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Simulating the Effects of Increased Ski-lift Capacities on Waiting Times

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Abstract

Across Europe and the rest of the world, skiing enjoys great popularity. However, it is assumed that the number of ski areas that will remain climatically operable will decrease dramatically in the near future. Accordingly, overcrowding and longer waiting times at ski-lift stations are identified as an economic threat to skiing areas. In this study, we investigate the mitigation potential of increasing the ski-lift capacities in the small Austrian ski resort of Fanningberg. To analyse the relationship between waiting time, number of skiers and ski-lift capacity, we implemented an agent-based simulation model. Results indicate diminishing returns in terms of waiting-time reduction with a further increase of ski-lift capacities.

Keywords:

applied systems analysis, spatial simulation, lift capacity, waiting time, tourism

1 Introduction

For numerous populated mountainous regions, ski tourism is the most important economic sector. On a global scale, over recent decades yearly numbers have been stable, with approximately 400 million skier visits (Vanat, 2021a). Despite the threat of losses to skiable areas due to climate change, ski tourism even continues to grow in Eastern Europe and Central Asia (Vanat & Yu, 2022). At the same time, due to higher temperatures and decreasing annual snow cover, more and more ski resorts have been forced to close or shorten their season (Moscovici, 2022). As a consequence, visitor concentrations are likely to increase, especially on sunny days and weekends, at resorts that remain climatically operable (Rutty et al., 2015).

Overcrowded slopes are a factor that threatens economic development of ski resorts (Vanat, 2021b). A study conducted by Pikkemaat, Bichler and Peters (2020) showed that crowding at strategic sites, such as valley stations, contributes to an increased perception of crowding. Other authors (e.g. Alvarado-Valencia, Tueti Silva & Montoya-Torres (2017), Robinson &

Chen (2011) or Bielen & Demoulin (2007)) have pointed out general effects of waiting times on customer satisfaction, loyalty, and associated costs for the industry.

Accordingly, one of the most important ski-area management goals is to minimize the waiting time at valley stations and at lifts so that skiers can maximize their time on the slopes. The use of online ticket systems is one strategy that could reduce waiting times at ticket offices. Another strategy (implemented in Switzerland) is to give skiers access to priority lanes for an extra charge (Poulhès & Mirial, 2017). For the second hotspot where waiting can occur, at the lifts themselves, the expansion or even replacement of older infrastructure with lifts that are faster and have a higher capacity (Poulhès & Mirial, 2017) could be effective in reducing waiting times. This would have the effect of making ski resorts more popular and increasing the satisfaction of skiers (Falk, 2008).

Investigations into the economic efficiency of cablecars in South Tyrol show diminishing returns when their capacity is increased Invest (Brida, Deidda & Pulina 2014). The complex relationship between ski-lift capacities and waiting times therefore needs to be investigated in detail.

In this study, we argue that the relationship between waiting times and lift capacity is not straightforwardly linear. Knowledge of this relationship reveals potential measures for mitigating the problem of wait times.

To investigate the relationship, we carried out a systems analysis by means of an agent-based model that incorporates geodata representing the ski slopes and ski lifts in the small resort of Fanningberg, in the Austrian Alps. Skiers are modelled as moving agents who make use of infrastructure according to predefined rules. The model is used to run different simulation scenarios by varying the model parameters, number of agents and ski lift speed in order to observe effects on waiting time. In the next section, the model is described in more detail.

2 Model Structure

Agent-based modelling (ABM) is an effective tool for analysing complex systems. As noted by Bonabeau (2002), it has three major advantages over other modelling techniques: the ability to capture emergent phenomena, the ability to provide a natural description of a system, and high adaptability. ABM is based on object-oriented programming, which enables it to simulate people, animals or plants (Nicholls, Amelung & Student, 2017), and their interactions and behaviours (Balbi et al., 2013), in a single model.

