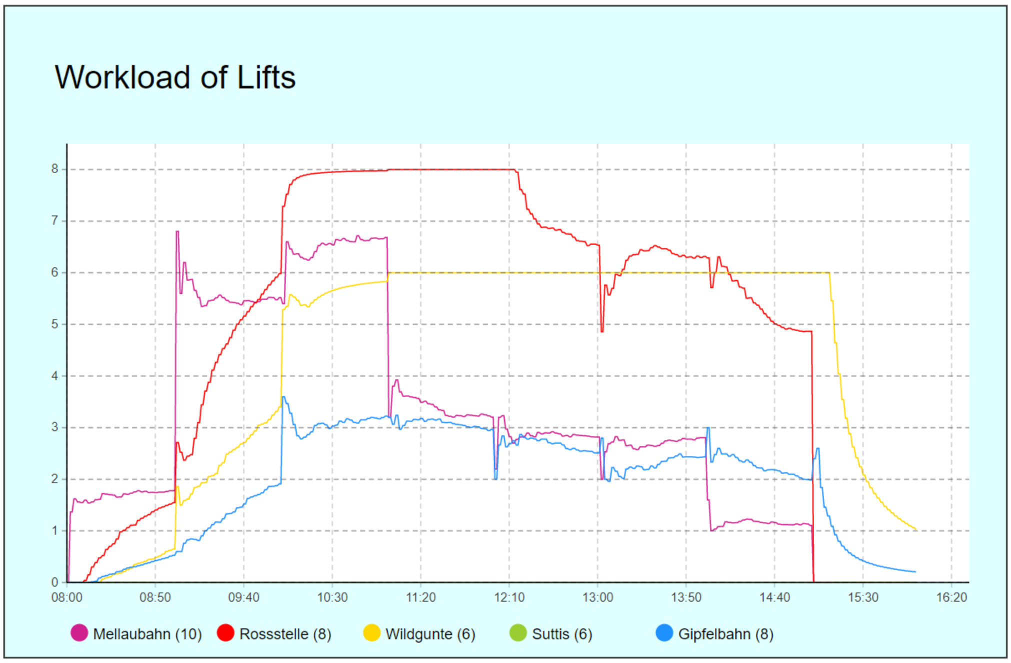


Figure 6.14: Technical defect of lifts - workload of the lifts

Wildgunten not running

If the Wildgunten is not running, the only lifts the skiers can take is the Rossstelle and the Gipfelbahn to Damüls. In this case, the demand on these two lifts, especially on the Rossstelle, is very high.

In Figure 6.15 the parameters of the configuration are presented. They are the same as before with the difference that the check mark at Wildgunten is not set, indicating that it is out of order. Again, the simulation is done with three different loads (low, medium, high).

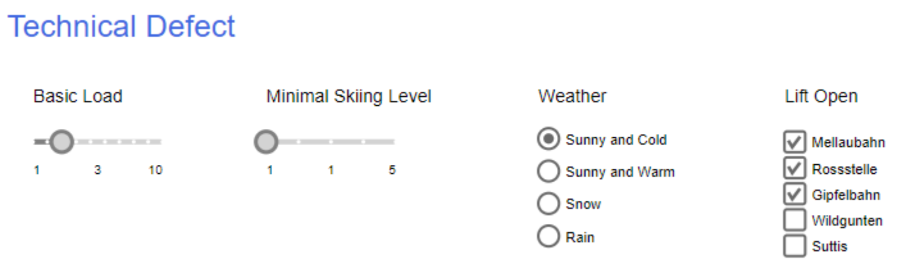
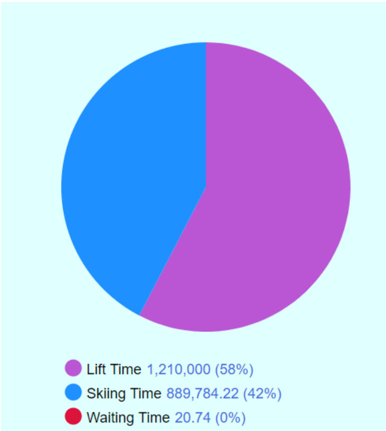


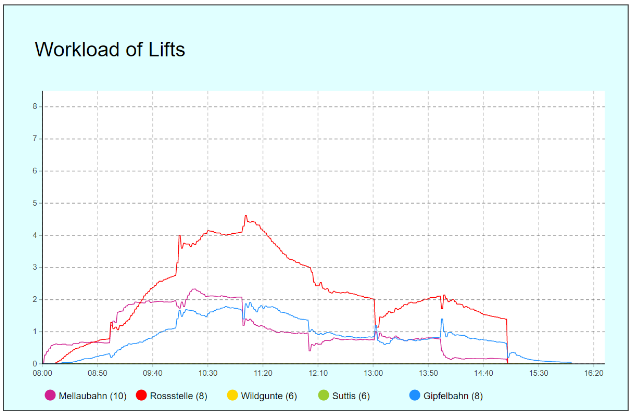
Figure 6.15: Technical defect of lifts - parameters

Load = 3 - low load

If the load is low, the very high capacity of the Rossstelle can keep up with the high demand without any waiting time for the skiers as can be observed in Figure 6.16a. The workload is not on the maximum at any point of the day, see Figure 6.16b.



(a) Time spend by skiers

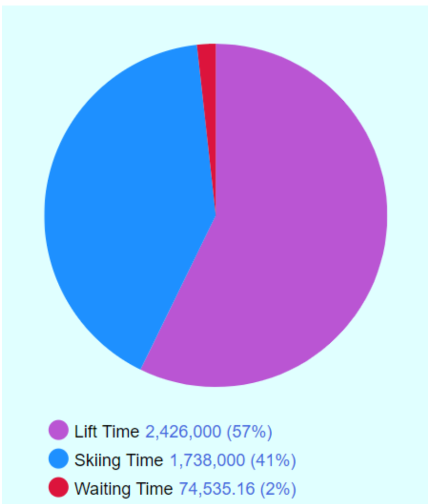


(b) Lift workload

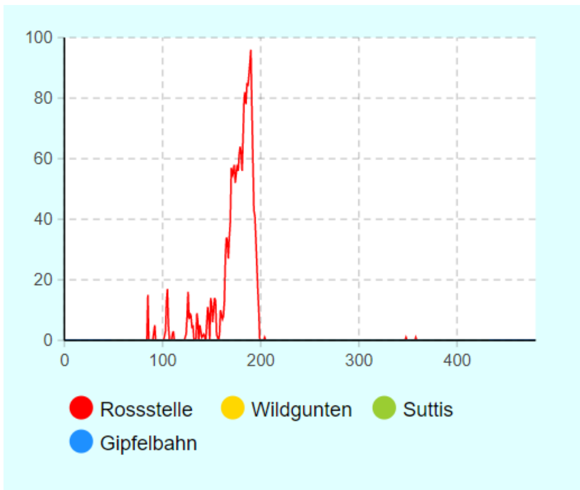
Figure 6.16: Statistics of a technical defect of lifts with load 3

Load = 6 - medium load

Setting the load higher increases the demand on the one single lift enormously and there is a queue starting to appear, especially at midday, when most skiers are in the area.



