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ASSESSMENT OF THE DYNAMICS IN AVALANCHE RISK: A CASE STUDY FROM THE KHIBINY MOUNTAINS, RUSSIA

MASTER THESIS

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ABSTRACT

Snow avalanches pose a hazard to traffic infrastructure in mountain areas, resulting in economic losses because of necessary road and railway closures. In order to decrease such economic losses, a decision on a hazard-adapted use of an exposed object at risk should be based on the comprehensive analysis of the hazard as well as the exposed damage potential within given social and economic settings.

The following research illustrates the importance of the dynamics in avalanche risk, taking the railway and the road sections situated in the Khibiny Mountains, Russia, as a case study. The study bridges the existing methodological gap in dynamic avalanche risk assessment on a large scale in Russia and introduces a practical implementation of the existing European approaches adapted for the specific site conditions.

Two different timeframes were selected to address long-term development and short-term dynamics in hazard and risk. In an annual timeframe, the risk was evaluated for both, the road and the railway section, and was consequently expressed in terms of fatality risk and economic losses. In a daily timeframe, the spatio-temporal variability of damage and hazard potential was assessed for the railway section on the basis of a fuzzy logic model. In addition, to quantify possible consequences of an increase in hazard and damage potential, three scenarios were applied using the validated avalanche simulation model ELBA plus.

The results highlight the importance of the temporal and spatial variability of hazard and elements at risk, focusing on avalanche risk. Furthermore, the findings of the conducted research represent the current situation in the region and offer a basis for the development and implementation of decision-making processes in respect to the avalanche risk.

ABSTRACT

Lawinen stellen eine ständige Gefahr für alpine Siedlungsräume dar und bringen daher hohes Gefahrenpotential mit sich. Um Personen- und Objektschäden zu vermeiden, sind, neben einer Gefahrenanalyse, sozio-ökonomische Aspekte sowie Risikoelemente zu berücksichtigen.

Die vorliegende Studie hebt die Bedeutung der Dynamik in der Risikoabschätzung von Lawinen hervor. Das Untersuchungsgebiet liegt im Khibiny-Gebirge auf der Kola-Halbinsel in der Russischen Föderation. Die Arbeit trägt dazu bei eine Methode zu entwickeln, um die langfristige Entwicklung sowie kurzfristige Fluktuationen des Lawinenrisikos unter Berücksichtigung von aktuellen europäischen Studien und Methoden abzuschätzen.

Für die Risikoanalyse der gewählten Straßen- und Schienenabschnitte wurden zwei unterschiedliche Zeithorizonte herangezogen. Im zeitlichen Rahmen eines Jahres wurde das Risiko als Todesfallrisiko und im Hinblick auf ökonomische Auswirkungen betrachtet. Die raum-zeitliche Variabilität von Schäden und das Gefahrenpotential für die Bahnstrecke wurde auf Basis eines Fuzzy-Logic-Modells auf Tagesbasis geschätzt. Zudem wurden drei Szenarien mit Hilfe des dynamischen Lawinen-Simulationsprogramm "ELBA plus" simuliert, um mögliche Konsequenzen von höheren Gefahrenpotentialen quantifizieren zu können.

Die Ergebnisse der Arbeit unterstreichen die Wichtigkeit der zeitlichen und räumlichen Risikovariabilität, und heben die Bedeutung für die Abschätzung des Schadenspotentials im Rahmen von Risikoanalysen hervor. Sie können verwendet werden, um die derzeitige Situation in der Region fundiert zu beschreiben und bieten eine Basis für darauf aufbauende Studien, um das Lawinenrisiko betreffende Entscheidungsprozesse zu optimieren und objektiv nachvollziehbar zu gestalten.

DECLARATION OF AUTHORSHIP

I certify that this project is entirely the original work of student registration number 0941669. The material obtained from published or unpublished works has been fully acknowledged by citations in the main text and inclusion in the list of references. The work presented here has been written to the best of my knowledge and has not been submitted, either in part or whole, for a degree at this or any other University.

Tatiana Pukhtel

TERMINOLOGY[1]

Avalanche hazardous period: time with snow accumulation and mechanical resistance conditions of snowpack on the slopes providential for avalanche release.

Avalanche path: an entire area down which an avalanche moves, which is made up of the starting zone, track and run-out zone.

Avalanche site: an upper part of an avalanche path where the movement of avalanche originates from. It includes all possible starting zones for the path.

Blizzard: a severe snowstorm characterized by strong sustained winds and lasting for a prolonged period of time - typically three hours or more.

Dry snow avalanche: an avalanche that occurs in dry snow at below freezing temperatures.

Damage potential: is based on the qualitative assessment, which estimates the possible harm that avalanche can cause, taking into account elements at risk in avalanche path.

Danger: a phenomenon which, if it occurs, leads to human or material losses.

Elements at risk: include tangibles: the built environment, infrastructure lines, traffic corridors, economic activities, public service utilities; as well as the population: residents, commuters and tourists, in the area potentially affected by avalanches.

Event: an avalanche located in space and time.

Exposure: a susceptibility of an element at risk to avalanches defined by the position and time of presence in avalanche terrain.

Favourable conditions: low to moderate wind speeds, air temperature close to 0°C, strongly irregular old snow surface, frequently skied slopes.

Hazard: a potential threat to people and assets valued by the humankind.

Hazard potential: a function of likelihood of hazard occurrence of a certain magnitude in a given location.

Magnitude: a magnitude of an avalanche event is usually defined in terms of volume and impact pressure (hazard maps, hazard management).

Risk: a measure of the probability and severity of an adverse effect to health, property or environment.

Run-out distance: a point of the farthest reach of avalanche debris.

Snow avalanche: a mass of loosened snow suddenly and swiftly sliding down a mountain.

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[1] The cited terminology is adopted from IUGS 1997 and Glossary of snow and avalanches (European Avalanche Warning Services).

Snowfall: an accumulated depth of freshly fallen snow over the horizontal unit area between observing periods.

Snow cover: a net accumulation of snow on the ground resulting from solid precipitation deposited as snowfall, ice pellets, hoar frost and glaze ice, and water from rainfall, much of which subsequently has frozen.

Unfavourable conditions: a high rate of precipitation, strong winds, low temperature, smooth old snow surface (surface hoar, melt-freeze crust or ice, very old snow surface), rarely skied slopes.

Vulnerability: a degree of possible losses or impact damages to a given element or set of elements within the area affected by avalanche(s) with certain intensity. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the property, and for persons it will be the probability that a particular life will be lost, given the person(s) affected by the avalanche.

Wet snow avalanche: an avalanche consisting of snow which contains liquid water.

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1. INTRODUCTION

1.1 Research problem statement

The central aspect within snow avalanche risk assessment is to ensure an acceptable safety level and sustainable use for the selected mountain areas with regards to economic and social conditions. This becomes of vital importance when tailoring to avalanche risk assessment along a road segment with high significance, limited number of applicable structural measures, and dynamic environment of elements at risk (Margreth et al. 2003).

The currently used methodologies for avalanche risk assessment are carried on different scales: on a small or a medium scale (Vashalova and Shnyparkov 2003; Seliverstov et al. 2008) and on a large scale (Andreev et al. 2000). However, all the methodologies applied for avalanche risk assessment in Russia, address snow avalanche risk as a static approach, using relative and generalized socio-economic parameters, which finally turn to a simplified and unrealistic picture. The results of such an evaluation, expressed in mean values (Vilchek et al. 2005; Vikulina 2011), are questioned as to whether they are considered to be a sufficient representation of a situation. In a real world application, possible risk peaks arising at a certain period of time due to an increased number of elements at risk or variations in hazard potential can subsequently turn the territories with a generally acceptable level of avalanche risk into the areas with an unacceptable risk.

In actual fact, for a sound risk assessment, a proper scale to incorporate precise investigations of geophysical parameters of snow avalanches and elements at risk, together with accounting for a dynamic nature of snow avalanche risk is required. Thus, a special consideration should be given to a dynamic approach, which takes into account temporal and spatial variation in avalanche hazard and damage potentials. Moreover, by incorporating a different timeframe, a dynamic approach can be a proper foundation for selecting structural and organizational countermeasures at a given site.

1.2 Research objectives and outlines

The following thesis inquires into a question of assessment the dynamics in avalanche risk, focusing on the avalanche risk development for a road and a railway section. The study area is located in the Khibiny Mountains, found on the Kola Peninsula in Russia. The project contributes to developing a methodology, accounting for a long-term development and a short-term fluctuation of avalanche risk, based on recent European studies and practices on risk assessment. A particular consideration is given to the methodological gap in dynamic avalanche risk assessment on a large-scale risk in Russia and to the introduction of a practical implementation of the European approaches adapted to local conditions.

The study area provides a perfect environment to conduct an assessment of the dynamics in avalanche risk. The local conditions in combination with the development rate, which results in an increasing pressure on the region, continuous change of topography and avalanche release conditions, present ideal settings for the research. In addition, an extensive data base of avalanche events and findings from the previous studies insure a basis for the further development of a risk concept and a risk consideration in the Arctic regions.

The presented research questions are:

1. Can the developed methodology serve as a basis for an approach for risk assessment on a large scale?

2. Will the adapted methodology be capable of accounting for risk development in long-term and short-term timeframes for the study area?

3. How will the observed short-term peaks in hazard and damage potentials change the picture of the overall situation in terms of avalanche risk and possible mitigation strategies?

The sub-objectives required to answer these research questions include the:

1. evaluation of the current situation in terms of slope inclination, meteorological and geomorphologic conditions;

2. study of the cadastre of the hazardous events and depicting avalanches that hit the road and/or railway section;
3. validation of the simulation avalanche model ELBA plus with a back calculation of the well-documented avalanche incidents for each avalanche path;
4. long-term assessment of avalanche risk for the railway and road section in an annual resolution;
5. short-term assessment of spatio-temporal variability of hazard and damage potentials in a daily resolution;
6. quantitative risk assessment, based on the designed scenarios with respect to a particular avalanche path;
7. recommendations on the possible mitigation measures.

1.3 Structure of the thesis

The presented work is structured into five chapters, starting with the introduction to the research significance and the fundamental research objectives.

The second chapter provides an overview on avalanche risk assessment and aims to discuss the state of the art in avalanche risk assessment together with the most widely used approaches and procedures to account for it. Moreover, the issue of static approach in the field of avalanche risk assessment is unveiled, highlighting the importance of temporal and spatial dynamics of both, hazard and damage potentials. The situation is discussed with respect to the current situation in Europe, as well as in Russia, where the study site is situated.

This is followed by the detailed description of the study area, where the fundamental meteorological and slope conditions for avalanche formation are evaluated (chapter 3). The results of the performed analyses are used to select and adjust the methodology to account for the dynamics in avalanche risk under the local conditions.

Based on these findings, the risk assessment is conducted within two different timeframes (chapter 4). The long-term development of risk illustrates the present situation and is used to define the prioritized avalanche paths with the most frequent events and the highest risk. The long-term risk has been calculated separately for the railway and road sections. For the road section long-term risk is calculated on the basis of the traffic census and is expressed as individual and collective death risk. For the railway section risk is calculated on a scenario basis, quantifying consequences of a collision between a train and an avalanche in economic losses. In the short timeframe, risk assessment is conducted for the railway section with the aim to reflect a spatio-temporal variability of hazard and damage potential. The temporal variability of avalanche release on a daily resolution is based on a fuzzy logic model, which evaluates the degree of membership for the statement “avalanche release expected” and “no avalanche release expected” using a set of meteorological parameters for an individual day. The variability of damage potential is determined on the basis of information about avalanche release(s) from the avalanche cadastre. In addition, various scenarios are proposed to illustrate an effect of the increase in hazard or damage potentials in the case of a particular event.

In the final chapter, the recommendations for further research and possible mitigation strategies are presented grounded on the results from the long-term and short-term risk assessment.

