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Queues in Ski Resort Graphs: the Ski-Optim Model

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Abstract

It is rather unknown how skiers move inside ski areas. However, new data collection systems, such as RFID chips on ski passes (which allow counting skiers at the gates of the cableways), can be used to analyse the movement of skiers in the cableways network and in the ski runs graph. This will show how queues arise at the cableways departures and how crowds are formed on the ski runs. This short paper is reporting a multi-agent simulation approach called Ski-Optim to study graphs and queues arising in a ski area. A software simulation was experimented on the ski area of Verbier in Switzerland.

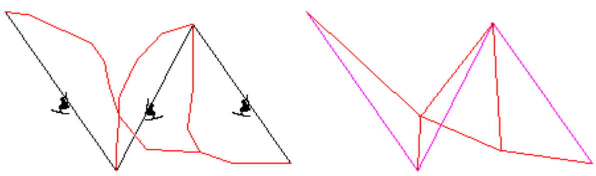
Keywords: Multi-agent simulations ; flows; queues ; ski area ; graphs

1 Introduction

The Ski-Optim model was elaborated for the Swiss ski area of Verbier. This place was selected for this project as it is entirely provided with the Ski Data system (management system RFID of the gates at the cableways) and also with a georeferenced plan of the ski runs. Besides, Verbier has the advantage to be one of the biggest ski resorts in Switzerland with a big number of skier days (950'000 in 2013), a complex network of 34 different cableways and 195 km of ski runs. Thus, the model can be tested in a sufficiently big environment.

Every ski resort can be modelled from a unique basic form with one ski lift, one toggle and one ski run [1]. Formally, a ski resort is a connected oriented graph. The axis properties are specific and influence the behavior of the agents (the skiers), which will follow a way as a function of their projet of ski (Figure 1).

Figure 1 : Flow graph of a ski area.



Crossings at ski lifts is a typical queue problem. Skiers are clients who arrive randomly in a waiting zone composed of one or several ski lift (called servers in queue theory [2]). The service duration (the skier on the ski lift) is also random and when all the servers are occupied, a queue appears with a waiting, which corresponds (the most of the time) to first come, first served [2]. Now, the question is how to handle these phenomena in a network such as a ski area because this problem is important due to potential influences of negative skiing experiences.

2 Mechanism of the Running of a Ski Area: Characterization of the Skiers Behavior

To simulate skiers' behaviors in a ski resort, it is necessary to model the load increase of skiers in the network and to model the skiers' diffusion on the ski runs [3].

In a ski resort, the schedule of a day is uniform. In a first step, skiers arrive and cross the snow front (entrance point in ski areas). Then, they go up with the cableways until the network point that corresponds to the departure of the specific ski run they wish to go to.

Skiers have action plans (which will be used in the simulation). They can decide for example to reach the highest point of the ski resort or choose a precise sector according to their plan. As the access to the ski runs depends on the cableways, the load increase in the network is not

homogenous. There is a time lag for the cableways and ski runs which are reachable by only other cableways or other ski runs. This leads to jam processes at the beginning of the day. After some time, following a dilution process of all skiers in the network of the ski resort, a steady state arises. This can explain why the cableways with the biggest transport capacities are located at the beginning of the network where the ski runs are also broader. These infrastructures should be able to absorb a punctually great number of skiers at the beginning and at the end of the day. Due to this collective effect, they are also the most used ski runs in the course of the day.
As most of the ski resorts are provided with RFID systems for getting through cableways turnstiles, it is nowadays possible to obtain the number of skiers on the cableways according to any time slot. It is however still impossible to measure the number of skiers on the ski runs. The local behavior (ski run selection and path) of the skier is therefore unknown. So, the information put on the graph is incomplete. It leads to difficulties for the processing of the queues by an analytic method in classical queue theory. As we cannot use an analytic method, we use a multi-agent-based simulation.