(a) Time spend by skiers



(b) Queue length over the day

Figure 6.17: Statistics of a technical defect of lifts with load 6

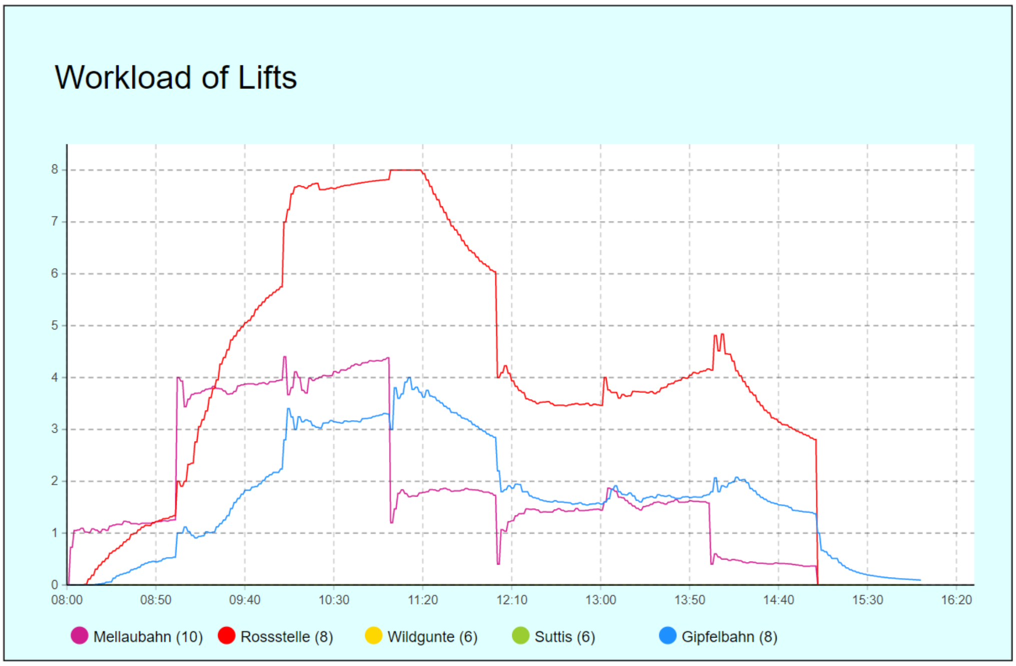
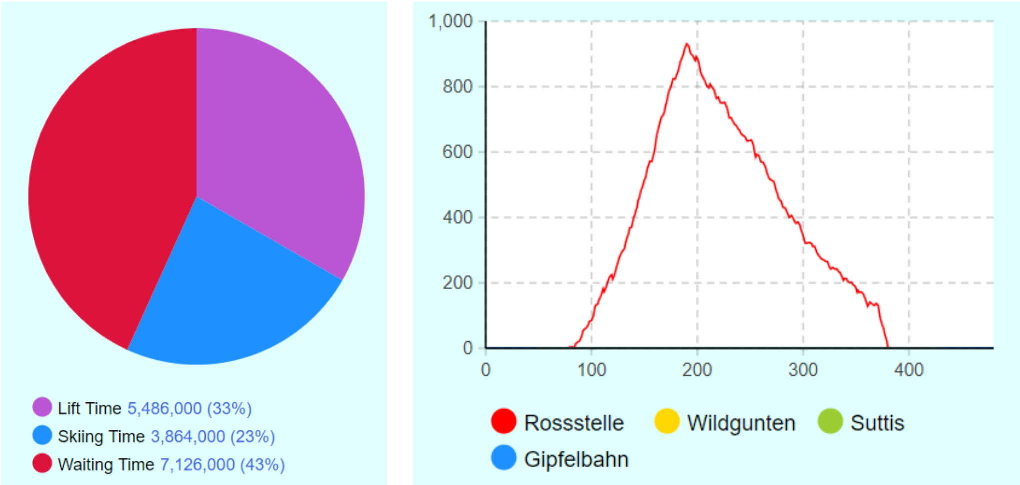


Figure 6.18: Technical defect of lifts - workload of the lifts

Load = 9 - high load

With high loads the Rossstelle is definitely overcrowded and massive waiting times and queues are building up. In Figure 6.19b the queue length is at over 900 skiers, which in turns lead to the time distribution in Figure 6.19a being very much on the waiting side with 43 % of waiting time. As to be expected the work load on the Rossstelle is at its maximum throughout the entire day which can be seen in Figure 6.20.