2. THEORETICAL BACKGROUND OF RISK ASSESSMENT

2.1 Risk vs. hazard: terminology

The idea of risk is an integral part of the global community, being one of the key issues on the political stage worldwide. Despite growing public attention, a confused perception towards risk is common (Short 1984; Renn et al. 1992; Vlek 1996). This leads to a conflict between the public's expectations concerning safety, susceptibility to natural hazards and the real potential of the risk management institutions.

In general, risk relates to a particular asset at risk, which could be anything valuable to someone at a specific time. Thus, as McClung (2005) states, risk definitions strongly refer to a selected field of application. In the case of snow avalanches, risk reflects the probability of damage resulting from physical interactions between the avalanche hazard and the exposed objects. Thus, key factors to determine avalanche risk, apart from the avalanche hazard itself, are the exposure of elements at risk, and their vulnerability to the avalanche hazard; both are dynamic with temporal and spatial variations (Mileti 1999). Figure 1 shows avalanche risk as a function of avalanche hazard and the exposure of elements at risk.

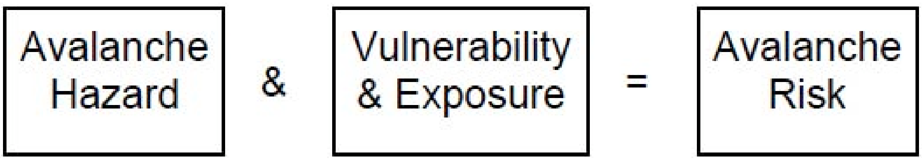

Figure 1: Avalanche risk as a function of avalanche hazard, vulnerability and the exposure (Statham 2008)

Hazard, generally, is a potential threat to humans and assets valued by them. Avalanche hazard, thereby, represents the avalanche hazard potential, and is a function of the likelihood of occurrence, frequency and the magnitude[2] in a specific location (Statham 2008).

Avalanche hazard does not depend on asset(s) at risk nor vulnerability, nor exposure of the objects at risk. As an example, a hazard can be announced to be at a high level while nothing is exposed to it.

[2]In case of snow avalanches, the proxy for the magnitude is chosen to be impact pressures in the run-out area, which is used for a hazard map design and a hazard management according to the international standards (Bründl et al. 2010).

According to O'Gorman (2003): "*avalanche hazards in mountainous terrain are common, but they represent a risk only to people using such locations when a certain depth of snow exists, thus presenting an exposure to risk*". Typically, the avalanche hazard is based on snow stability and avalanche triggering possibility, being reported according to an avalanche hazard scale. An example of the avalanche hazard scale applied in Europe is given in Figure 2.

	Danger level	Snowpack stability	Avalanche triggering probability	Consequences for transportation routes and settlements / recommendations	Consequences for persons outside secured zones / recommendations
5	very high	The snowpack is poorly bonded and largely unstable in general.	Many large and multiple very large natural avalanches are expected, even in moderately steep terrain.	Acute danger. Comprehensive safety measures.	Highly unfavourable conditions. Avoid open terrain.
4	high	The snowpack is poorly bonded on most steep slopes*.	Triggering is likely even from low additional loads** on many steep slopes. In some cases, numerous medium-sized and often large-sized natural avalanches can be expected.	Many exposed sectors are endangered. Safety measures recommended in those places.	Unfavourable conditions. Extensive experience in the assessment of avalanche danger is required. Remain in moderately steep terrain / heed avalanche run out zones.
3	considerable	The snowpack is moderately to poorly bonded on many steep slopes*.	Triggering is possible, even from low additional loads** particularly on those steep slopes indicated in the bulletin. In some cases medium-sized, in isolated cases large-sized natural avalanches are possible.	Isolated exposed sectors are endangered. Some safety measures recommended in those places.	Partially unfavourable conditions. Experience in the assessment of avalanche danger is required. Steep slopes of indicated aspects and altitude zones should be avoided if possible.
2	moderate	The snowpack is only moderately well bonded on some steep slopes*, otherwise well bonded in general.	Triggering is possible primarily from high additional loads**, particularly on those steep slopes indicated in the bulletin. Large-sized natural avalanches are unlikely.	Low danger of natural avalanches.	Mostly favourable conditions. Careful route selection, especially on steep slopes of indicated aspects and altitude zones.
1	low	The snowpack is well bonded and stable in general.	Triggering is generally possible only from high additional loads** in isolated areas of very steep, extreme terrain. Only sluffs and small-sized natural avalanches are possible.	No danger	Generally safe conditions

Figure 2: Avalanche hazard scale (Swiss Federal Institute for Snow and Avalanche Research SLF, Davos)

To sum up, a hazard becomes a risk if there is likelihood that this potential is released in a way that produces harm (Bartesaghi et al. 2012).

2.2 Different approaches

Natural disaster risk refers to a potential of adverse consequences being realised without a clear indication of release time. Therefore, it could be seen both as a social construct and a representation of reality (Renn 2008); and is addressed from both, sociological and natural science approaches. Up to now, these two approaches conduct the research on social and natural processes separately neglecting possible interaction between them (White et al. 2001).

Risk determination from a sociological approach is based upon an idea that disaster occurs only when damage exceeds the population's capacity to resist it, corresponding to the political system, economic and social conditions within a given country or community (Few 2003).

The main drawbacks here are that the results are dependent upon the approach chosen by the expert and thereby vary considerably. At the same time, broadness of judgments makes it almost impossible to compare individual risk perceptions and select one representative for decision making on risk (United Nations 2004).

On the contrast, in a natural science approach, the focus is on hazards and their physical consequences. The attention is put on physical aspects with a goal to quantify or objectively assess resulting risk. The foundation for risk assessment is in defining the endangered elements, calculating the probabilities for adverse consequences, and combining both components by multiplying the probabilities by the magnitude of effects (Kolluru and Brooks 1995).

This can be expressed in the following equation:

$$R_{i,j} = f(p_{Si,} c_{Oj}) \quad (1).$$

s_i - scenario i
o_j - object at risk j
p_{Si} - probability of occurrence of the defined hazard scenario (s_i)
c_{Oj} - resultant consequences on the objects at risk exposed (o_j)

To quantify the consequences, elements at risk and their corresponding extent of damage are considered (Fuchs 2009). Equation 2 presents the quantification of the risk, including:

- individual value of the objects at risk;
- vulnerability of the objects at risk;
- exposure of the objects at risk.

$$R_{i,j} = f(p_{Si}; A_{Oj}; v_{Oj,Si}; p_{Oj,Si}) \quad (2).$$

A_{Oj} - individual value of the exposed elements at risk j
$v_{Oj, Si}$ - vulnerability of objects at risk j under scenario i

$p_{Oj,Si}$ - probability of exposure of the specified objects at risk j under a given scenario i

This approach is very popular among engineers and natural scientists; however it has been heavily criticized from the social sciences' side (Hoos 1980; Freudenburg 1988; Schrader-Frechette 1991; Adams 1995).

Being based on the positivist postulates, it contributes to one component of risk - the hazard and the related outcomes, neglecting that risk is also a social construct. It is focused on the objectively assessed damage: loss of human life or health, harm to the environment and property. The likelihood is calculated from experiments, models and scenario techniques and is derived from the relative frequencies of the events.

Consequently, each of the disciplinary risk concepts provides a fragmented view with addressing of a limited scope of effects and does not suffice to determine the multi-faceted phenomenon of risk. Risk is a complex and fuzzy concept, which refers to a future state of reality and is bounded with uncertainty. Elms (1992) states that it could be characterised as something in the mind, related to the personal or collective perception, but on the other hand, a sense of objectivity presents in the risk analysis. The foundation for any effective risk investigation is to understand that the risk concept is rooted in the interaction between social and physical spheres (Barrows 1923).

In order to assess risk on an interdisciplinary level, one should be concerned with physical damage, life and economic losses together with other social factors. A number of authors (e.g. Bankoff et al. 2001) have claimed that the best way to reduce a natural hazard threat is a development of the integrative risk concept, relied on the insights of the natural, technical and social sciences.

2.3 Integrated risk concept

The International Decade for Natural Disaster Reduction (IDNDR, United Nations General Assembly 1989) has promoted global awareness of natural hazards and increasing economic losses due to hazardous process on an international level (White 1994). Several authors considered the risk-based management of natural hazards, denominated the risk concept, as a key component for mitigation of the natural hazards and the resulting risks (e.g. IUGS 1997;

Fell et al. 2008a). The above-stated concept triggered a shift from previous hazard oriented studies to a broader context, involving the socio-economic dimensions of risk.

Since that decade, various integrated approaches for the natural hazard management, where the model-based hazard description is combined with the quantitative assessment of the consequences, have emerged in European countries (Merz and Emmermann 2006; Jonkman et al. 2008). The originally designed approaches have been further developed to be applicable for different scales. Bollinger et al. (2000) and Keiler et al. (2004) made major inputs with respect to the small-scale analyses; while more recent studies, focused on the large-scale, were carried out by Fuchs et al. (2008).

In the alpine countries, the overall concept for natural hazard risk management currently in use is based upon the ideas outlined in Kienholz et al. (2004); Fuchs (2009) and Hübl et al. (2009). The major principle of integrated approaches reflects natural hazard management as a complex task with a focus on three key steps (Kaplan and Garrick 1981):

- risk analysis;
- risk evaluation;
- appropriate mitigation strategies (if needed); sometimes referred to as the management of risk.

The illustration of three key steps, which form a risk concept, complemented with the detailed explanation of the individual module is presented in Figure 3.

The stated concept provides a general theoretical background. For a certain practical application the general risk concept should be further adapted for a specific system boundaries and requires well-defined temporal, spatial and thematic conditional characteristics.

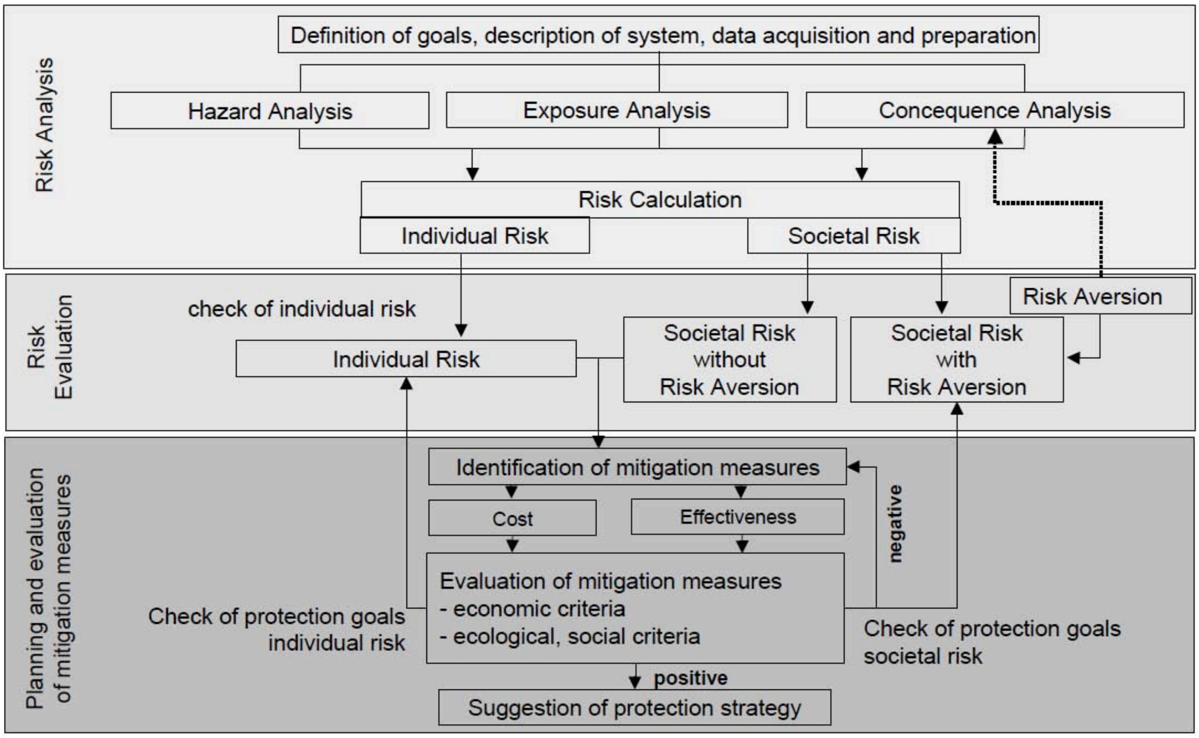

Figure 3: Main modules of the integrated risk concept (Bründl et al. 2009)

2.4 Risk analysis

Risk analysis is a complex task, which derives the possible consequences due to adverse processes. Following Equation 2, it is based on the in-depth hazard analysis; qualitative and quantitative considerations of assets at risk: their exposure in respect to spatio-temporal probability of presence and vulnerability analysis (Fuchs et al. 2007b).