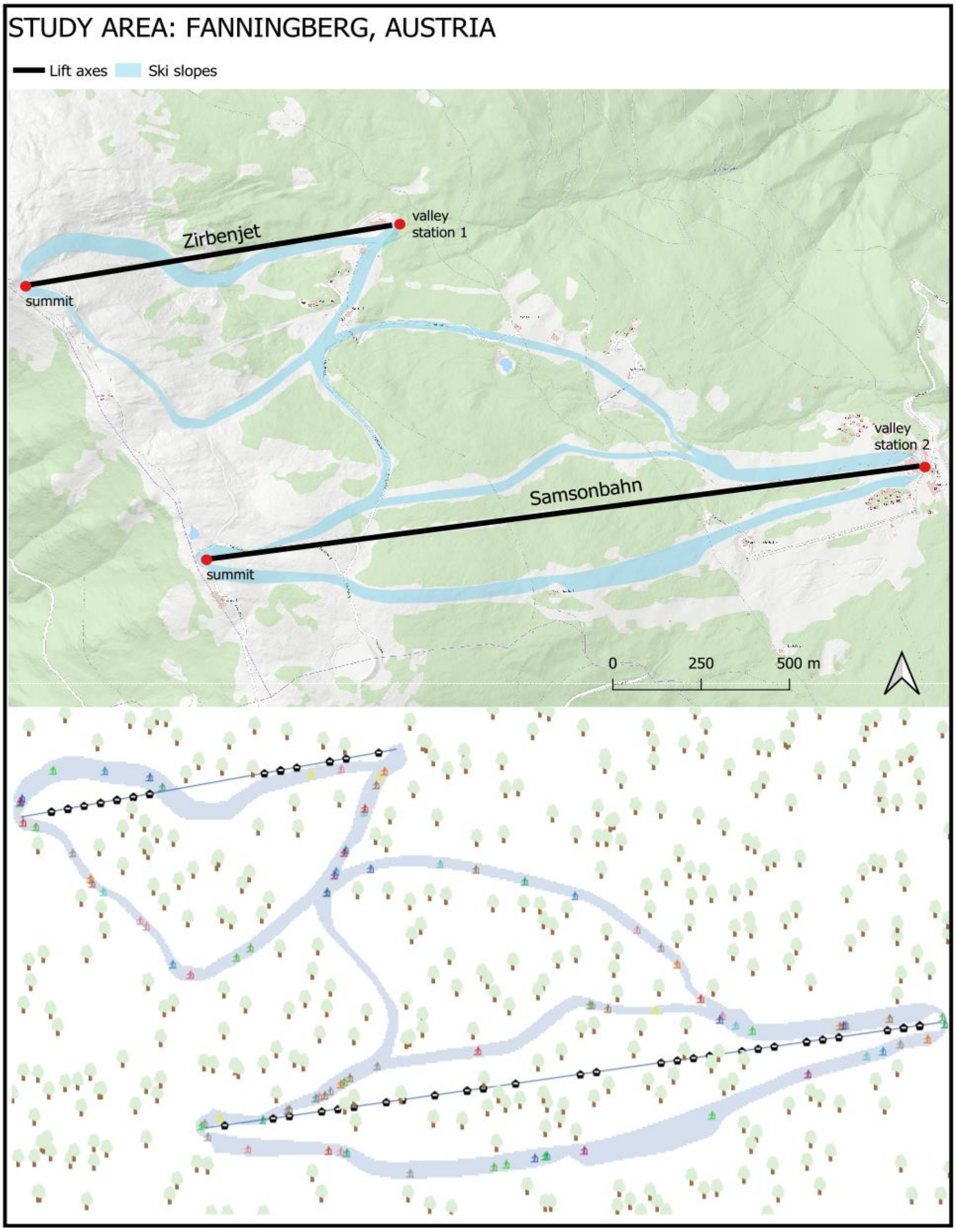

Figure 1: Study area (top) and NetLogo model interface (bottom)

We used the ABM software NetLogo (version 6.2.2) to model the Fanningberg ski area (see Figure 1), which has two lifts and six slopes. Shapefiles of slopes and ski-lift axes were provided by PowerGIS, which were loaded to NetLogo by means of NetLogo's GIS extension. In what follows, the model is described according to the ODD summary recommendation by JASSS (Grimm et al., 2020).