(a) Time spend by skiers (b) Queue length over the day

Figure 6.19: Statistics of a technical defect of lifts with load 9

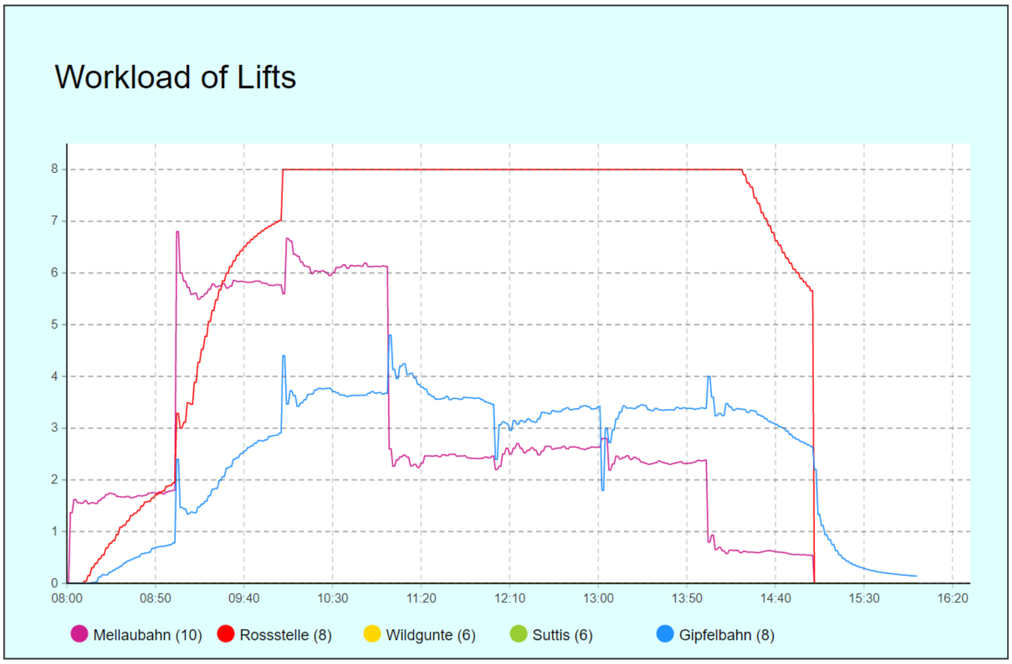


Figure 6.20: Technical defect of lifts - workload of the lifts

6.1.3 Weather related shutdown of specific lifts

As described in Chapter 5, the Gipfelbahn is prone to shutdowns on days with strong winds. This section evaluates such a scenario happening.

In Figure 6.21 the parameters are set as described in the scenario. Because the weather is set to wind, the Gipfelbahn is shutting down and all the skiers which are already waiting there, return to the Rossstelle and the slopes leading to the Gipfelbahn are closed as well.

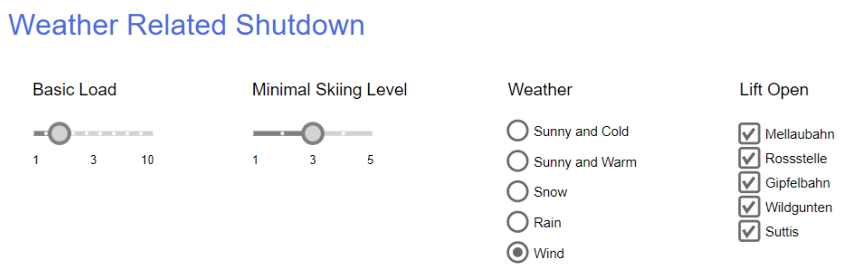
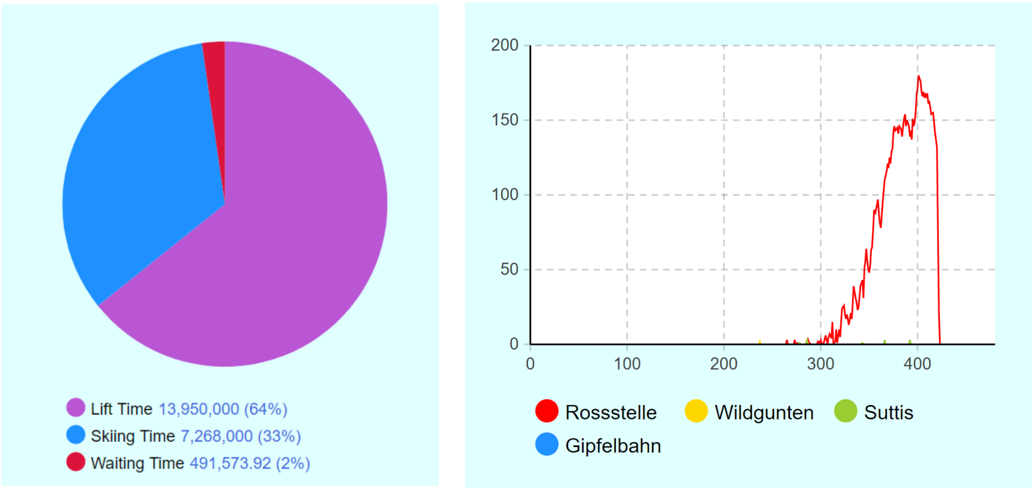


Figure 6.21: Weather related shutdown of specific lifts - parameters

Load = 3

The load of the Gipfelbahn ends abruptly as can be seen in Figure 6.23. Also the maximum queue length in Figure 6.22b shifts to the afternoon, since the skiers who otherwise would go to Damüils have to stay in Mellau. The time distribution is interesting as the waiting time only takes up 2 % even though there are some queues in the afternoon which can be seen in Figure 6.22. Reason for this is, because the lifts are running smoothly in the morning and the skiers do not have to wait. Only for a brief time frame in the afternoon skiers are waiting but the capacity is still good enough to handle the load.



(a) Time spend by skiers

(b) Queue length over the day

Figure 6.22: Statistics of a weather related shutdown of specific lifts with load 3

