A network-based approach for the study of criticalities in ski-resorts

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ABSTRACT: The correct management of ski-resorts requires wide knowledge in mountain hazards, as well as a large experience. Usually ski-resorts cover a surface that encompasses more than one side of a mountain (or more than one valley); for this reason, the meteorological conditions may vary locally and rapid decisions have to be taken in order to ensure the safety of the skiers.
Any intervention on the structure of the resort may entail cascade events and other critical situations. For example, a temporary closure of a lift may create large queues in other parts of the ski-area. In the same way, a closure of a ski-slope might engender overcrowding in other ski runs. All these situations are potential sources of risk.
We propose an approach to the study of criticalities in ski-resorts by means of transportation network approaches based on the ability of the skiers and the grade of the ski run. An example is made on the Antagnod branch of MonteRosaSki resort. The effects of a sudden interruption of part of it, i.e., ski-slope closure or lift temporary interruption, are simulated.

KEYWORDS: Ski-resort management, Graph theory, Criticalities.

1 INTRODUCTION

A correct management of ski-resorts is a difficult task since it requires a large experience and a wide knowledge in mountain hazards. In a ski-area that encompasses more than one valley (or side of a mountain), different meteorological conditions (visibility, wind) or snow-avalanche hazards, are possible. Moreover, accidents can occur in any part of the resort and the first aid procedures may require the temporary closure of the slope or the lift.

Any intervention on the structure of the resort may entail cascade events and other critical situations. For example, a temporary closure of a lift imposed by strong winds may create large queues in other parts of the ski-area. In the same way, a closure of a ski-slope due to avalanche hazard might engender overcrowding in other ski runs. Usually, critical situations in which human belief is present are difficult to control and should be avoided. In addition, overcrowding is a potential source of risk.

In this paper, we propose an approach to the study of criticalities in ski-resorts by means of transportation network approaches (Derrible and Kennedy, 2010; Erath and others, 2009). Skiing traffic problems have been studied, in the past, by Holleczek and Tröster (2012). They implemented a particle-based model based on a survey made on 21 GPS tracks on an intermediate and on a difficult ski slopes. Shealy and others (2005) made a statistics of the average speeds of skiers in three different ski resorts in the US.

The use of graphs for the analysis of a transportation network have been shown to be helpful for solving transportation system problems (Lu and Shi, 2007).

The paper is organized as follow. A preliminary section introduces few concepts on graph theory that are fundamental for the understanding of the calculations, then the case study is presented and the computations on the hourly flow through the ski-resort is performed. Then the effects of a partial closure of a ski slope or a ski lift are highlighted and discussed.

2 GRAPH THEORY CONCEPTS

In this section, few definitions about graphs are presented. A detailed treatment on this mathematical topic can be found in Diestel (2010).

A graph is a mathematical structure consisting of two types of elements, vertices and edges. The vertices are usually pictured as dots. Each edge, which is usually pictured as a line, has two endpoints belonging to the set of the vertices. In mathematical terms, a graph, G, can be expressed as

$$G = G(E,V) \tag{1}$$

where E are the edges and V the vertices.

A graph is considered as "directed" if a direction is given to each edge, which is named as "directed edge".

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A “weighted graph” associates a label (the weight, which is usually a real number) with every edge in the graph.

3 ANTAGNOD BRACH OF MONTEROSASKI RESORT

MonteRosa ski resort is a large skiing domain encompassing three valleys in the North-western Italian Alps (Ayas Valley, Gressoney Valley and Valsesia). Different branches compose the ski area. In Ayas Valley there are the Antagnod and the Estoul branches, in Gressoney Valley there is the Weissmatten branch. The large Champoluc-Staffal-Alagna branch gives the connection between the three valleys.

The ski resort has 180 km of ski slopes ranging between 1200 and 3275 m a.s.l. The capacity of the 37 chair lifts and cable cars reaches 50000 persons per hour.

The Antagnod branch is set in the proximity of the village of Antagnod in Ayas Valley at 1700 m a.s.l. and is composed by two chair lifts (no. 1 and 2 in yellow circles in Figure 1) and two “tapis roulants” (no. 3 and 4 in yellow circles in Figure 1). The branch has three “easy” ski slopes (A1, A2 and A4 in Figure 1), two “intermediate” ski runs (A3 and A7 in Figure 1) and one short “difficult” ski slope (A3 in black box in Figure 1).