The overall purpose of the model was to examine the impact of lift capacity (represented in the model by variable 'lift speed') and skier density (represented by variable 'number of skiers in the ski area') on waiting time at the valley station. The ABM replicates individuals' behaviour (such as skiing, or waiting at a valley station) and processes of the lift infrastructure itself. By adjusting lift speed and number of skiers, the model seeks to determine how these two factors can affect waiting time at lift stations.

A central model parameter was the maximum lift-capacity, which was defined as the maximum number of skiers who could be transported per hour at a maximum lift speed of 5m/s. According to Skiresort Service International (2021), these numbers were 2,362 for lift 1 (Zirbenjet) and 2,400 for lift 2 (Samsonbahn).

Gondola capacity (gc) was set as a constant of 6 persons per gondola. Accordingly, gondola return period in seconds (R) was defined as

$$R = \frac{lv_{max} \times gc \times 3600}{lc_{max} \times lv} \qquad \text{(Eqn 1)}$$

where lc_{max} was the maximum lift capacity per hour, lv was the lift speed, and lv_{max} was the maximum lift speed in metres per second. This equation defines the movement of gondolas in process '*g.move*' (see Figure 2).

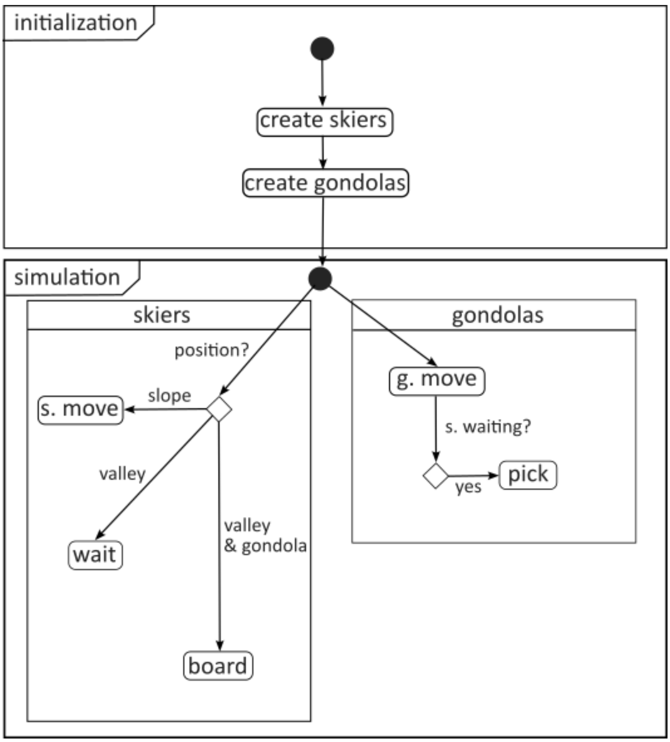

Figure 2: UML representation of processes modelled

In the model, skiers waiting at the valley stations were picked up every R seconds by a gondola and transported to the summits at lv metres per second (process '*pick*' in Figure 2).

Once skiers arrived at the summit, they skied down the slope network at speed sv. The skiing-speed parameter of individual skiers was randomly drawn from a normal distribution of 4.4m/s and standard deviation 2.2m/s. At network intersections, skiers randomly choose from available downhill directions ('*s.move*' in Figure 2).

On arriving at the valley stations, skier-agents stopped and waited until a gondola picked them up ('wait' and 'board' in Figure 2). The modelling processes were executed at every simulation time step (one time step = 0.1 seconds in reality).