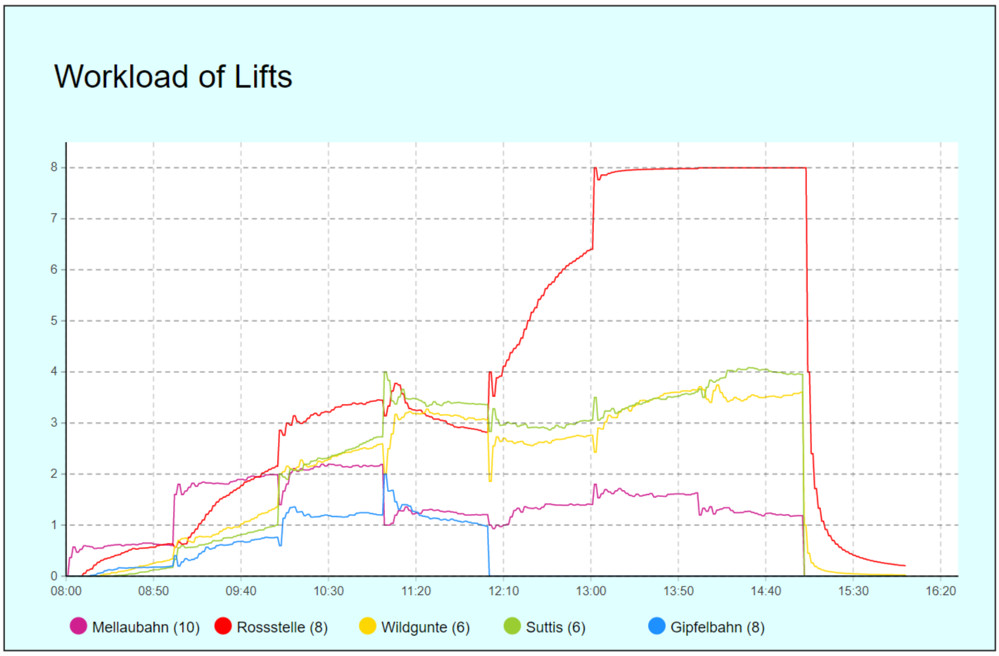


Figure 6.23: Weather related shutdown of specific lifts - workload of the lifts

Another interesting and unique thing in this scenario is happening with regard to the total number of skiers in the area. In the other scenarios, skiers arrive in the morning and they leave the skiing area to Damüls and less skiers come back in the afternoon. Because the probability to leave the area at the bottom is lower than to leave it to Damüls, more skiers stay in this scenario. Therefore, the peak of skiers in the weather related shutdown scenario is in the afternoon, compare Figure 6.24.

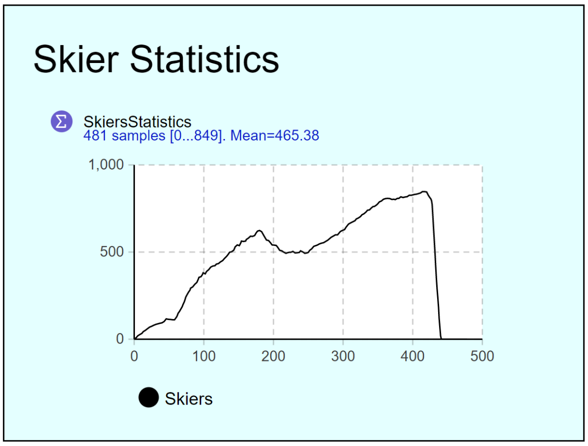
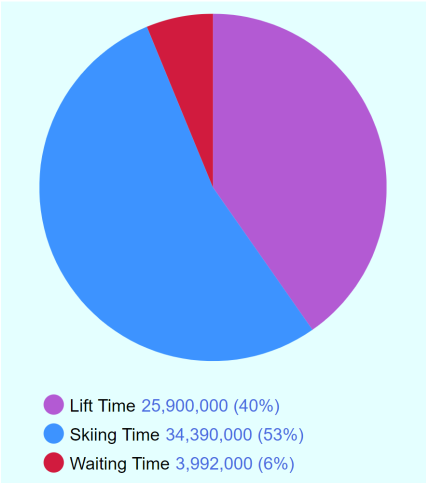


Figure 6.24: Weather related shutdown of specific lifts - skiers over time

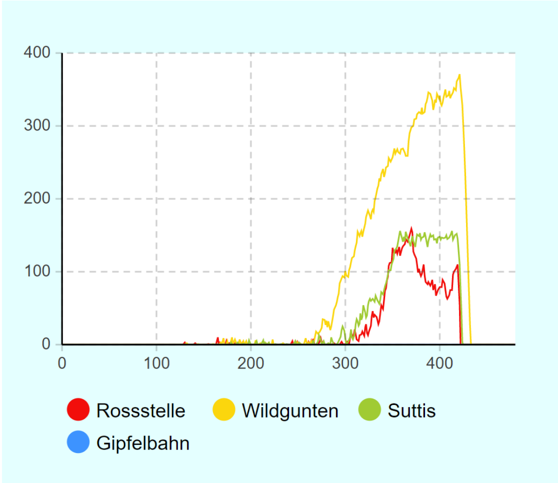
Load = 6

If the load is put to a higher value, the amount of skiers build up to an amount, that the regular system can not handle anymore. Therefore, the configuration used for the scenario specified in subsection 6.1.4 is combined with the one presented here. This means that the distribution of skiers over the remaining lifts should be equal rather than one overcrowded and the others are empty. As Figure 6.25 indicates, the waiting time is at a low level with only 6 % of waiting time and 53 % of skiing time. The queues are shorter than the queues on a normal day presented with a high load.

The same as before with load 3 happens with the number of skiers. The high point is in the afternoon rather than in the morning when most people are arriving at the skiing area, see Figure 6.26.