2.4.1 Hazard analysis

Hazard analysis is a fundamental component with the main goal to describe specific natural hazards present at a site and to evaluate the corresponding magnitude and frequency of their occurrence. In the case of snow avalanches, however, hazard analysis is more frequently based on scenarios, rather than well-documented design events due to the short period of observation is most of the cases (Eckert et al. 2012). Scenario planning with the use of qualitative and quantitative methods enables planners to determine what has and therefore could happen at a specific location.

Qualitative methods principally focus on the relationship between a triggering mechanism and process characteristics. Such methods are classified into statistical or probabilistic, and process-based (Fuchs et al. 2008). They characterize basic process parameters required for each specific case, such as run-out distance or magnitude and are used to decide on the occurrence probably of the process. Talking about snow avalanches with a complex cause-effect mechanism, the probability of the main triggering mechanism or the probability to reach a defined point during run-out in the accumulation zone is used instead of the occurrence probability of the event itself. This results in substantial uncertainties (Mazzorana et al. 2009).

2.4.2 Analysis of elements at risk

The elements at risk are those situated in the area affected by a specific hazard, including population, residential and non-residential constructions, infrastructure lines, economic activities and ecological features (Fell et al. 2005, 2008a). The type of elements at risk and the level of details are selected according to the scale and the target of the performed analysis. Usually the analysis of elements at risk is conducted on a small-scale or national level (Spiker and Gori 2003; Roberds 2005; Thieken et al. 2007) with assets at risk being consequently classified into object groups. This allows dividing large areas into more or less at risk and estimating losses based on the spatial location of the assets. Nevertheless, the problems arise from it are: the level of details and the development of the methodology to account for the elements at risk on a local level.

With respect to a large-scale, there is a certain methodological gap in evaluation and comparative techniques (Fuchs et al. 2006; Keiler et al. 2006a). Accordingly, a lack of widely accepted and standardised approaches results in a subjective evaluation, which cannot be either transferred to or compared with other regions. Hence, the major revealed issues are detailed studies on spatial distribution of elements at risk and their temporal development with resulting variability in damage potential, which will be a basis for a precautionary and sustainable way of dealing with natural hazard phenomena and efficient investments (Fuchs et al. 2007a).

2.4.3 Vulnerability analysis

Vulnerability is one of the key aspects in the concept of risk, being a condition for consequences evaluation. Hence, the proper identification and analysis of vulnerability can be seen as a significant prerequisite to reduce negative consequences of the hazard as well as the resulting risk (Holub et al. 2011). In the case of mountain hazards, vulnerability is practically based on a natural-scientific approach and is expressed as a physical impact on the elements at risk (Fuchs et al. 2011). Quantitatively it is determined as a degree of loss to a given element or set of elements at risk from the defined event with corresponding intensity, frequency and magnitude (Schuster and Kockelman 1996; Fell et al. 2008a, b). Thus, the vulnerability assessment is conditioned by various parameters from the built environment, and magnitude-frequency analysis from the hazardous process. Vulnerability values mirrors the susceptibility of the selected elements to different hazards with variable parameters in space and in time, being expressed on a scale ranging from 0 (no loss/no damage) to 1 (total loss/complete destruction) (Varnes 1984). For property, the loss is equivalent to the value of the specific property or to the required reinstatement costs; whereas, evaluation of human life, as a non-market good, is a more complex issue. There is no universally accepted concept to derive a monetary value of life; however in the case of natural hazard risk assessment, value of a statistical life (VSL) is proposed (Salvati et al. 2013). The statistical value of life is determined by willingness to pay (WTP) or willingness to accept (WTA) approaches (Pommerehne and Römer 1992).

2.4.4 Risk evaluation

Risk valuation is more a political issue, since decisions are often made by affected stakeholders. The target of risk evaluation is to decide which risks are acceptable for a specific case, involving possible comparison of the derived risk values with other risks or with risk acceptance criteria. Currently, the acceptance criteria and threshold values of acceptable risk for natural hazards is implemented in practice in a few countries, in European countries it is done in Iceland. The procedure of risk evaluation is strongly dependent on the life experience and value system of the person(s) in charge (Kienholz et al. 2004). In addition, there is a phenomenon of risk aversion, when accidents with huge damage are considered to be much more hazardous if compared with frequent events causing minor damage (BABS 2003). Risk managers should be aware of these biases because they may become underlying causes for a public response.

2.5 Temporal and spatial variability of risk

The issue of the natural hazard risk dynamics with temporal and spatial variability remains still open (Fuchs et al. 2004, 2012). Numerous studies try to approach this issue; meanwhile, risk analysis applied to natural hazards is treated mostly as static approaches (Jónasson et al. 1999; Gächter and Bart 2002; Bell and Glade 2004). However, static approach demonstrates the limited capacity for reliable risk assessment, as risk is a subject to temporal changes (Fuchs and Keiler 2006).

As previously discussed, risk results from the interaction between two independent systems: physical and social (Keiler et al. 2006b). The first system mirrors the physical part of the process; whereas the second system represents values at risk and the related vulnerability. Both of the components are of a dynamic nature, resulting in spatio-temporal variation of risk and the associated losses. Variations from a hazard site can be caused either by natural factors, such as changes in the triggering factor (e.g. change in snowiness due to climate change; values different from the mean snowiness due to annual variability), or by implementing protective structures in the starting zone to affect the release probability. The development in elements at risk is usually grounded on the variations in number of elements at risk, applied reinforcement measures to the existing buildings, and installation of passive defense structures with the aim to protect the assets from the hazardous processes by reducing the maximum run-out and size of a system at risk (Holub and Fuchs 2009).

Up to now, the overall increase in the number of natural hazards and the expected losses is repeatedly reported in the European Alps (Barredo 2007; Solomon et al. 2007). There is a statistically significant evidence for an increase in mean precipitation (Kundzewicz et al. 2005; Keiler et al. 2010). However, the recorded upward trend is doubted to be based on higher frequency and magnitude of the hazardous processes solely (Barredo 2009), being associated also with an extension of settlements into hazard-prone areas (Holub et al. 2011). The development in number of harmful processes and resultant losses is still under debate and requires further research. Nevertheless, the cited above findings highlight that both of the theories are to be considered for selection of mitigation strategies to decrease the intensity and/or frequency of natural phenomena. The present hazard-oriented approaches, underestimates the growth in number of elements at risk being exposed (Kron 2003; Penning-Rowsell et al. 2005; Cutter and Finch 2008), and can not fully quantify the natural hazard risk and justify the public expenditure on various mitigation measures (Fuchs and Keiler 2008).

Spatial and temporal distribution of the endangered elements to a large extent affect the damage potential and resulting risk and should be included, therefore, in the risk management approaches. The strong connection between spatial distribution and resulting damage can be illustrated by an example, when a particular event could be turned into a hazard due to a spatial expansion of elements at risk. Figure 4 illustrates the situation from a case study in Davos, Switzerland with a clear growth of the settlement, being the major factor of an increased risk (Fuchs et al. 2004). The cited study compares three different scenarios: quantified damage potential for the initial state of the system in 1950 against the damage potential related to 1950 and being recalculated for the erected protective measures (the original number of a building was used), and finally the scenario with the recalculated damage potential and spatial development of the settlement. Difference between the original system condition (accounting for initial settlement expansion and hazardous process behavior), and the modelled state (initial settlement expansion and realized protective measures) reveals the theoretical development of damage potential.

Whereas, the comparison between the first and the third scenarios represents the temporal risk development, resulting from the positive growth in the number of endangered elements and the opposite trend in hazard potential due to the implemented countermeasures (reduced run-out distances).

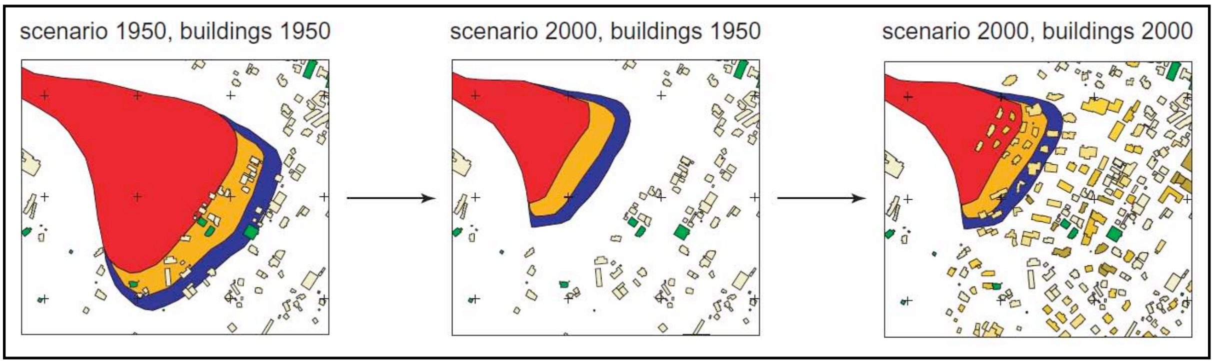

Figure 4: Temporal development of risk (Fuchs et al. 2004)

When including the general evolution of elements at risk and the obtained temporal peaks into risk equation, the results range remarkably and represent the role of the dynamics for input parameters. The risk management, therefore, should be based on the hazard assessment as well as on the evaluation of the dynamic changes in elements at risk. Consequently, this will help to decide on a suitable type of protective structures to be economically efficient for risk reduction in a specific area.

Summing up, the importance of temporal and spatial changes for the risk analyses in the alpine settlements has recently been highlighted by Fuchs et al. (2004, 2005) and Keiler et al.

(2005, 2006a), but still there is a need to bridge the existing methodological gap. Another future challenges towards the development of the dynamic concept of risk could be to analyze the dynamics in terms of climate change and variation in the frequency-magnitude relationship of events, as well as to introduce of the risk maps (for some countries they already exist) and risk zoning for the practical purposes.

2.6 Long-term and short-term development of elements at risk

In order to assess and manage hazard risks effectively, the development of elements at risk is to be studied in both, short and long timeframes. This combination can provide comprehensive information about the expansion of elements at risk, allocation of temporal peaks and selection of protective measures (Schwab et al. 2005; Fuchs et al. 2009; Fuchs and Keiler 2013). Various temporal scales can be used to represent variations in elements at risk.

Analyzing the situation in the European Alps, due to the socio-economic development and change in land-use regulation, evolution of elements at risk varies significantly on different temporal resolution (Keiler et al. 2006a). The long-term development (resolution of decades) of elements at risk is mirrored in the case studies from Switzerland and Austria, which were carried out by Keiler (2004) and Fuchs et al. (2005). The cited studies detected an increase in damage potential, grounded on the growth in number and value of elements at risk. The increase in the total number of immobile elements at risk has been boosted by spatial expansion of the settlements in the hazard-prone area before introduction of hazard zone maps, and shift in the building categories. Regarding the increase in the number of endangered persons, the major inputs are:

- from the residents relocated in the hazard prone area;
- tourists in case of the tourist-dependent settlements in Austria.