Modelling processes took place in an area measuring 521 by 271 patches, where one patch was a square with a side length of 4.956m. For the initialization of the model, the number of skier-agents and the lift speed were varied: ranges were 100 to 3,000 skiers, and 3 to 5 m/s for lift speed. Skier-agents were distributed randomly on the slopes. To cancel out effects of model initialization (in particular the initial random distribution of skiers within the ski area), we ran the simulation until the number of skiers waiting at the valley stations became roughly constant.

The model's source code is available on GitHub.

3 Results and Discussion

At the beginning of the simulation, skiers were randomly located only on slopes – i.e. there was no skier-agent either queuing or in the lift. After model initialization, the waiting time rose sharply and eventually levelled off to an approximately steady state (see Figure 3).

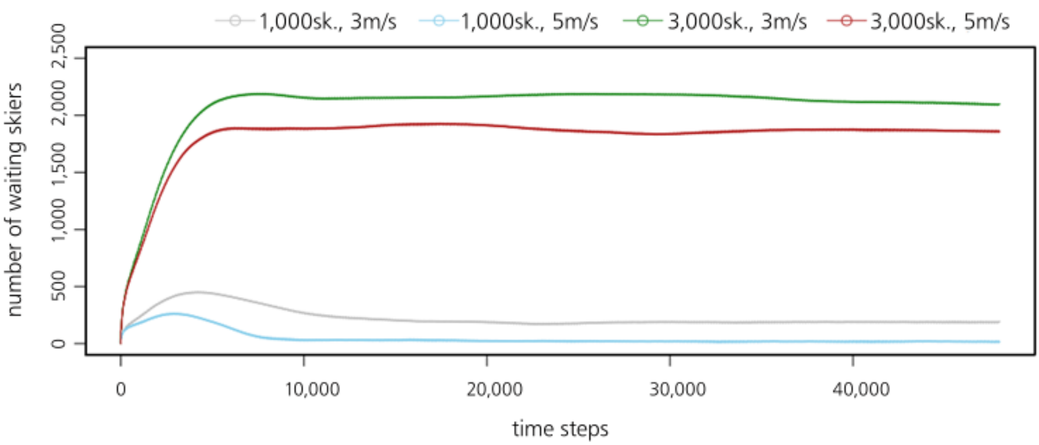

Figure 3: Total number of skiers waiting at both stations, averaged over 100 runs. Confidence intervals are smaller than the line thickness.

Interestingly, in most scenarios the number of skiers waiting reached a maximum immediately before the system reached its steady state. Even though all skiers were moving forwards, the number waiting piled up before constant arrival and departure rates at the valley station resolved the situation. This wave-like behaviour is also common in traffic jams (Wilenski, 2022).

Based on this result, we decided that the best time to monitor system behaviour begins after 12,000 simulation time steps (twenty minutes), when every scenario run had reached its steady state. For our main experiment, we varied the *lift speed* and *number of skiers* in the ski area; the system variables on which we focused were *average waiting time per skier*, *average skiing time per skier* and *average waiting time per ride.* Averages were calculated over a duration of 36,000 simulation time steps (one hour). The simulations showed that when the number of skiers in the ski area was below a threshold (~800, the exact threshold is marginally dependent on the lift speed scenario) the average waiting time was zero and the skiing time was essentially constant, and thus independent of the number of skiers (see Figure 4).

However, when the number of skiers increased over that threshold, waiting time increased and skiing time decreased. The curves for skiing time and waiting time flattened as the number of skiers was increased further. This was observed over all lift-speed scenarios, which indicated efficiency gains under highly-crowded conditions.