(a) Time spend by skiers



(b) Queue length over the day

Figure 6.25: Weather related shutdown of specific lifts with load 6

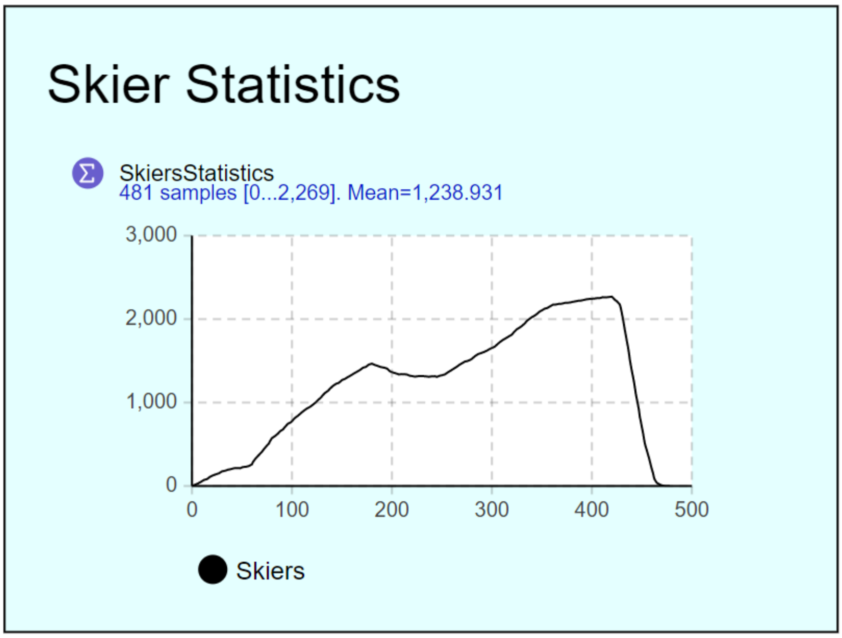


Figure 6.26: Weather related shutdown of specific lifts - skiers over time

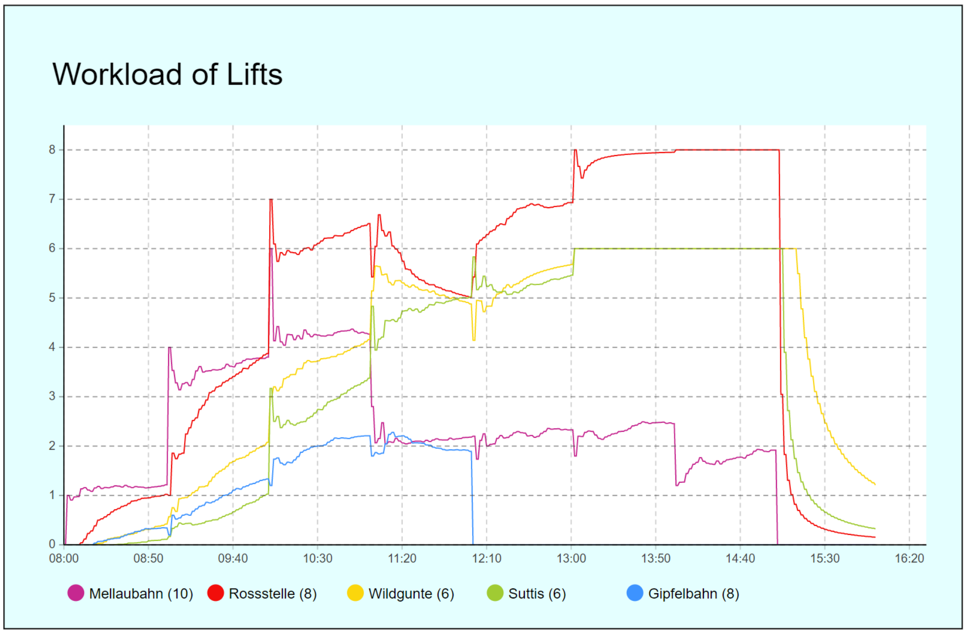
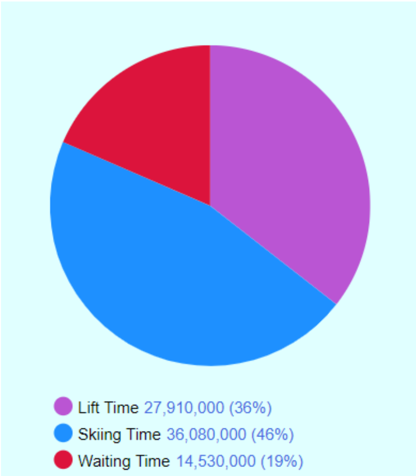


Figure 6.27: Weather related shutdown of specific lifts - workload of the lifts

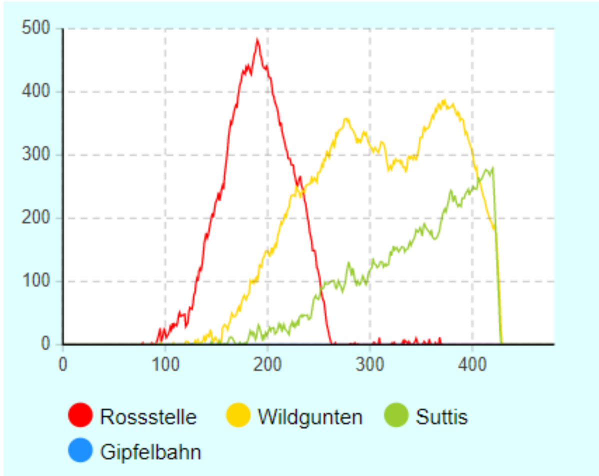
6.1.4 Special Scenario - information provided to skiers

By providing the skiers with information about how many skiers are waiting at specific lifts, we tried to control the load over the whole skiing area. This is accomplished by modifying some decision makings at junctions in the skiing area exactly this goal was reached. The scenario represents a normal skiing day with all lifts running and the maximum load. First, in Figure 6.28 the simulation was done with no adapting of the junctions and in Figure 6.29 the decision making was done with the information of the currently waiting skiers at the bottom of the lifts.

The more equal distribution of skiers in the area can be noticed in the more even curves of the queue length in Figure 6.29b compared to Figure 6.28b as well as the lower maximum of waiting skiers at each lift in Figure 6.28b and Figure 6.29b. As a result the waiting time of all skiers is decreased by 5 %.