The growth of the permanent residential population has been regarded as a minor factor.

The short-term fluctuation can be derived by dividing the timeframe into smaller periods, depending mainly on the area of investigation and values at risk involved. As an example, for the calculation of snow avalanche risk in Alpine settlements with a strong dependency on tourism (e.g. the case study in Austria, Galtür), the main difference in number of persons at risk is observed due to seasonal variations (Keiler et al. 2005). According to the tourist flow, highest peaks are in winter months during skiing season and during holiday periods. In addition, from the short-term perspective, fluctuation during daytime can be analyzed to account for changes in the number of people at different locations. As outlined in Keiler et al. (2005) in the Austrian case studies, the number of persons during the day at a given location varied by a factor of 1.4 in the off-season, and by a factor of 3.4 in the period of the main season.

With regards to mitigation strategies, the investigated time scales have different targets. The long-term evolution of assets at risk could be seen as a basis. To reduce risk resulting from the basic disposition, the main tools are permanent constructions and land-use regulations, which focus on the immobile values and decrease the process's area spatially (Fuchs and Keiler 2008). Short-term changes are regarded as an addition, forming the variable damage potential. As mitigation strategies, temporal protective measures like temporal road closure or evacuation are recommended to reduce the damage potential in a short timeframe (Fuchs and Keiler 2013).

Figure 5 illustrates the importance of incorporation the knowledge on multi-temporal variations in elements at risk and corresponding damage potential for the efficient risk management.

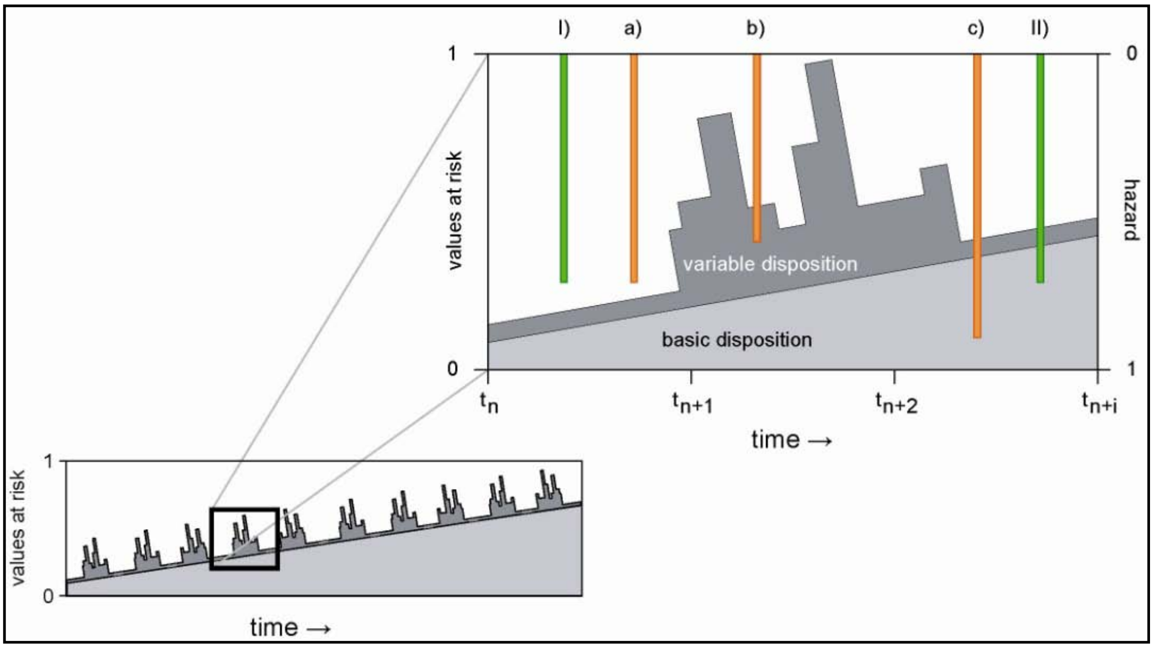

Figure 5: Evolution of elements at risk in respect to mitigation strategies (Fuchs and Keiler 2008)

As is illustrated in the figure, the scenario (a) will not affect neither basic nor variable dispositions of values at risk. The scenario (b) represents the situation when damage occurs due to the sharp increase in number of elements at risk from the variable disposition, while hazard magnitude is moderate. For this specific situation temporal mitigation measures aimed reduction of the variable disposition are feasible. The scenario (c) demonstrates a high hazard magnitude which affect elements at risk in both, long and short terms. Thus, effective risk reduction requires active and permanent measures with the focus on the hazard potential.

The above-discussed example underlines the significance of a multi-temporal approach in the identification of high-risk situations and the implementation of the optimized and cost-effective risk-based measures, being a combination of active, passive and organisational measures (Bründl et al. 2004).

2.7 Risk assessment for roads

The road network serves as important, and in some cases the only possible, transportation corridors. The economic value of roads experiences an upward trend owing to the increased traffic in the Alpine regions and change in land-use. Due to high importance and value, there is a vital need for a developed procedure to account for hazard and damage potentials, and the resulting risk for elements at risk distributed along road and railway sections (Kristensen et al. 2003).

In practice, avalanche risk assessment for roads is bounded to the approaches developed by Wilhelm (1997, 1998, and 1999) and Borter (1999a, 1999b). The developed approaches were successfully applied in various studies to the high alpine pass roads in Switzerland, mountain roads in Austria and Italy, as well as to the roads in Norway with adaptation to existing data and local conditions. Following these studies, risk is expressed in terms of individual and collective risks, which are summed up to a cumulative risk for the investigated pass road or road section (representing the annual number of people killed in the area of concern). Another possible unit to measure risk for the road section is annual loss of material assets or economic risk, expressed for example in EUR/year, if referred to Wilhelm (1998). However, the tangible losses are usually not covered by analyses carried for the alpine pass roads, which can be the opposite case for the sites being the main transportation routes for different goods.

On a whole, a model proposed by Wilhelm for risk computation for roads is a scenario build with assumption that a specific avalanche corresponding to a certain return period is known. It is based on the following input parameters:

- daily traffic volume (WDT) [vehicles];
- mean number of passengers per car [persons];
- average speed of the vehicle [km/h];
- length of the exposed road section [km].

Figure 6 illustrates the cited model for a given avalanche site, where the hazardous process is presented by:

- the mean width of avalanche blocking the road g [km];
- probability of occurrence, which is equivalent to inverse value of the mean return period T [years].

The endangered system is included by accounting for a mean value of winter daily traffic during a winter season (WDT) and a mean speed of vehicles (v). Number of persons hit by avalanche is derived from the average number of passengers and their vulnerability, which is presented as a death rate.

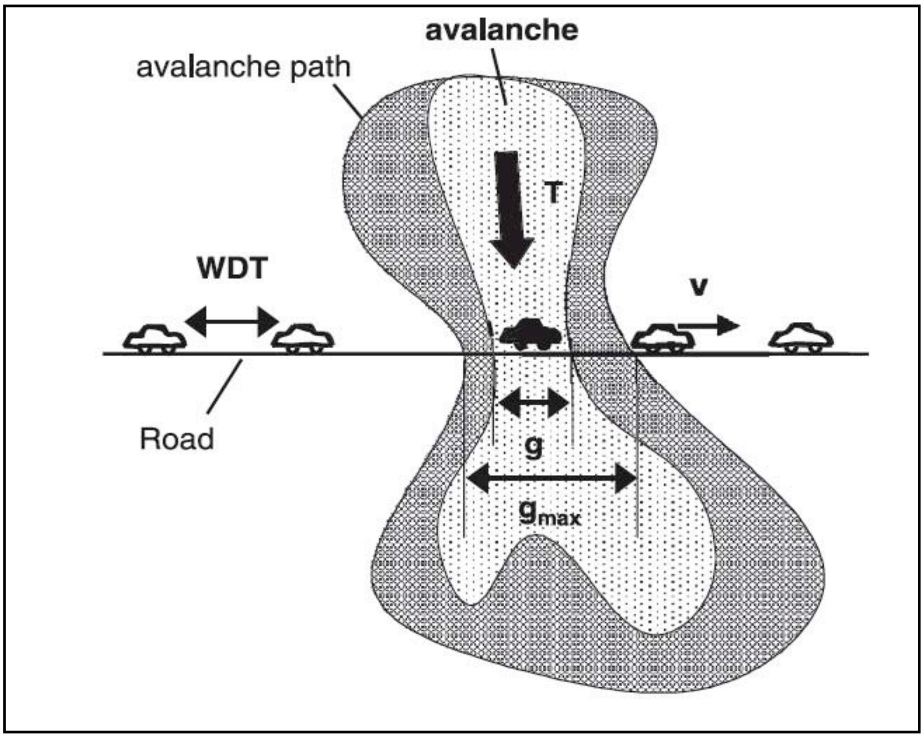

Figure 6: Model to compute an avalanche risk for roads by Wilhelm, 1998 (Margreth et al. 2003)

The weak points of the approach are:

- the return period of avalanches that hit the road, which is hard to estimate without an inventory of past events;
- the probability of an avalanche release. As suggested in Wilhelm (1997) it is grounded on the probability of occurrence of the specified snowfall event.

Moreover, the probability of a collision between an avalanche and a car for future state of the system also involves a lot of uncertainties and possible variations of the process. In addition, it is argued that the death rate used in the approaches above is not sufficient to justify the defense measures (Margreth et al. 2003). It can serve for purposes of comparison between different paths and with the existing thresholds, but for the in-depth cost-benefit analysis same units are needed to compare the investments and outputs. To overcome it, the monetary extension of Wilhelm's framework with the same currency expression is proposed by Rheinberger et al. (2009).

2.8 Application of the risk concept in Russia

The term “риск” (in Russian) has recently emerged in the scientific literature as well on the political stage in Russia (Shnyparkov et al. 2012). The most popular and widely accepted definition relates to statistical parameters, expressed as the probability of danger (Ragozin 1995).

At the moment, there is no solid reason for conducting risk assessment or risk mapping, controlled by legal acts or guidelines. The current situation highlights two most prominent issues in terms of risk assessment:

- static approach in risk assessment;
- threshold values of acceptable risk.

The currently performed risk assessment is done on two different scales:

- federal or small scale;
- local or large scale.

On a federal scale, risk assessment is done following the formerly designed small-scale maps of avalanche distribution and avalanche activity[3] and using generalized information about the following input parameters:

- geophysical parameters of the process: return period, the duration of avalanche hazardous period and area affected by avalanches;
- socio-economic component: population size and density, time spent in the avalanche prone zone and vulnerability (Yolkin 2004).

The results of such an assessment show the most dangerous areas and enable a very general consideration about future development and utilization of the territory. It is feasible due to the size of avalanche prone territories, as well as insufficiency of information for some sites. On the other hand, this approach by involving a certain degree of simplification for the input parameters prevents funnelling down to a more detailed investigation to obtain realistic results for the subsequent mitigation solutions in a specific site.

There are some recent works focused on risk assessment on a large-scale; mainly the assessment was done for pass roads, for example: Kazakov (2000); Andreev et al. (2000); Vilchek et al. (2005). However, the above-cited works serve only as test sites for the scientific research without translation into practical implementation yet. Besides, they address long-term risk development and apply generalized parameters about elements at risk. While, to reflect a real situation in terms of natural risk, a dynamic nature of hazard potential and elements at risk should be considered. This can be done by introduction of shorter timeframes to evaluate geophysical parameters of a hazardous process and to study a spatio-temporal development of elements at risk. The short-term dynamics in elements at risk is highly important for the areas with considerable seasonal or daily variations in endangered elements.

Another issue, which remains open for the European Alps as well, is a threshold value of acceptable risk. Up to now, for hazard risk assessment temporal recommendations of the Russian Ministry of Emergency Situations are proposed (Vorobiev 2005). The recommendations are based on the ALARA principle (as low as reasonably achievable) and define the following values:

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[3] Avalanche activity characterizes the intensity of avalanche formation processes according to geomorphologic and meteorological conditions together with the surface cover type (Seversky 1978).