3 Approach by Multi-Agent-based Simulation: Ski-Optim

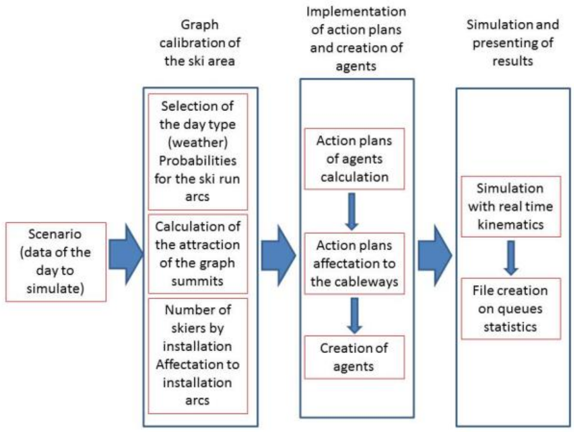
A multi-agent-based system can be defined by a set of processes running simultaneously, exchanging information mutually and sharing common resources [4]. These processes are called “agents”. In our case, there are several agents using at the same time the ski runs. Those agents do not interact directly with each other.

3.1 General Principles of Ski-Optim

In the Ski-Optim model, an agent follows an action plan [4], which it gets at the departure and which it will not modify during his whole day on the ski runs. The simulation corresponds thus to a daily pattern. The daily simulation can move a great number of agents on the ski runs graphs. Furthermore, the model relies on the counting of data at the turnstiles of the cableways. This information is useful to simulate the influence of the flow of skiers depending, on one hand, on the flow rate of every cableway and, on the other hand, on the location of the cableways in the graph. We can therefore follow the change in waiting time at the departure of every cableway on the basis of the number of skiers using the cableways during the day. It is also possible to follow the change of the skiers flow for each ski run segment. This permits to proceed for adjustments of flow rates and speed at the different cableways and then to measure the impacts during the simulation.

The figure below shows the complete simulation process. The following sections explain those steps.

Figure 2 : Mechanism of the simulation progress.



3.2 Graph Calibration

The calibration process of the graph is one of the most important part of the simulation as it is at this level that the diffusion rules in the network are implemented. The diffusion factors are only partly known in the network (only on the cableways) as it is impossible to give a measurement of the number of skiers on the ski runs. This is why a probability selection on the ski runs used on the form of rules is inserted (Figure 3). These rules are defined according to the weather (simplified by four types of weather situation: sunny/warm, sunny/cold, rain, snow). They were created as a result of a survey on skiers’ behavior.

Figure 3 : Definition rules on probabilities of ski run use.

```
if(jourType == 1) // Sunny and warm
{
  blueProba = 0.27f;
  redProba = 0.42f;
  blackProba = 0.23f;
  yellowProba = 0.08f;
}else if(jourType == 2) // Sunny and cold
{
  blueProba = 0.09f;
  redProba = 0.36f;
  blackProba = 0.25f;
  yellowProba = 0.25f;
}else if(jourType == 3) // Rain
{
  blueProba = 0.27f;
  redProba = 0.44f;
  blackProba = 0.21f;
  yellowProba = 0.08f;
}else if(jourType == 4) // Snow
{
  blueProba = 0.23f;
  redProba = 0.46f;
  blackProba = 0.21f;
  yellowProba = 0.10f;
}
```

This operation is performed manually via an icon set which gives the opportunity to decide in which weather frame the simulation will take place. The result of the operator selection is the assignment of the weightings on the ski runs arcs of the ski area graph. This is followed by the calculation of the attraction coefficient from the summits to the departure of the cableways. For this purpose, the model uses an algorithm (described in [3]) which calculates the attraction coefficient from each departure point from the summit of a cableway, depending on the number of skiers which used that cableway according to the counting done at the turnstiles. This coefficient is the indicator which gives the opportunity to determine if a departure of a cableway is more used than another in the course of an hourly time slot. This coefficient is recalled for every temporal iteration. This algorithm calculates also the action plan of an agent, depending on the available ski run type combined with the selection of the day type by the operator.

3.3 Implementation of Action Plans and Creation of Agents

The model agents are simplified and do not interact independently. They follow an action plan, which determines the way to go from a point A to a point B.

Before calculating these action plans, three steps are necessary:

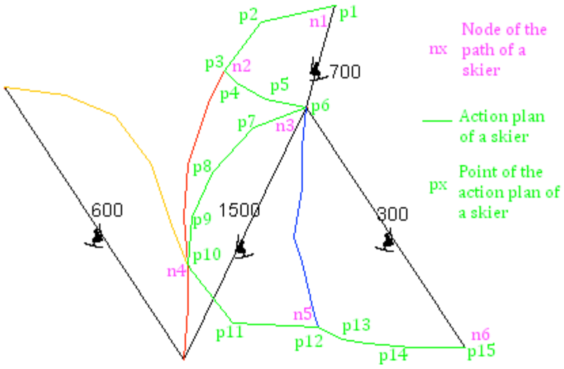
1. Collection of all the counting file data at the cableways turnstiles;
2. Calculation of the difference of the number of agents in comparison to the preceding period, in order to keep the total number of agents on the graph;
3. Values update depending on the principle cableways (in the particular case : entry and exit points)

Secondly, the action plans are created, grouped by departure point, mixed and inserted in a list. Each agent created on the summit of a cableway gets an action plan and unrolls it until his point of arrival (figures 4 and 5).