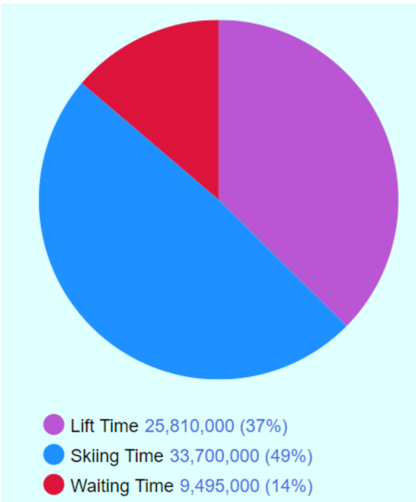


(a) Time spend by skiers

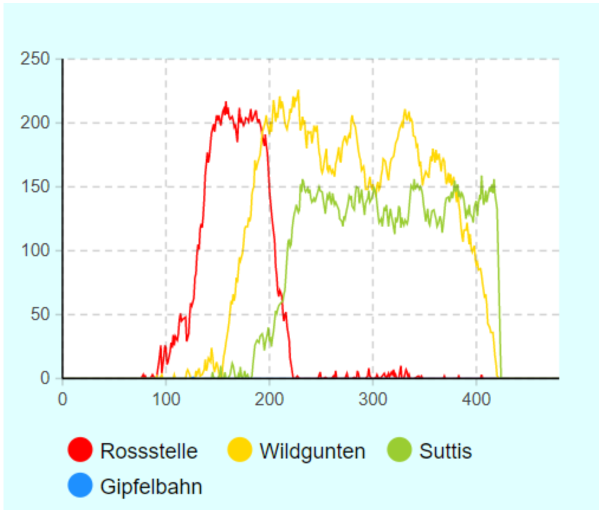


(b) Queue length over the day

Figure 6.28: Special scenario - no information provided - load 10



(a) Time spend by skiers - adapted



(b) Queue length over the day - adapted

Figure 6.29: Statistics of the special scenario - adapted - load 10

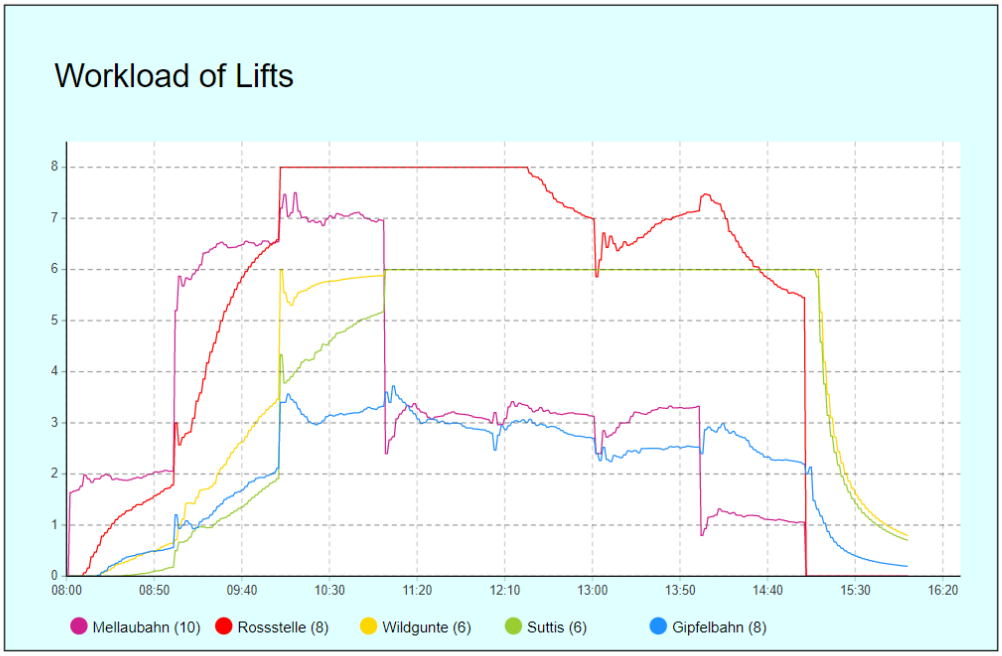


Figure 6.30: Statistics of the special scenario - workload of lifts

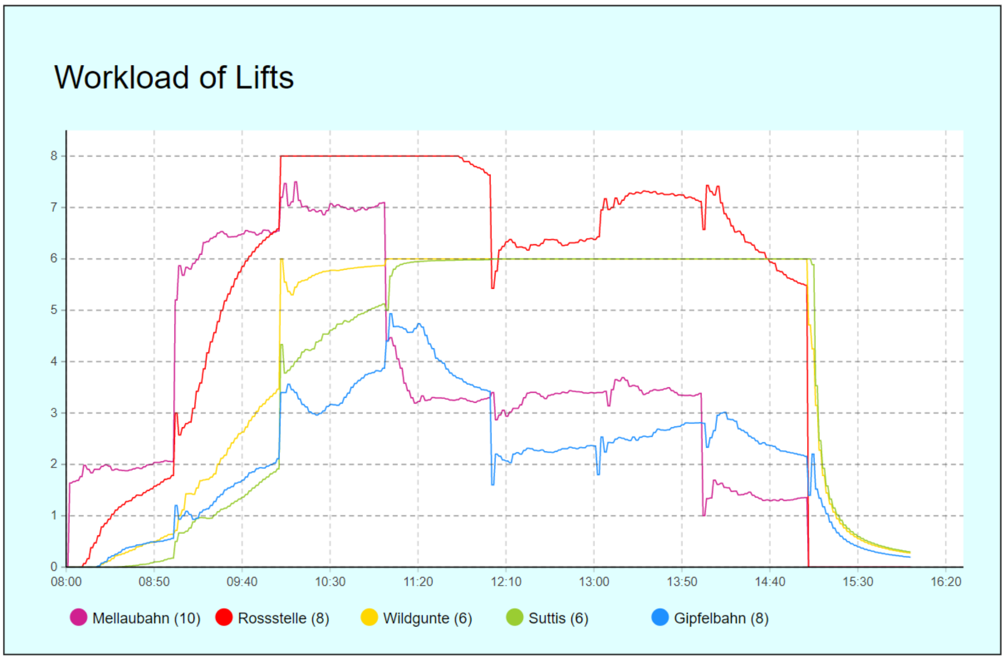
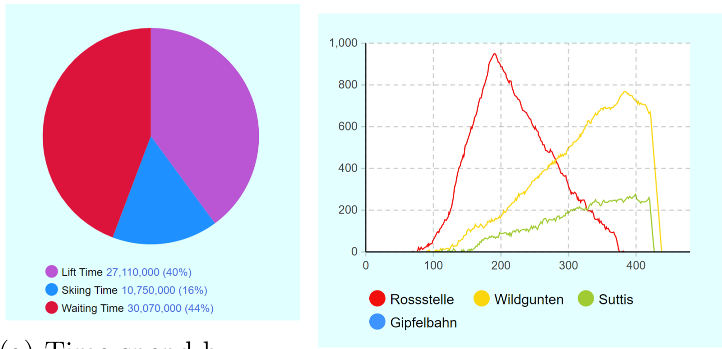


Figure 6.31: Statistics of the special scenario - adapted - workload of lifts

6.2 Open simulation

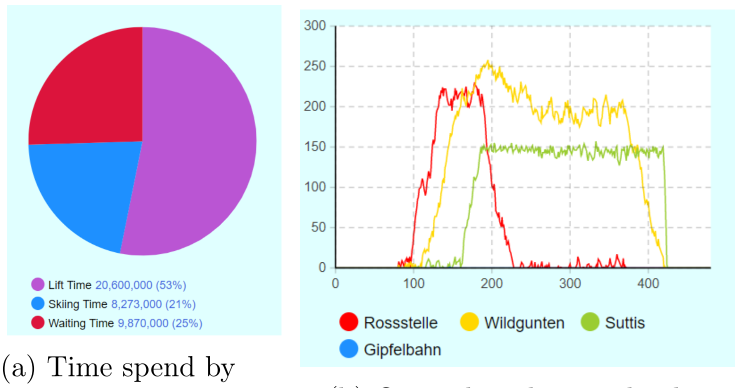
Setting up the simulation with only very advanced skiers and a high load over-crowds the whole system. The waiting time are taking up almost 45 % of the skiers time. The lifts are at a maximum load for almost the entire day and the queues still build up to a large amount. Comparing the same parameters in a simulation with the special scenario where information is provided to the skiers, the waiting time can be improved even more compared to the simulation of all categories of skiers. In Figure 6.33 the waiting time improved to 25 % and even the queue length is in a realistic range with a maximum of 250 people waiting, which translates to a maximum waiting time of 7 minutes.