- less than $1*10^{-6}$ [deaths/year] - acceptable risk, no additional measures are required to reduce the risk;
- $1*10^{-6}$ - $1*10^{-4}$ [deaths/year] - admissible risk, the development of infrastructure is possible with considerable investments in large-scale avalanche protection programmes;
- more than $1*10^{-4}$ [deaths/year] - unacceptable risk, fatalities and damage to the structures is unavoidable. The land-use for human settlement and agricultural activities and new construction projects are prohibited.

The above-listed norms are general recommendations, which have to be adjusted to the nature of the hazard (natural or technological hazard) and economic settings in the defined area (Vikulina 2009).

In summary, for a sustainable use of avalanche prone areas, both on political and practical levels, it is necessary to switch from small-scale general maps of avalanche activity, danger and risk to large-scale detailed studies with the unified input parameters to ensure readability and comparability. Moreover, an introduction of a dynamic avalanche risk assessment is required to enable a reliable conclusion for the studied areas with respect to temporal and spatial variations of risk.

3. RESEARCH DESIGN AND METHODOLOGY

3.1 Overview of the study area

The practical part of the work presents assessment of the dynamics in avalanche risk carried out for the railway and public road sections at the toe of the Yukspor Mountain (see Figure 7). The investigated railway and road sections are situated between Kirovsk town and the 23rd Kilometre Station, which is a remote district of the town. The area of interest is located within the Arctic Circle between 67°N and 68°N in the central part of the Kola Peninsula in the Khibiny Mountains. The highest point of the massif is Yudytchvumtchor Mountain, 1200.6 m a.s.l. (Myagkov and Kanaev 1992).

The region of the Khibiny Mountains is one of the well-developed areas in the Russian Arctic. The development traces back to 1929 and gained nation-wide importance after the apatite-nepheline industry was found in the former unsettled area. Known as a highly industrialized area, it has enjoyed a remarkable economical growth with an increase in mining and tourism in recent years. In addition to the existing facilities, which are partly utilized and party abandoned, new mining works of open and underground types, together with the required infrastructure, have emerged in new locations.

The studied railway belongs to the supporting infrastructure - it leads from the mining dump towards the factory. The main role of the railway is continuous ore transportation for apatite-nepheline concentrate production. The road situated down the slope, in contrast, serves public needs and is a major traffic artery, connecting two parts of the settlement and some mining facilities in the vicinity.

Snow avalanches released from eleven avalanche sites above impact both of the traffic axes and are presented in Figure 7. The avalanche path 15 is not reflected in Figure 7, which is built upon the official map from the CAS (Center for Avalanche Safety, JSC "Apatit"). The accidents with extraordinary damage are summarized in Appendix B and are based on the chronicles and the documented events from the CAS avalanche cadastre. The most severe events, which resulted in dramatic economic losses and fatalities, were registered in the first decade of the settlement development. The biggest fatality rate dated back to the 5th December, 1935, when 89 people lost their lives and 42 were wounded.

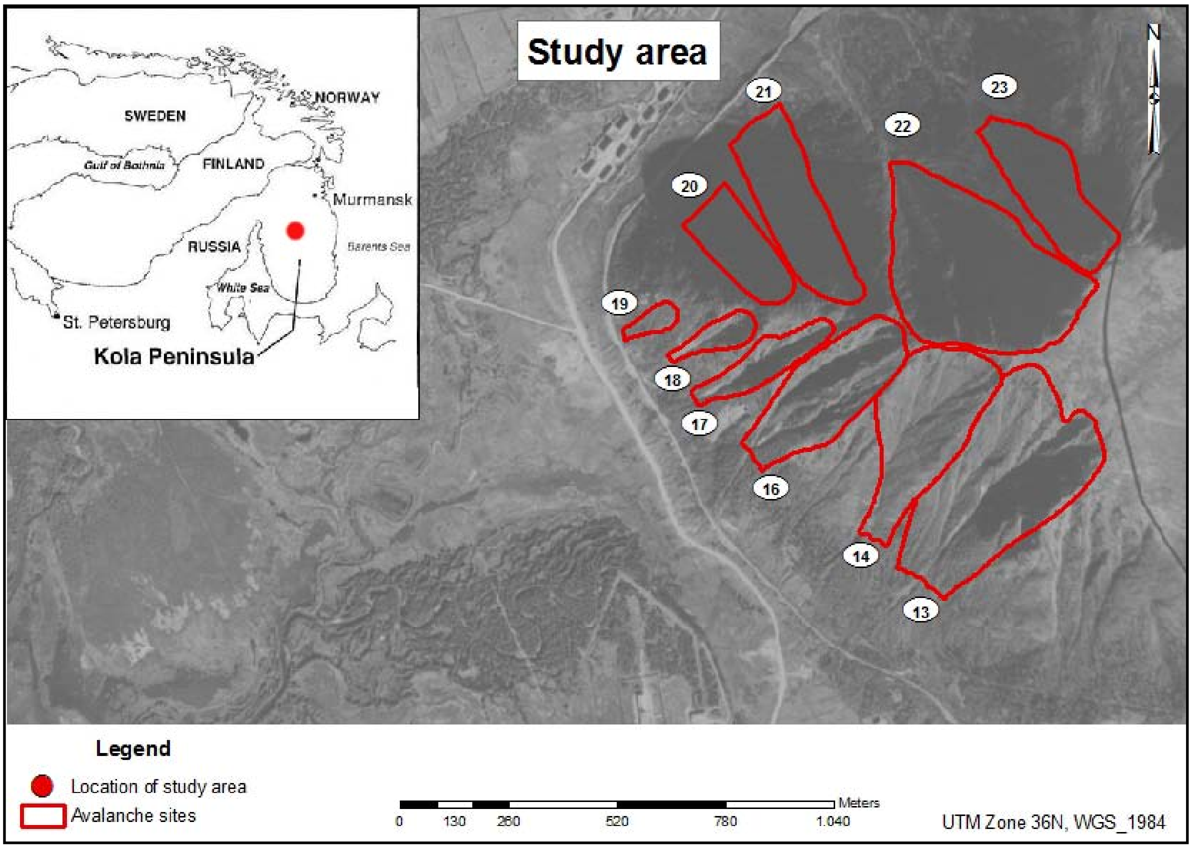

Figure 7: Study area of the railway and public road, Russia, Murmansk Oblast', Kirovsk town

The current mitigation approaches are built upon the avalanche forecasting, combined with safety plans and artificial avalanche release, which is effectively used to decrease avalanche danger within the limited timeframe.

The current protection measures in the area include:

- concrete snow fences erected in 1970 to protect the garage for the special transport, vehicles as well as the railway and road section from snow avalanches in the avalanche paths 13 and 14 (see Figure 8). The total length of the fences is 285 m (including voids) and the vertical height - 5 m. These concrete fences were designed for avalanche events with maximum flow height of 3 m, maximum front width of 300 m and flow velocity of 45 m/s, corresponding to the return period of 50-70 years.

Figure 8: Concrete snow fences for the avalanche paths 13 and 14 (Pukhtel 2012)

- terracing of the slope above the existing fences done in 1976. The total length of four horizontal terraces was 150 m with the width of 20 - 30 m;
- splitting wedge for the pavilion of the main district heating network number 2 situated in the avalanche path 19 (see Figure 9);

Figure 9: Splitting wedge for the pavilion of the main district heating network number 2 (Fuchs 2012)

- earth dams for the avalanche paths 22 and 23 constructed in 1985 (see Figure 10).

Figure 10: Earth dams for the avalanche paths 22 and 23 (Fuchs 2012)

Statistics for avalanche parameters and characteristics of the avalanche regime have been obtained by observations since 1936, and a large database of documented events was created at the CAS of the JSC "Apatit". This enables the detailed analysis of the hazardous processes and the resulting risk. Moreover, several studies in the field of risk assessment were already done for the investigated area (Vilchek et al. 2005; Vikulina and Shnyparkov 2006). The first study was carried on a large-scale for the same railway and road sections, where individual avalanche risk calculation was based on the probability of an avalanche to reach a certain point in the run-out area. From the side of elements at risk, the average number of the endangered persons has been used. Accordingly, the results of the evaluation can reflect only the hazard potential disregarding the damage potential development, which is a significant component of a risk assessment and a prerequisite for a dynamic approach. Reporting the results, the investigated sections of railway and road demonstrate the degree of individual avalanche risk (risk of death to individual) as follows:

- unacceptable (more than $1*10^{-4}$ [deaths/year]) according to the assessment on a local scale or large-scale (results are illustrated in Figure 11);
- and admissible ($1*10^{-6}$ - $1*10^{-4}$ [deaths/year]) by the research on a regional level.

Taking into account the previous studies, the role of the transport axes and current situation in the area, there is a special need to tailor the approach down to a specific site or area of a special importance. This will ensure a higher precision in the selection of mitigation measures and allow assessment of the dynamics in avalanche risk. Moreover, it is doubted that the level of risk follows the contour lines, as suggested by Figure 11.

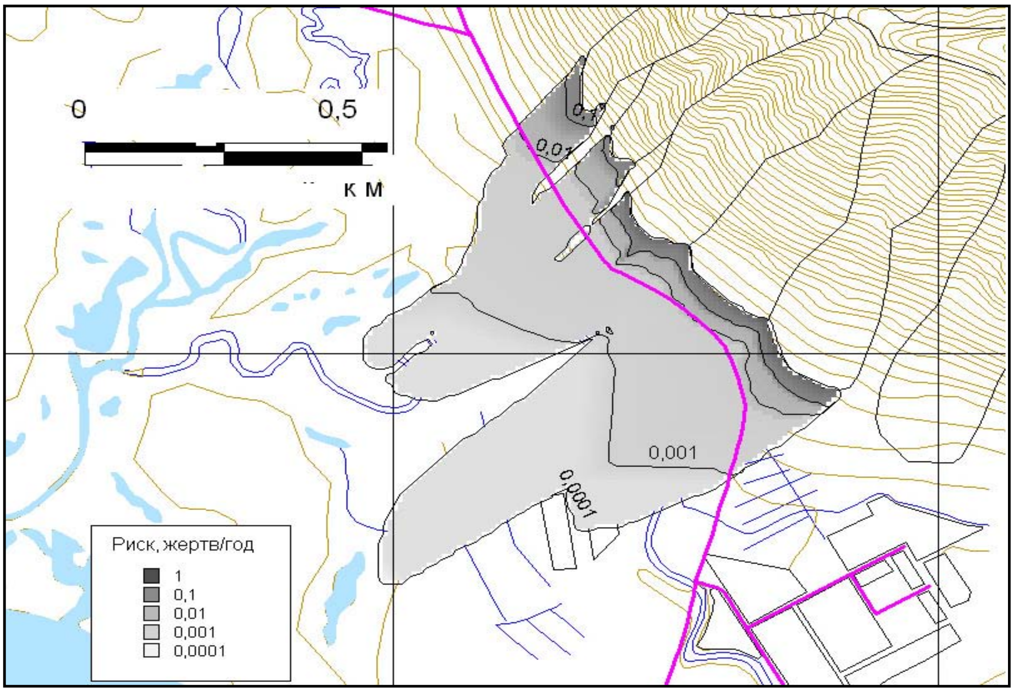

Figure 11: Individual avalanche risk along the road section at the Yukspor Mountain, which is expressed in fatalities/year (Vilchek et al. 2005)

3.2 Analysis of the meteorological conditions

In order to perform risk assessment on a precise scale for the railway and road section, all the analyses were performed in the case of the slope of interest or selected sample of avalanches. The sample of avalanches includes the events hitting the railway or road in the run-out or deposition zone. In terms of meteorological conditions, the principal goal is to draw conclusions about the local conditions and the meteorological factors influencing the avalanche formation in the area, which can be later used as significant parameters to trigger an avalanche release.