Figure 4 : Pseudocode of the action plans management

```
FOR EACH action plan corresponding to one cableway (APs)
    FOR EACH cableway
        IF the departure of the cableway = first point of the first of the APs THEN
            Add the APs in the list of the cableway
        END IF
        IF the saving of the action plans < the current list THEN
            Save the list of the action plans for
            1. The last cableways
            2. When there are no more action plans available anymore
        END IF
        IF The cableway has action plans THEN
            Shuffle the list of the action plans
        END IF
    END FOR EACH
END FOR EACH
```

Figure 5 : Example of an action plan of a skier in a graph



3.4 The Case of Entry and Exit Points

The number of skiers is known at the turnstiles of the cableways. However, a double counting should be eliminated, in order to add or withdraw only skiers who actually enter or come out of the ski area in the next time slot. For this purpose, the counting done at the main cableways are used, i.e. in the cableways where skiers are obliged to pass by for coming in or going out of the ski area. A cableway is considered “main” when the number of crossing is greater than other cableways. It is also assumed that more agents are going to the bottom of this main cableway. The calculation depends if the agents enter or go out from the ski area but the general mechanism is identical and is based on the difference of counting with the previous hourly time slot. This result is used to correct the number of RFID counting of a main cableway, so that the result remains coherent. In the case where there are several main cableways in the ski area, the model splits the new skiers and the skiers going out of the ski area proportionally to these main cableways according to the raw RFID counting.

(1) the case of the incoming skiers

Generally, skiers entering choose ski lifts at the interface with the snow front. The input mechanism is measured by time slots. At T-1, it is possible to calculate the frequency of usage based on volumes measured by the RFID chips. These frequencies allow, by a simple multiplication of the volume by frequency, to distribute correctly on each main ski lift; new skiers enter at T +1.

In addition, new agents are created at the departure of cableways at regular intervals in the ongoing hourly time slot.

These new numbers of agents will be used for the calculation of the action plans. In addition, new agents are created at the departure of cableways at regular intervals in the ongoing hourly time slot.

(2) The case of outgoing skiers

When the number of skiers decreases, as for example at the end of the day, the counting should also be adapted. As at this time, the skiers using the main cableways are less numerous than the skiers at the exit point, the outgoing skiers have to be added to the RFID counting according to an equivalent but inverse process, which has been described for the incoming skiers. In a second step, the number of agents to delete is assigned to the cableways in question. Thus, the model deletes the foreseen agents at the different departures of the main cableways at regular intervals during the following hourly time slot, by distributing uniformly the number to delete. This creates a decimal number of agents, depending on the time slot. As a number of agents can only be an integer, the decimal part is stored in a variable created specifically (agentsFloat), in order to conserve the information. The calculation is done according to the following pseudo-code (figure 6).

Figure 6 : Pseudocode of management of the remains in the deleting of the outgoing agents

```
FOR EACH Cableway
    IF the cableway has agents to delete THEN
        IF the cableway has no agentsFloat to delete THEN
            agentsFloat = number of agents to delete / number
        of steps for 1h simulated
        END IF
        The value is stored after the coma of agentsFloat
        An integer is withdraw if >= 1.00
        This integer is added to the number of agents to
        delete during this step
  END IF
END FOR EACH
```

Furthermore, every time that an agent arrives at the departure of a main cableway, the model should test on one hand, if the cableway is closed, and on the other hand, if the agents have to leave the ski area at this point or if the agents have to be inserted in the queue (figure 7).