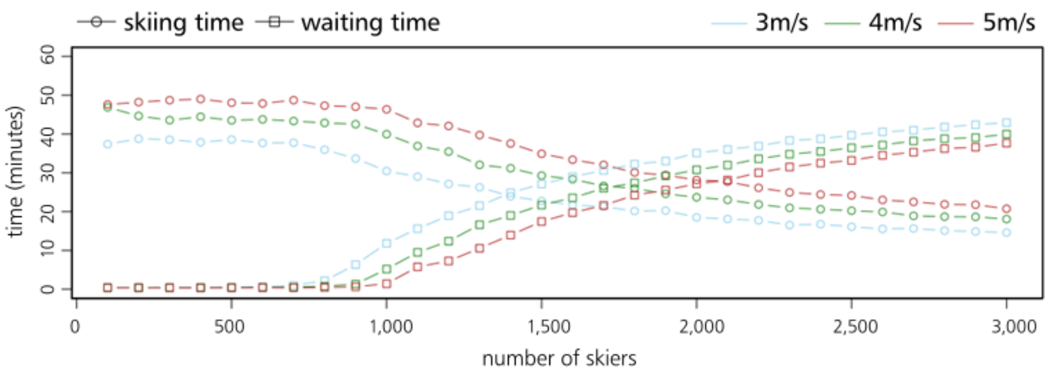

Figure 4: Average waiting and skiing time per skier vs. number of skiers at different lift speeds

Similar patterns were observed for the relationship between lift speed and average waiting time per ride. A higher lift speed resulted in a shorter waiting time, yet the additional gain in time diminished with higher speed, which makes acceleration increasingly inefficient. The general pattern of this relationship can be modelled by exponential decay functions (see Figure 5).

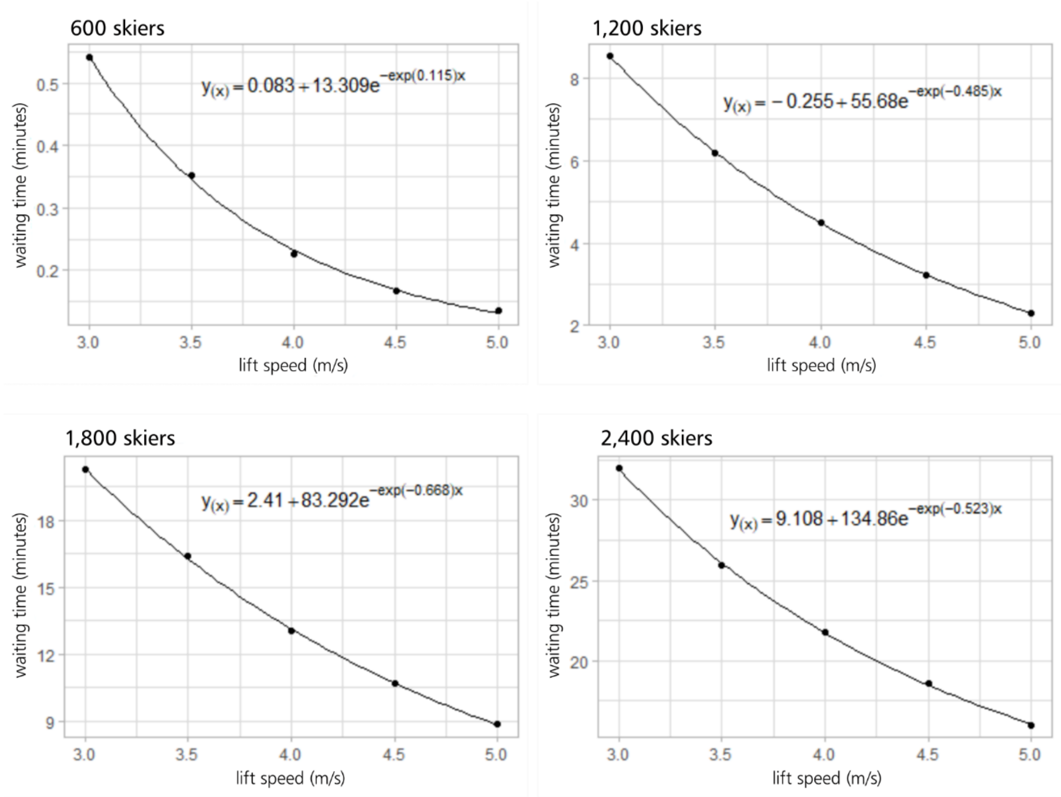

Figure 5: Average waiting time per ride vs. lift speed, for different numbers of skiers