Several meteorological stations are located in the area with their main goal being to provide data for an actual avalanche forecast for the mining spots. The meteorological station

“Yukspor” (67°42’N; 33° 45’E) is situated on the top of the Yukspor plateau, altitude 910 m a.s.l., which could be the best location to get data for the site analysis. The station “Yukspor” is closed since 1980; thus the data from this station is used only for the general information about a wind direction and a total solar radiation. More precise data for the analyses, such as mean daily precipitation, mean daily temperature, snow heights were obtained from the meteorological station “Central’naya” (67°36’N; 33°52’E). The station conducts regular meteorological observations since 1961 and is located on the Lovchor plateau, 1091 m a.s.l. Figure 12 presents the location of meteorological stations.

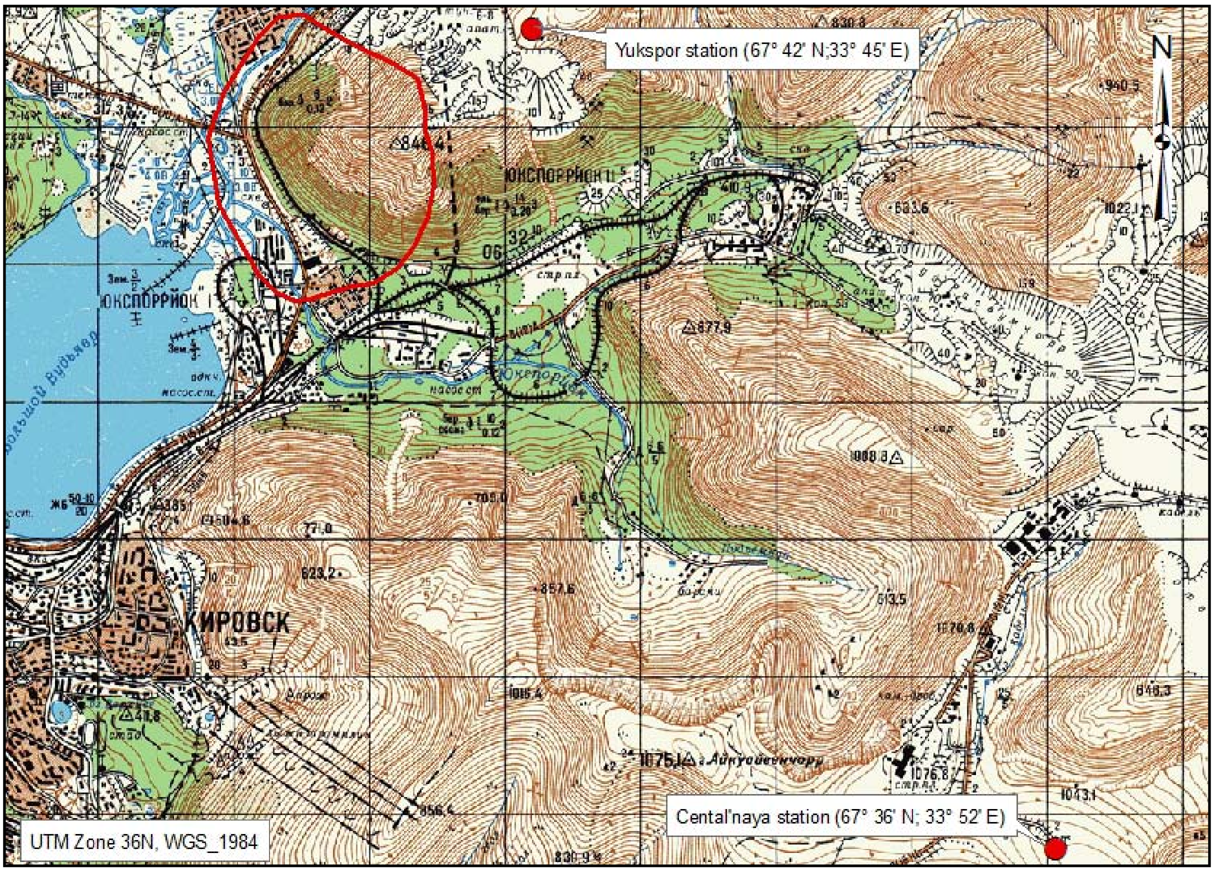

Figure 12: Meteorological stations in the area

Precipitation is distributed not uniformly with changes over the area and with height. It is characterized by heavy and frequent snowstorms, and varying weather conditions and precipitation falls according to the cyclonic activity (Luzin et al. 1994). Mean monthly precipitation for the avalanche formation period measured at the “Yukspor” station is 80 mm in water equivalent. The maximum precipitation is received during October, November and December and is associated with intense cyclonic activity. Solid precipitation has the greatest proportion at the location of meteorological station (Demin and Zyuzin 2006), being 95% out of total precipitation for the analyzed period. Figure 13 presents the monthly distribution of precipitation for the months January - June and October - December (avalanche period). The precipitation is measured in mm of water equivalent four times a day with an error of 0.25 mm for each measurement.

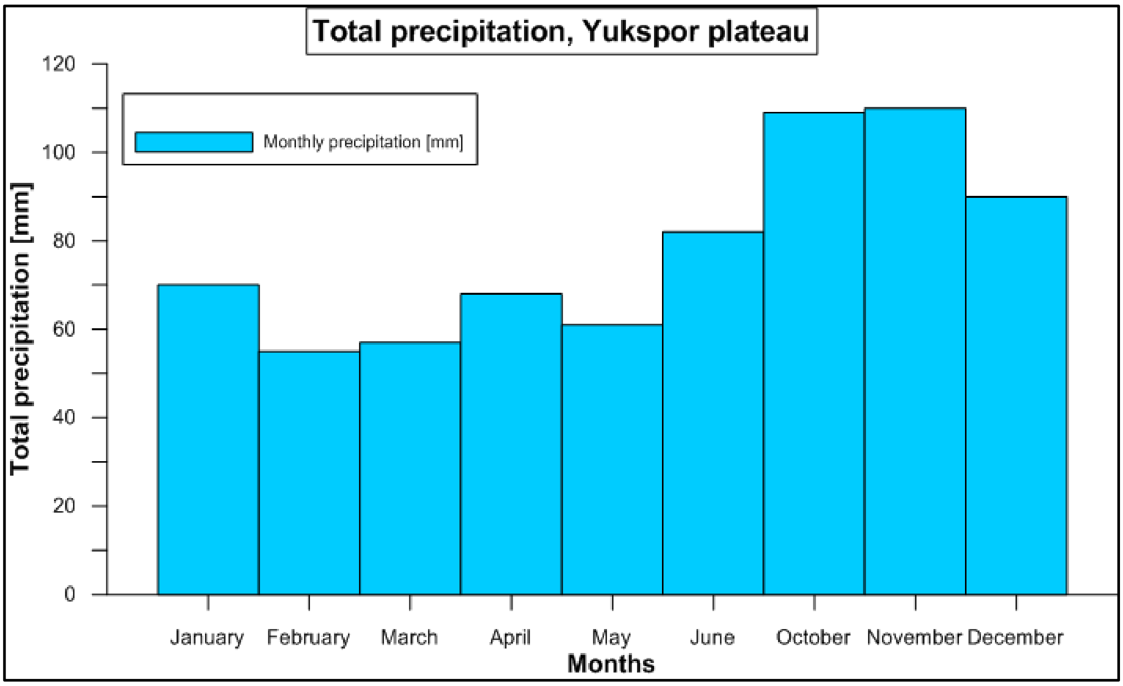

Figure 13: Total monthly precipitation at the "Yukspor" meteorological station (Mokrov 2005)

The maximum snow heights at the Yukspor plateau are observed in February (winter months) and in the end of April (spring months), corresponding to a higher probability of avalanche release in this time. The snow heights are measured as total snow height with temporal resolution of 24 hours. There are no separate measurements of new snow accumulation and development, similar to the procedure applied in Europe according to the existing regulations. The monthly snow heights are presented in Table 1.

Table 1: Mean monthly snow height [cm] (CAS observation)

Month	**1**	**2**	**3**	**4**	**5**	**6**	**10**	**11**	**12**
Yukspor (910 m a.s.l.)	110	120	130	145	140	85	25	60	90

The mean atmospheric temperature for the area recorded at the “Yukspor” meteorological station, 910 m a.s.l. is presented in Table 2. The recorded values are relatively close to the studied avalanche starting zones with the difference of 261.5 m (in comparison with the mean release height for all avalanche paths). The coldest months within the avalanche hazardous period are January and February, with a trend of general increase in temperature from March. This can be partly dependent on the solar radiance, which significantly increases after the shift from polar twilight to dawn and dusk, respectively and is doubled in March.

Table 2: Mean monthly temperature [°C] on the Yukspor plateau (CAS observation)

Month	**1**	**2**	**3**	**4**	**5**	**6**	**10**	**11**	**12**
Yukspor (910 m a.s.l.)	-12.2	-12.6	-10.9	-6.9	-1.9	4.8	-4.1	-7.7	-10.5

Due to the flat-topped topography of the Yukspor plateau intensive snow transport by wind takes place. The investigated slopes are aligned in the southwest and the northwest directions. Hence, when the direction of strong winds coincides to the above stated, large amounts of snow can become transported and deposited on the leeward side of the slope in the possible release areas increasing the snow height and avalanche hazard level further.

The main wind directions for the Yukspor plateau are northern, north-western and south-western, showing slight variations over the year. Figure 14 demonstrates the prevailing wind directions in terms of monthly wind direction and represents the snow transport in the form of a blizzard[4] rose, reflecting the direction of the major snowstorms in the study area. The presented blizzard rose is built upon the snow drift observation made on the Yukspor plateau by Akkouratov (1966).

Analyzing results of blizzard direction, the major conclusions are as following:

- the principal direction of snowstorms in the region is from North to South;
- the stated blizzard direction affects the slopes with southern aspects and leads to accumulation of drifted snow in the starting zones;
- the majority of the inspected avalanche paths covers the Southwest of the slope, where snowdrift loading can be an important parameter to take into account.

[4]Blizzard is defined as a severe snowstorm characterized by strong, sustained winds and lasting for a prolonged period of time, typically three hours or more (Zyuzin 2006).

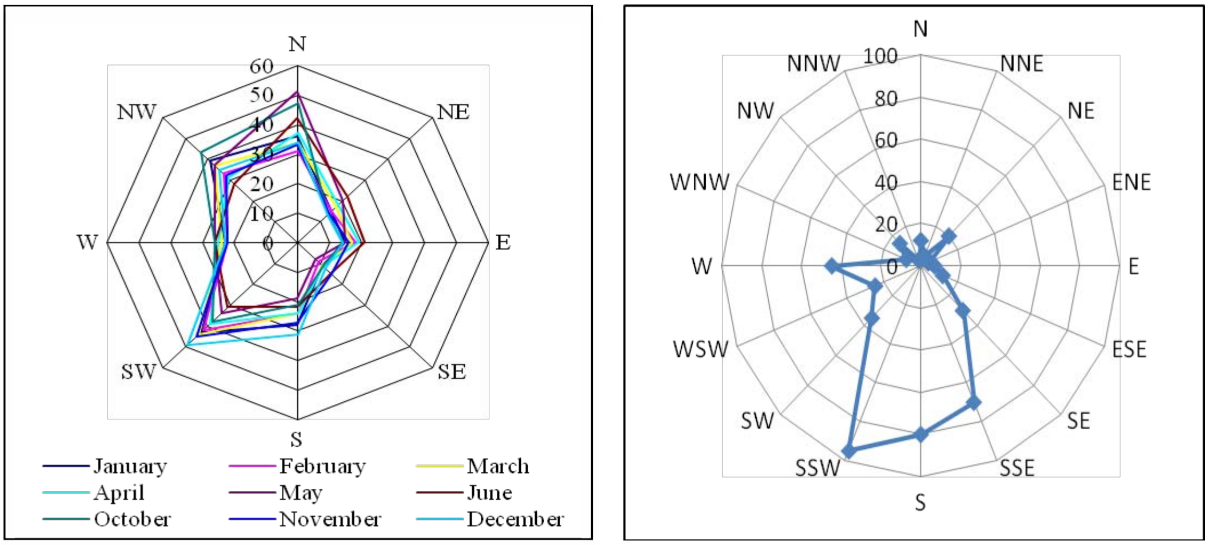

Figure 14: Prevailing wind directions (CAS observations) on the left side and blizzard rose (Akkouratov 1966) on the right side

3.3 Significant meteorological parameters for avalanche formation

In order to obtain the most significant meteorological factors for avalanche formation and to base the probability of occurrence of avalanches hitting the traffic axes, discriminant function analysis was derived. The values of precipitation, wind speed during snowstorms and mean daily temperature were analyzed. Due to data availability, the statistical treatment of the stated parameters was applied for the period from the 1st November 1997 till the 31st December 2011.