The directed graph representing the Antagnod branch is depicted in Figure 2.

Figure 1. Skirama of Antagnod branch of MonteRosaSki resort (source monterosaski.com)

4 A SIMPLE MODEL OF THE FLOWS OF SKIERS IN THE RESORT

The flow in the resort is modeled through graph theoretical approaches. In this preliminary study, the focus is on the hourly number of skiers passing through a specified part of the ski domain. The following assumptions are formulated:

- for each set of ski runs with a given level of difficulty, the choice of the skier is random;

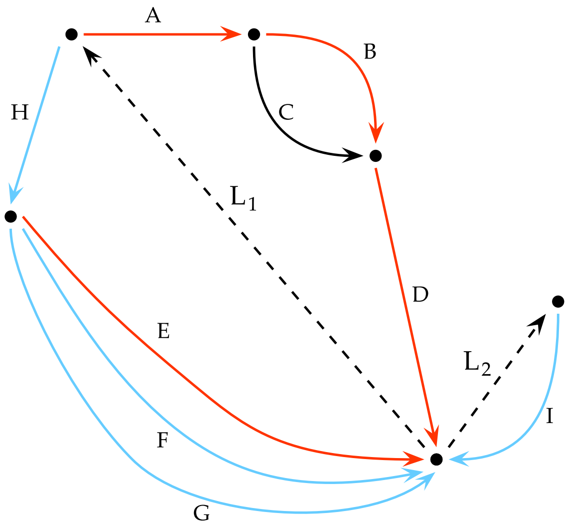

Figure 2. Graph of Antagnod branch of MonteRosaSki resort. The graph is directed. Dotted lines represent the lifts, plain lines the ski runs. Blue lines refer to “easy” ski runs, red lines to “intermediate” ski runs and black lines to “difficult” ski runs

Graph edge	Length	Level of Difficulty
A	650 m	Intermediate
B	1650 m	Intermediate
C	850 m	Difficult
D	800 m	Intermediate
E	1800 m	Intermediate
F	2250 m	Easy
G	2650 m	Easy
H	1050 m	Easy
I	750 m	Easy
L1	1885 m	Chair lift no.1
L2	827 m	Chair lift no.2

Figure 3. Details on the level of difficulties associated to the edges of the graph represented in Figure 2.

	Ski run level of difficulty		
Skier skills	Easy	Intermediate	Difficult
Bad	0.70	0.25	0.05
Medium	0.30	0.40	0.30
Good	0.05	0.45	0.50

Figure 4. Table illustrating skiers’ choice in ski runs (depending on their level of difficulty). The values are arbitrary.

- each skier, with a given ability in skiing, chooses the ski slope following the percentages reported in Figure 4.

For sake of simplicity, since the level of difficulty of the ski runs in the MonterosaSki domain requires low abilities, the following percentages are supposed: 50% of the skiers has bad skiing skills, 30% has medium skills and 20% has good skills. The total hourly number of skiers in the domain is supposed 2500, i.e. there are 1250 bad skilled skiers, 750 medium skilled skiers and 500 good skilled skiers.

Ski run	Level of difficulty
H + G	Easy
H + F	Easy
H + E	Intermediate
A + C + D	Difficult
A + B + D	Intermediate
I	Easy

Figure 5. Level of difficulty of the six ski runs graphed in Figure 2. The letters composing the ski run refer to the directed graph of Figure 2.

The modeled Antagnod branch is a simplification of the real situation and it has three “easy” ski runs, two “intermediate” ski runs and one “difficult” ski run. The level of difficulty of each ski slope is given as the maximum of each part composing it. For example, ski run “A + C + D”, see Figure 5, is graded “difficult” because this is the level required by edge C (of the graph of Figure 2). Since the choice between ski slopes with a given grade is random, the 70% of the “bad skilled skiers”, i.e. 875 persons, split equally in the three “easy” ski runs, and so forth. Figure 6 shows the hourly number of skiers in each ski run. Since the chair lift no.2 serves only the ski run named “I”, the number of people using the ski lifts is: 2125 for chair lift no.1 (L1) and 375 for chair lift no.2 (L2).