The behaviour observed can be explained by a counter-intuitive crowding effect. The effect can be summarized in a simplified mathematical model with two compartments (*compartment 1:* number of skiers at the valley station VS; *compartment 2:* number of skiers at the summit station SS), and two differential equations that model flows between compartments (see Figure 6, and equations 2 and 3).

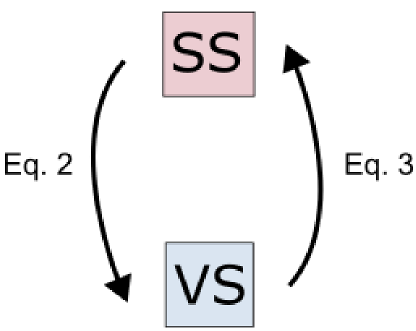

Figure 6: Two-compartment model with uphill flows (uphill transport of skiers by ski lift, represented by Eqn 3), and downhill flows (skiers skiing downhill, represented by Eqn 2)

Flows between compartments are calculated as

$$\frac{dVS(t)}{dt} = \frac{SS(t)}{\frac{sl}{sv}} \qquad \text{(Eqn 2)}$$

$$\frac{dSS(t)}{dt} = \frac{VS(t)}{\frac{ll}{lv}} \qquad \text{(Eqn 3)}$$

where sl is the length of the slope, ll is the length of the lift, sv is the skiing speed, and lv is the lift speed.

The simplified formulation illustrates that uphill flows (number of skiers going uphill per time interval) and downhill flows (number of skiers going downhill per time interval) are mutually dependent. Even though skiing speed is constant, a higher uphill flow increased the downhill flow, resulting in more arrivals back at the valley station. In other words, a higher uphill flow due to increased lift speed increased departures from, and arrivals at, the valley station. Accordingly, the elevated number of arrivals counteracted the upsurge in departures and undid the positive effects on waiting time of increasing lift speeds.

4 Conclusion and Outlook

We implemented an agent-based model that simulates the Fanningberg ski area with the objective of revealing relationships between ski-lift capacity (modelled as lift speed), number of skiers, and waiting time at valley stations.

The simulation showed efficiency gains associated with a higher number of skiers in the ski area – i.e., with higher numbers of skiers, the magnitude of additional waiting time per additional skier decreases (see Figure 4). The simulation also showed efficiency losses at higher lift speeds (see Figure 5) – i.e., with higher lift speed, the magnitude of waiting time reduction per additional speed unit decreases.

These results clearly speak against a further expansion of ski-lift capacities. However, to turn these results into concrete recommendations for action, two points need to be clarified.

- *The effect of slope length, slope structure, slope crowding, and use of other leisure infrastructure in the resort (e.g. ski huts):* It is assumed that delays associated with these factors have relevant effects on the relationship between ski-lift speed and waiting time. Transferring the model to other study areas as well as an explicit modelling of skier interactions and decisions could help elucidate these relationships.
- *Economic parameters such as profit and turnover:* Assessment of the profitability of increasing ski-lift capacity is dependent on factors such as the speed-energy consumption ratio of technical infrastructure, energy prices and other economic considerations.

Nevertheless, the current model is a suitable tool for the exploration of questions related to the carrying capacity of ski areas. The diminishing return of the expansion of lift capacities is an interesting study outcome that has the potential to spur further discussion and research. To turn the observed model behaviour into empirical evidence, on-site surveys are needed.

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