The days were consequently grouped into:

- days without snow avalanches;
- days with snow avalanches;
- days with snow avalanches that hit the road or/and railway.

The computed discriminant function analysis followed a MANOVA test, which has had shown a statistically significant effect of meteorological factors on an avalanche release, F (14; 6.4) = 9.7; $p < 0.05$. For more details on the computed MANOVA test see Appendix C.

The conducted discriminant function analysis revealed two functions, which in combination significantly distinguish the dependent variables with the parameters as follows: $\Lambda = 0.96$; χ^2 (14) = 136; $p = 0.000$. The discriminant function plot in Figure 15 shows that the first function differentiates the “days without snow avalanches” (1) from “days with snow avalanches that hit the road or/and railway” (3). In addition, the second function discriminates the “days with snow avalanches” (2) from both groups but the difference is not as considerable.

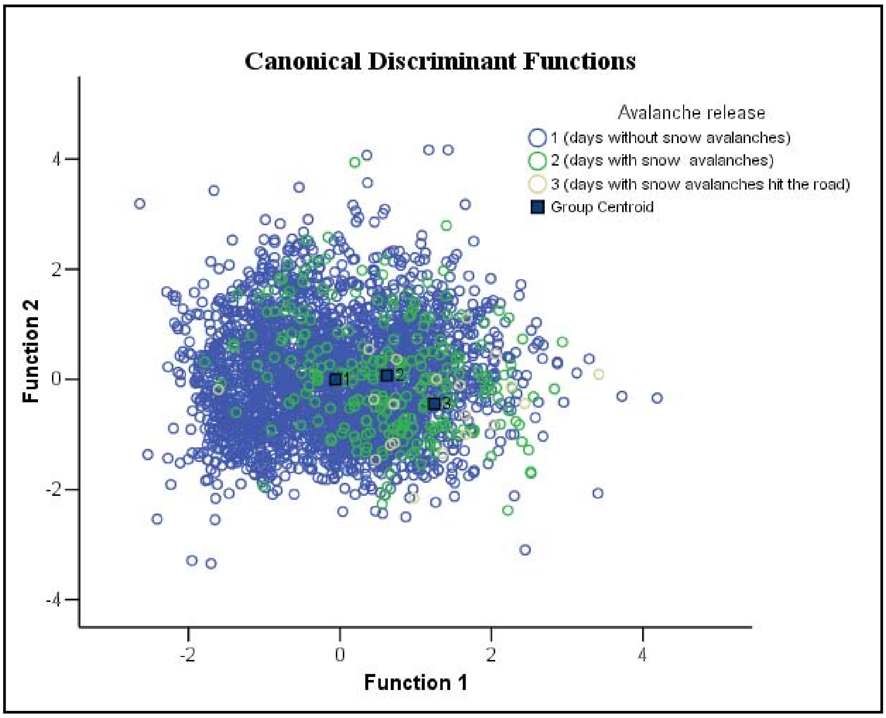

Figure 15: Canonical discriminant functions

The discriminant functions work not equally for all the groups, demonstrating poor results in the case of “days with snow avalanches” (27%); moderate result for the group “days without snow avalanches” (60%); and the best result of 75% correctly classified cases - for the third group of the dependent variable “days with snow avalanches that hit the road or/and railway” (see Table 3). A rather good classification results for the third group illustrates that the set of meteorological parameters selected can be further used as predictor variables to discriminate the days with the release of snow avalanches that hit the road or/and railway sections.

Table 3: Classification results

		Avalanche release	**Predicted group membership**			**Total**
			1	**2**	**3**	
Original	Count	1	1.779	641	548	2.968
		2	81	65	95	241
		3	1	4	15	20
	%	1	59.9	21.6	18.5	100.0
		2	33.6	27.0	39.4	100.0
		3	5.0	20.0	75.0	100.0

According to the inspection of group means and standard deviations, as well as checking the equality of group means, statistical evidence of differences is observed in the following independent variables (they are presented in the decreasing order of F numbers):

1. wind speed [m/s];
2. snow height [cm];
3. mean daily temperature [°C];
4. precipitation within 24h [mm].

Other independent variables can be discarded from the group distinctions. For more details on the discriminant analysis see Table 4 and Appendix D.

Table 4: Test of equality of group means[5]

Parameters	Wilks' Lambda	F	df1	df2	Sig.
Mean wind speed [m/s]	0.974	42.841	2	3.226	0.000
Snow height [cm]	0.991	15.174	2	3.226	0.000
Mean daily temperature [°C]	0.993	12.181	2	3.226	0.000
Precipitation within 24 h[mm]	0.993	11.276	2	3.226	0.000
3 days precipitation sum [mm]	0.999	1.851	2	3.226	0.157
Temperature gradient [°C]	1.000	0.440	2	3.226	0.644
Snow addition 24h [cm]	1.000	0.420	2	3.226	0.657

3.4 Analysis of the slopes

As a part of the terrain analyses, the major factors for avalanche formation such as topography, roughness and slope aspects for each avalanche path will be examined based on the observation in situ and maps for the area. An additional factor to influence the local conditions is an anthropogenic change of the slope relief due to mining activities in the area.

[5] Wilks' Lambda characterizes the significance of the differences between the tested groups and illustrates which variable(s) can be used for groups' separation. The smaller is the Wilks' Lambda, the more important is the variable for the discriminant function.
F number is a test statistic used in MANOVA and discriminant analysis, indicating the discriminating power of an independent variable. The larger is the number of F, the greater discriminant weight an independent variable has.
Significance represents the level of statistical significance of an individual independent variable.

3.4.1 Topography

The mountain slopes within the study area are of similar shape either rectilinear or slightly concave in the upper part. The tops are generally flattened or slightly inclined, creating propitious conditions for extra snow accumulation and cornice formation. The size of avalanche starting zones is relatively small with typical elevation within a range from 425 m a.s.l. to 835 m a.s.l. The release zones are frequently allocated above the timberline, except for the avalanche paths 18, 19 and 20.

The inclination of slopes in the starting zones of all avalanche tracks are more than 30°, which make relatively large areas to become potential release zones, excluding those that present a ridge. General information concerning the inclination is presented in Figure 16, which is produced from the DEM using ArcGIS.

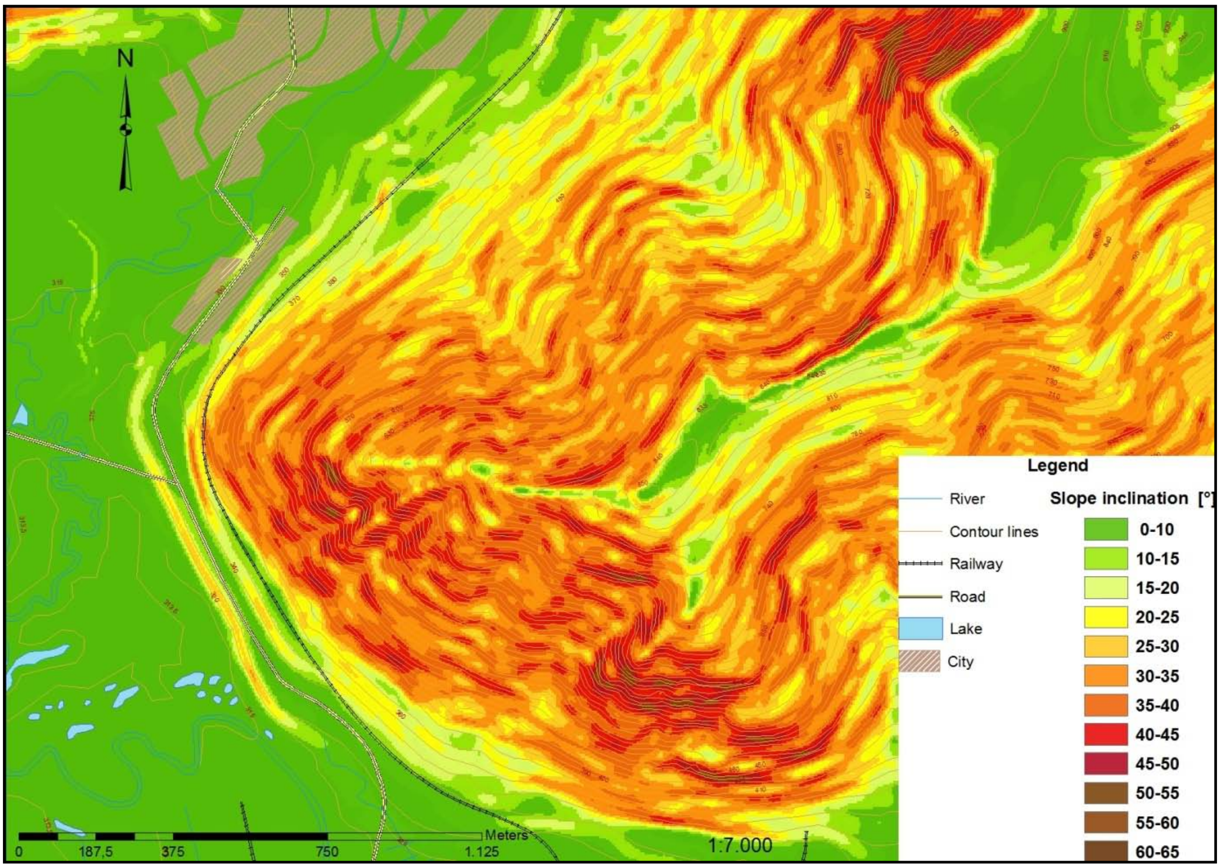

Figure 16: Slope inclination [°]

Other parameters for an individual avalanche path are summarized in Table 5 and include:

- mean slope angle characteristics;
- total area, including starting zone and avalanche track;
- slope aspect;
- information about the altitude.

Table 5: Parameters of the studied avalanche paths

Avalanche path	Altitude min [m]	Altitude max [m]	Altitude mean [m]	Slope mean [°]	Aspect	Area [m²]
13	560	825	739	39	SW, SSW	140 $x10^3$
14	425	825	774	39	SW; SSW; WSW	82 $x10^3$
16	500	750	685	40	SW; SSW; WSW	68 $x10^3$
17	440	675	555	38	SW; SSW; WSW	25 $x10^3$
18	470	610	553	40	SW; WSW	11.5 $x10^3$
19	400	530	466	38	SW; WSW; WNW	6.3 $x10^3$
20	585	600	593	37	NW	35 $x10^3$
21	355	355	355	33	NW	65.7 $x10^3$
22	460	835	770	35	NNW, NW; N	149$x10^3$
23	540	810	746	34	NW; WNW	55.5 $x10^3$

With regards to the nature of landforms, the investigated avalanche paths mostly belong to channelled avalanche catchments. This kind of catchment tends to have a longer transit zone if compared with the non-channelled, as well as more easily predefined avalanche flow direction. Figure 17 and Figure 18 present the overall view for the slope with the avalanche paths marked during winter time with snow cover (avalanche paths 13-19) and summer time (avalanche paths 21-23).