(a) Time spend by skiers

(b) Queue length over the day

Figure 6.32: Normal day with advanced skiers - load 10



(a) Time spend by skiers

(b) Queue length over the day

Figure 6.33: Normal day with advanced skiers - information provided - load 10

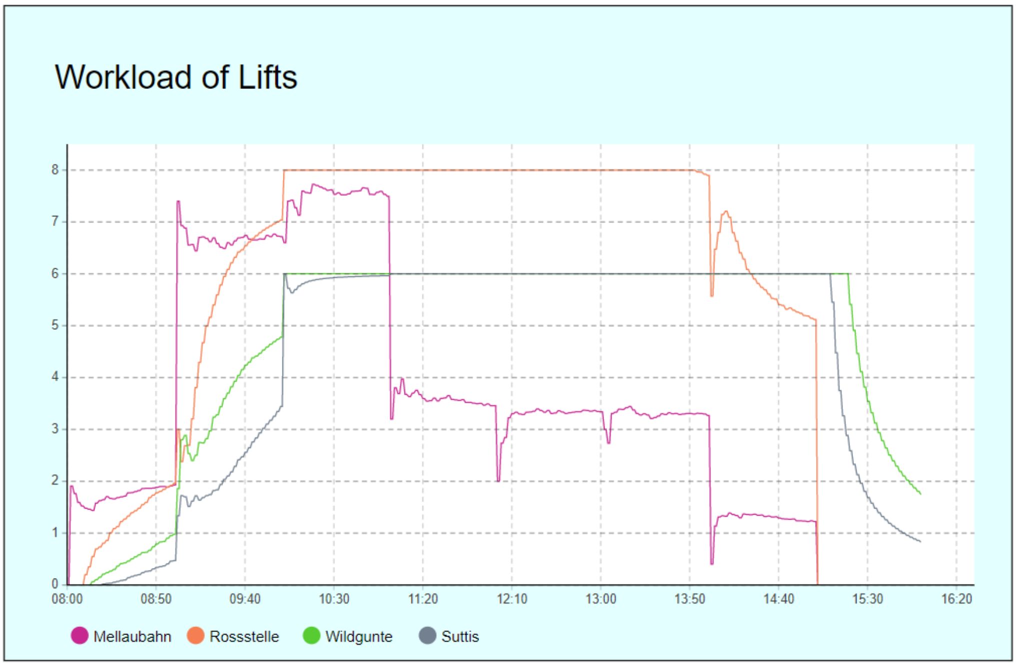


Figure 6.34: Normal day with advanced skiers - lift workload - load 10

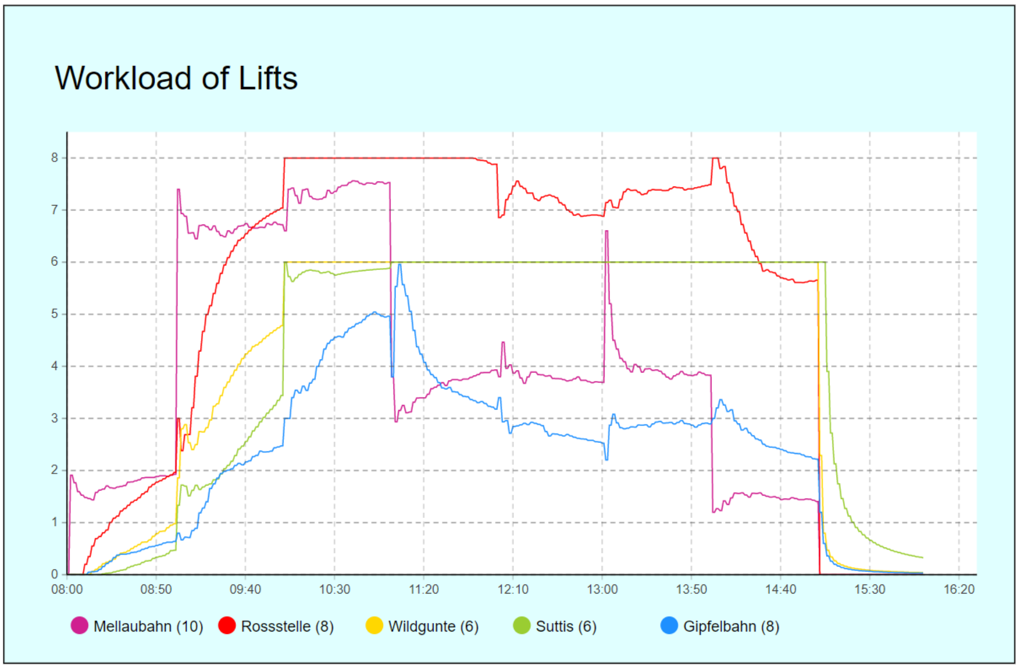


Figure 6.35: Normal day with advanced skiers - information provided - lift workload - load 10

6.3 Interpretation

In this section the results are summarized and the findings are presented. Additionally, insights from experts are included, which were obtained from an interview with with personal of the skiing area of Mellau.

6.3.1 Findings of simulation

As the results presented in this chapter show, the simulation of skiers in a skiing area provides a lot of possibilities and give insights into the complex behaviour of the skiers and the whole system of a skiing area. On the one hand, the behaviour of the skiers can be analysed on a normal skiing day and on the other hand, if changes are made, e.g., the shutdown of a lift, the changes in behaviour become visible and tangible. All this gives the carrier of the skiing area a possibility to have a better overview and control of their facilities.

The best example for this is the guidance of the main flow of skiers. The layout of the skiing area in Mellau has a distinct flaw as most of the skiers start at Mellau, taking the Mellaubahn followed by the Rossstelle and want to continue to the Gipfelbahn and Damüls. The reason is simply because there are more possibilities in Damüls since there are more lifts. This trend, according to the experts of the area, can not be prevented and is also not desired to be changed. The skiing areas Mellau and Damüls do not want to work against each other and keep skiers from going to Damüls. Although, as the waiting time at the Gipfelbahn is sometimes higher than the waiting time at the Wildgunten, it might be possible to provide the skiers with this information and attract some of them to stay in Mellau longer and take the Wildgunten and Suttis before going to Damüls.