Ski run	Bad	Medium	Good
H + G	292	75	8
H + F	292	75	8
H + E	156	150	113
A + C + D	62	225	250
A + B + D	156	150	113
I	292	75	8
TOTAL	1250	750	500

Figure 6. Hourly number of skiers in each ski slope divided by their skiing ability.

	Skiers ability			
Edge	Bad	Medium	Good	*TOTAL*
A	219	375	363	*956*
B	156	150	113	*419*
C	63	225	250	*538*
D	219	375	363	*956*
E	156	150	113	*419*
F	292	75	8	*375*
G	292	75	8	*375*
H	740	300	129	*1169*
I	292	75	8	*375*

Figure 7. Hourly number of skiers in each part of the ski domain (i.e., each edge of the graph of Figure 2).

5 EFFECTS OF THE CLOSURE OF PART OF THE SKI DOMAIN

The effects on the Antagnod branch of the closure of part of the ski domain are analyzed in the following paragraphs.

5.1 Closure of part of a ski run

The closure of part of the resort results in a redistribution of the flow. Four different situations are considered. As clearly visible in Figure 2, the ski resort can be approximately split into three parts: one composed by “intermediate” and “difficult” ski runs, another composed by “easy” ski runs served by chair lift no.1 (L1), and the last one composed by ski run “I” and served by chair lift no.2 (L2).

The first supposed closure is represented by the interruption of flow through the ski run corresponding to edge A. This partial closure implies the interruption of flow to downstream ski slopes (B, C and D) but it does not imply a redistribution of flows through the ski lifts, e.g. the hourly number of people on L1 and L2 does not vary (second column of Figure 8).

The second simulation is represented by the partial flow interruption on edge B (which is a “difficult” ski run). The flow is redistributed through the other “intermediate” ski runs and no effects are recorded on the flow on L1 and L2.

The third simulation is represented by the closure of edge G, belonging to the part of the ski domain with “easy” ski runs. A redistribution of flow is seen. The number of people using L2 increases since the flow through G splits on F and on I.

The last simulation relates to the closure of edge H. This event has large since the flow through L2 increases from 373 to 1125 persons per hour (+201%).

		Flow interrupted on edge:			
Edge	Oper	A	B	G	H
A	956	**0**	538	956	1375
B	419	0	**0**	419	838
C	538	0	538	538	538
D	956	0	538	956	1375
E	419	1375	838	419	0
F	375	375	375	563	0
G	375	375	375	**0**	0
H	1169	2125	1588	981	**0**
I	375	375	375	563	1125
L1	2125	2125	2125	1938	1375
L2	375	375	375	563	1125

Figure 8. Hourly number of skiers in each part of the ski domain following the interruption of the flow on one edge. The “Oper”-column refers to the undamaged situation (operational situation).

5.2 Closure of a chair lift

Besides the closure of a ski run, there is the possibility of interruption of a ski lift. In this sense, the effect of the closure of L2 corresponds in an increase of skiers through edges F and G and, consequently, H.

		Flow interrupted on chair lift:	
Edge	Oper	L1	L2
A	956	0	956
B	419	0	419
C	538	0	538
D	956	0	956
E	419	0	419
F	375	0	563
G	375	0	563
H	1169	0	1544
I	375	2500	0
L1	2125	0	2500
L2	375	2500	0

Figure 9. Hourly number of skiers in each part of the ski domain following the interruption of the flow on the chair lifts. The “Oper”-column refers to the undamaged situation (operational situation).

6 CONCLUSIONS

The effects of the partial closure of a ski domain have been highlighted through a simple model based on graph theory. An example based on a real test study has been proposed and detailed. The model is based on few assumptions and, because of that, can be implemented in larger ski resorts. The proposed example is based on an arbitrary statistics relating the choice of the ski slope to its level of difficulty and to the ability of the skier. A detailed survey is required for a more precise simulation. In the same way, the behavior of the network is sensitive to the number of skiers belonging to each ability-class. By varying the percentages, large variations are shown, in particular in the distribution of people on the chair lifts.

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