Figure 7 : Pseudocode of the selection between the deleting (exit of the ski area) or the insertion in the queue

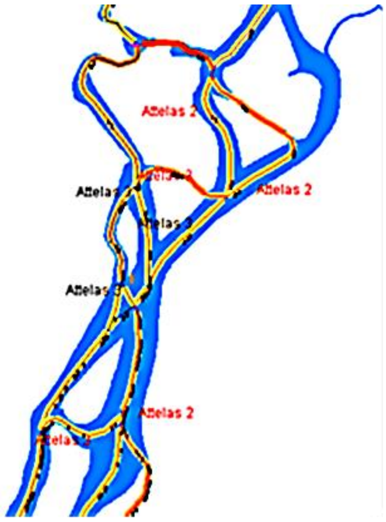
```
FOR EACH cableway
        IF the agent is located at the bottom of this cableway
    THEN
            IF the cableway is closed
                    AND agents to delete THEN
                The agent leaves the station
                The number of agents to delete of that
              cableway is decremented
            END IF
            IF remains agents to delete
                    AND remains agents to delete for this
                  time slot THEN
                The agent leaves the ski area
                The number of agents to delete at that
              cableway is decremented
                The number of agents to delete during this
              slot is decremented
            END IF
            ELSE
                IF the skier doesn't exist yet in the queue
                    The agent joins the queue
                END IF
            END ELSE
        END IF
END FOR EACH
```

This approach lets appear naturally the queue phenomenon by a simple test process. It corresponds to the counting of agents at the departure point divided by the hourly rate of flow of the cableway. The time variation in the waiting time is presented in real time in the kinematics simulation.

3.5 Simulation and Results

The Ski-Optim model simulates the congestion of the ski area with an hourly granularity as well for the queues as for the ski runs arcs. Figure 8 shows on the ski runs the emergence of zones congested by skiers (by the gradient variation from the green to the red)

Figure 8: Example of simulation results of the ski runs. The black points are the agents in action.



The simulation kinematics shows the change of the waiting time in the queues in real time by using the pictograms put on all the departure points of the cableways (figure 9).

Figure 9: Pictograms showing the waiting time in minutes und number of agents.

The values above the pictograms show the waiting time (without the brackets) in minutes and the number of agents in the queue (with the brackets). A statistics file is generated at the end of the simulation. It lets transcribing the change with time of the queues for every cableway of the graph for every time slot. In that way, the ski resort managers can perform the analysis on the potential global impacts (at the scale of skier diffusion in a graph) of a local choice of a graph property change (for example the change of an hourly rate of flow of a cableway). Figure 10 shows this output file of the simulation.

Figure 10: Output file generated from the simulation (zoom on hour no 5)

	Max waiting time	Min. waiting time	Average waiting time	Max agents on queue
Hour5				
Attelas1	.		.	1
Attelas2	3.2		1.6	109
Chaux2	.1		.1	4
Chxexpch				
Chxexpru	.7		.4	13
Combe1	.6		.3	11
Jumbo	.6		.3	10
LacVaux1	.4		.2	12
LacVaux3	.3		.1	5
Mayentzet	.9		.4	12
Medran	.8		.4	25
Ruinettes	13.5	11.8	12.6	344
Hour 5 averages	1.8	1.	1.4	

This file is an overview of the queues behavior at the cableways. It can be known for every hourly time slot, the longest, shortest and mean waiting time for the analyzed hour and the maximum number of agents in the queue. This information is of course available for any hourly time slot of the day and for any cableway.

Discussion: Ski-Optim model provides some answers on the mechanisms like the emergence of the phenomenon of queuing and packet skiers on the slopes. At the operational level, we observe that the diffusion in the graph is strongly impacted in secondary levels (accessible only lifts from other lifts) when the main lifts have their carrying capacity increased.Work will be undertaken to try to determine if this effect follows a probability law and if it is disturbed by the change in the structure of the graph. In this way the proposed adjustments infrastructure ski resorts can be integrated into the simulation. Improvements must, however, be added to the system so that the simulation is complete, especially at the influence of bars and restaurants that can change behavior locally in the graph.

4 Conclusion

The model Ski-Optim was tested for the ski area of Verbier and gave convincing results. It corresponds to the measures on the field. There is very little deviation between the counting at the turnstiles and the simulated values for each time slot. An emergence of the spatial structures of the ski runs congestion is not only shown by the model, but confirmed by the observation. It is possible to test the skiing infrastructure (for example the change of a ski lift to a chairlift or a new ski lift) and to see simply the effects on the skier flow. From the methodological point of view, the Ski-Optim model can be transposed efficiently on all issues on networks with queues or jams such as urban traffic. Furthermore, this approach has the advantage to give the opportunity to handle an unknown or only partially known situation. Some developments are in progress, such as the linkage of the variation of the cableway rate of flow depending on the forecast of the queues, in order to reduce the energetic impact of the cableways.

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