As can be seen in the open simulation in Section 6.2, the effect of evenly distributing the load to all lifts has a positive impact on the overall waiting time and, therefore, on the satisfaction of the skiers. This can also be noticed in the scenario of the weather related shutdown of the Gipfelbahn with the load set to 6 in section 6.1.3.

The simulation also showed, that the load, presented in the scenario, is quite manageable for the current lift and slope configuration of the skiing area. Even if big numbers of skiers arrive and some queues build up, the total waiting time and the percentage of waiting time to skiing time is always reasonable. Even if some lifts shut down as described in the technical defect scenarios in subsection 6.1.2 and the weather related shutdown scenario in subsection 6.1.3 the rest of the lifts can keep up with the load at least if it is not very high. This is reason to believe that the parameters set in the simulation as well as the probabilities at each decision points are chosen correctly. In the real world system, the skiers arrange themselves by autonomous decisions and in the simulation a similar effect is done by the distribution of the junctions.

A most interesting insight is the distribution of the time spent in the skiing area of different skiing levels. As can be seen in Figure 6.8, the waiting time of a skier in level 1, so a beginner, is percentage wise less than the waiting time of a very good skier. The reason is that the beginner skier takes longer for a single ride and therefore spends more time on the slope for each ride than an advanced skier. The very best skiers spend most of their skiing day sitting in the lift, because it takes less time for them to ski down a slope than it takes the lift to go from the bottom to the top. This is compliant with the authors experience as he spends some of his skiing days as a skiing instructor with beginners but also skiing on a high level on his own. In the statistic it is, however, exaggerated because the skiers do not take any breaks while skiing which would increase the time spend on a slope.

6.3.2 Evaluation with experts

To get a real world perspective into the work as well, an interview with two experts, the facility manager and the administration manager, of the skiing area of Mellau was conducted. They answered a few questions before getting to know the simulation and also after a more detailed introduction.

First, it was asked what their understanding of a simulation of a skiing area would be and how they benefited from such a simulation, they could not give a precise answer since this topic has not been addressed in the industry yet. However, they were thinking about some way to present the skiers with digital information on screens in the skiing area like their current position and possibilities to go next. Discussing the current statistics of the ski area revealed, that a lot of data regarding the skiers as well as the lifts and slopes is collected but not used for statistical insights. The only classification number are the entries at the bottom of the skiing area per day and over the curse of a season. For them, it is hard to see a gain in satisfaction of the customer by analysing all the data, since it takes a lot of time and resources to do so. However, it would be interesting to find out, where the crowd flow is going in the area and how to guide it. This would be by means of information of the waiting time at each lift on the slopes leading to it and on junctions of slopes. This would give the skier the opportunity to avoid lifts with long waiting time even if they do not know the skiing area. As a result, the satisfaction of the skiers would benefit from less waiting time and more skiing time.

After presenting the findings of the simulation, the experts were impressed on how accurate the simulation is, compared to their knowledge of the behaviour of skiers. Even the estimated numbers of incoming skiers are close to what they experience in the area. As for the statistical results, especially the load of the lifts is something, which has to be adjusted in the simulation. The information used for the capacity per hour a lift can manage was taken from the interactive map, but this only represents a theoretical maximum value which can not be met. As an example they mentioned the Rossstelle, which has a maximum value of 3400 people per hour at a speed of 5 meters/second. A more realistic speed for this lift is 4.5 m/s or even below on a day with many skiers. This means the lift is only running at 80 to 90 % of the capacity. The more skiers are waiting, the more accidents happen, e.g., tripping while trying to get onto the gondola. That is, the more people waiting the lower the speed of the lift has to be to avoid stopping. Also, it is not realistic for every gondola to be full and there the capacity also gets increased. All in all the experts estimate a 80 to 85 % capacity rate per hour from the maximum if more people are waiting. This means, that not 3400 people can be transported per hour but only 2700 to 3000 people which mean, especially if high loads are simulated, the results all change slightly. Other than that the results and statistics were compliant with what they would expect even though they did not have a way to verify it by means of their own statistics.

6.4 Outlook

In future work and to make the model more realistic, the model needs some minor adjustments to be useful and more realistic. Especially the load of the lifts has to be adapted, but also the behaviour of the skiers has to be modeled more fine granular like adding breaks on the slopes as well as a lunch break. A further factor, which has not been taken into account yet, but has a big impact is the ski courses. They start all at once at a specific time and location and put a lot of load for a short time to specific lifts. This can cause a backlog further into the day.

Another possible improvement of the system would be a more realistic decision making of the skiers. At the moment this is only by probability but it can be possible for the skiers to decide based on their skill level to only ski on correlated slopes. Furthermore, the skier can decide to foremost explore the skiing area and also take unknown slopes more often, if they have the chance. All this would lead to a more complex and more realistic behaviour of the skier.

The most important change however is, that this model only shows part of the skiing area. For it to be useful for any kind of prediction or flow control, the whole skiing area, including Damüls, has to be simulated. As the feedback of the experts of Mellau was really positive, the work on the simulation will continue in cooperation with both areas Mellau and Damüls.

7 Conclusion

This thesis presented the building process of a model and simulation of a skiing area based on information about the lifts, slopes and skiers. The simulation software Anylogic was chosen to implement a model of the skiing area of Mellau and simulate the movements of skiers through the system. Furthermore, scenarios were defined to analyse and compare how different loads with different configurations of the existing skiing area behave. Normal skiing days, technical defects and weather related shutdowns were simulated and the results analysed to get an insight in how changes to parameters, e.g. defect lifts, change the behaviour. Guiding skiers through the area by providing information about the waiting time on the lifts has also been analysed and the improvements are shown. For evaluating the model and the simulation an interview with two experts was conducted. In this interview the possibility to guide skiers was most interesting to the them. Finally, it was asserted, that the simulation can be beneficial to the carrier of the skiing area as well as the skiers. On the one hand this is due to the possibility for providing information otherwise missed or hard to analyse and on the other hand by giving the information of waiting time and therefore positively impact the experience in the area by reducing the total waiting time.

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Abbreviations

DES Descrete event simulation

ABMS Agent-based modeling and simulation

FEL Future event list

SD System dynamics

FIFO first in, first out

Statement of Affirmation

I hereby declare that all parts of this thesis were exclusively prepared by me, without using resources other than those stated above. The thoughts taken directly or indirectly from external sources are appropriately annotated. This thesis or parts of it were not previously submitted to any other academic institution and have not yet been published.

Dornbirn, am 10. Juli 2022 Kappaurer Michael