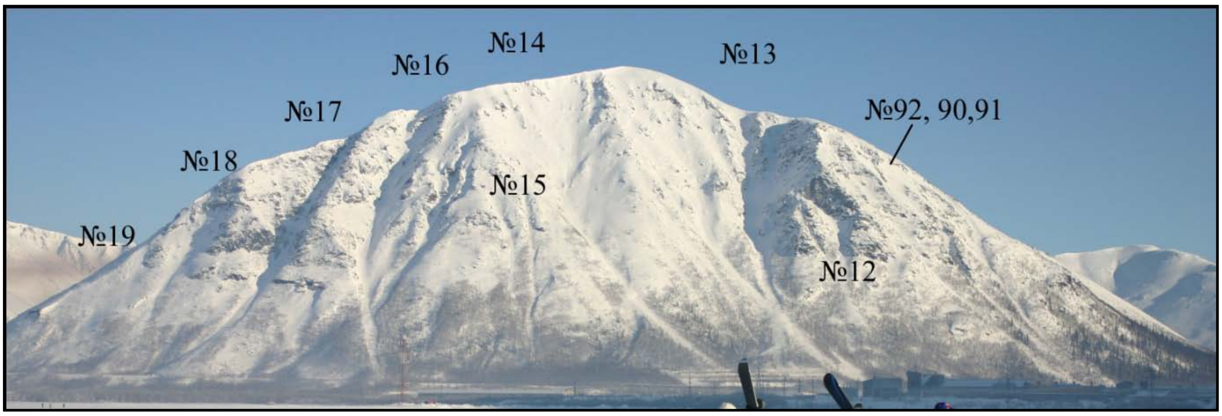

Figure 17: Studied avalanche paths on the southwestern slope (Vikulina 2009)

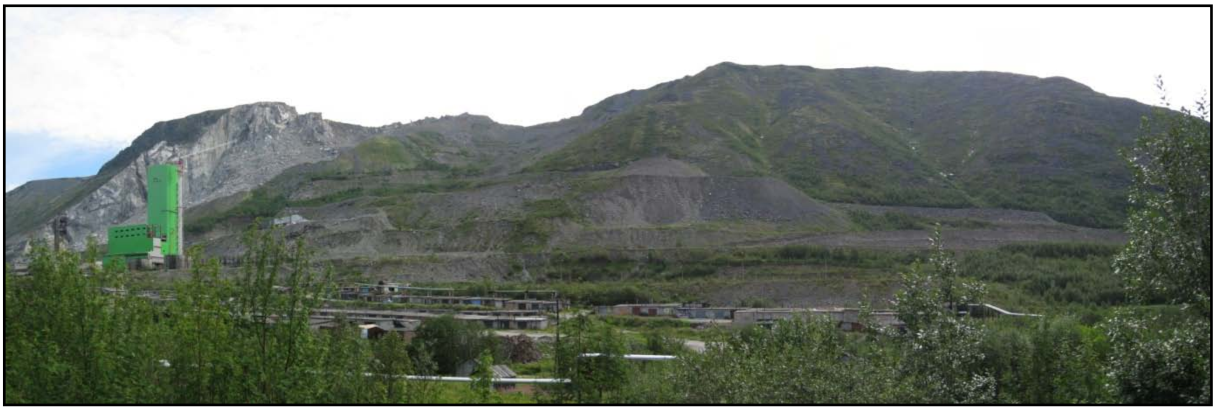

Figure 18: Studied avalanche paths on the northwestern slope (Fuchs 2011)

3.4.2 Aspect

The aspect of a slope is another key factor in avalanche formation, affecting the intensity of an incoming solar radiation on the slope and wind loading on a snowpack. The aspects of the studied slopes are presented in Figure 19, where the majority is fallen to the southwestern and northwestern exposure.

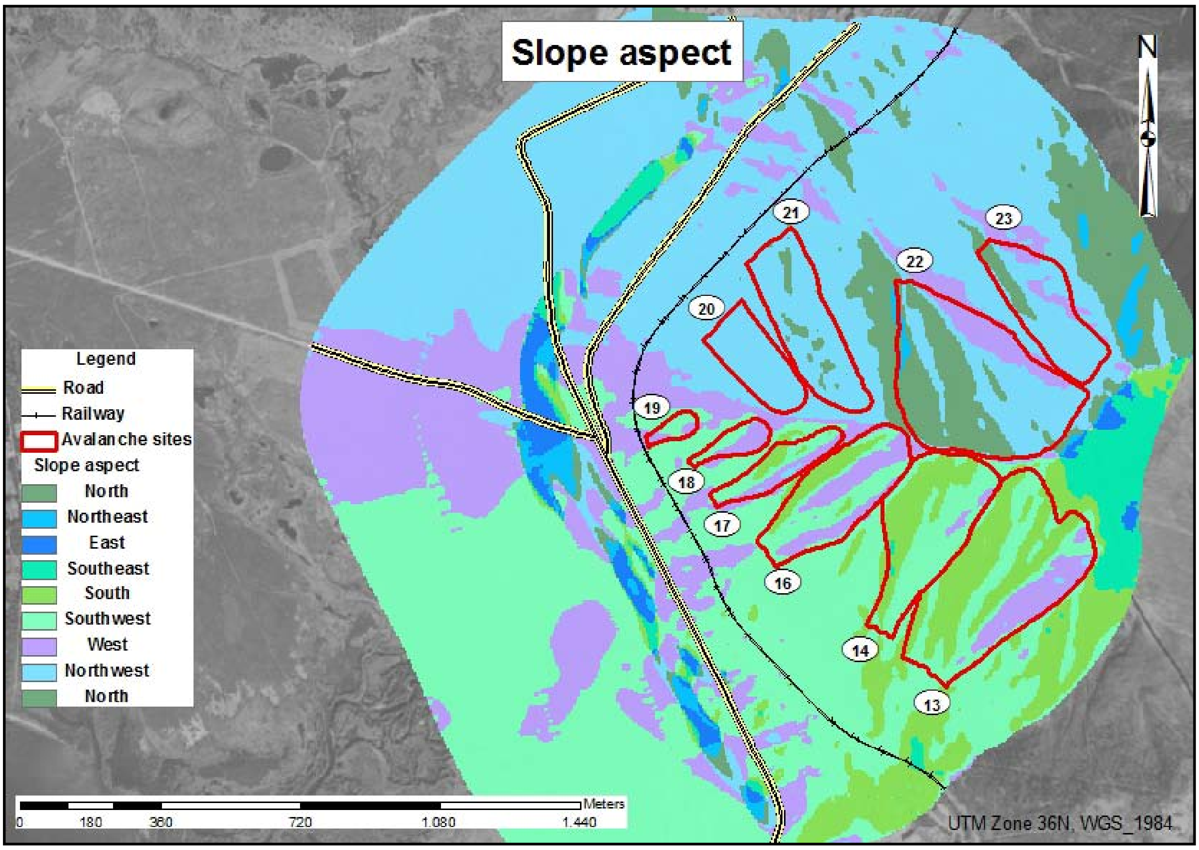

Figure 19: Aspect of the studied slopes

Despite the fact that the role of aspect in arctic latitudes is not nearly as important as at mid latitudes, the different exposure plays a significant role in avalanche propagation in spring time and should be surely considered for road and railway closure, as well as for artificial triggering of avalanches (Margreth et al. 2003).

The amount of the total solar radiation in the Khibiny Mountains is presented in Table 6 (Zyuzin 2006). The recorded total solar radiation has a slightly increase in values for steeper slopes on the south-facing slopes; for the slopes facing north, west and east directions it is the opposite.

Table 6: Amount of the incoming radiation for the slopes in the Khibiny Mountains [kcal/cm^2]

Month	2	3	4	5	6	10	11
Southern slope							
10°	1	4.4	8.6	11.5	13.2	2.2	0.3
30°	1.5	5.5	9.7	12.1	13.4	2.8	0.4
50°	1.8	6.3	10.1	11.2	12.4	3.3	0.4
Northern slope							
10°	0.6	2.6	6.3	9.8	11.7	1.3	0.2
30°	0.6	1.7	3.9	7.3	10.2	1.2	0.2
50°	0.5	1.4	2.9	4.9	6.8	1	0.2
Western and Eastern slopes							
10°	0.8	3.5	7.6	10.8	12.3	1.8	0.2
30°	0.8	3.4	7.4	9.6	11.8	1.7	0.2
50°	0.7	3.2	6.9	9.1	10.7	1.6	0.2

3.4.3 Roughness

Roughness in the investigated avalanche paths does not differ considerably. Figure 20 demonstrates the avalanche paths on the southwestern slope of the Yukspor Mountain after the snow has already melted, pointing out the most concave places with the maximum possible snow accumulation.

In general, roughness can be characterized as one consists of a rocky surface covered by moss, lichen and bushes in an upper part, followed by forest in a lower part. The forest vegetation covers the investigated foothills up to 300-450 m a.s.l. depending on the slope exposure; exceptions are the avalanche paths 22 and 23, which have no tree vegetation.

The forest vegetation belongs to the type of northern taiga, and is mostly formed by birch (*Betula* ssp.) with a little inclusion of spruce (*Picea* ssp.).

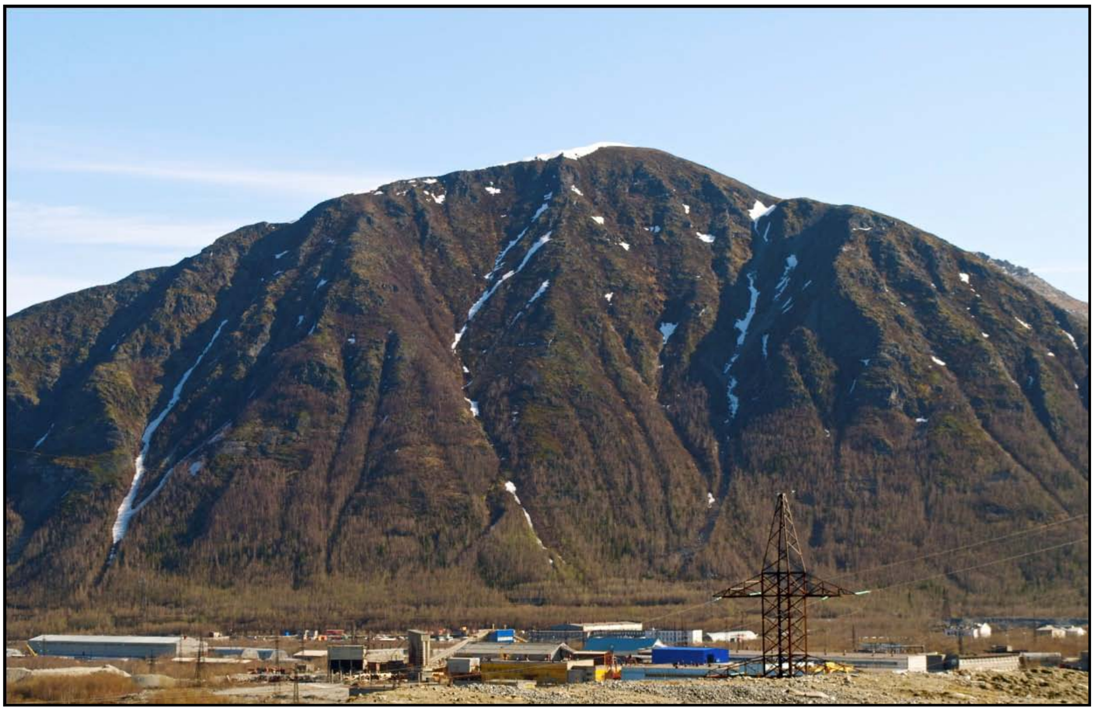

Figure 20: Avalanche paths in summer with the observed vegetation cover (Pukhtel 2012)

3.4.4 Anthropogenic changes of the relief

As it was stated above, one of the study slopes is situated within the mining area. Thus, a distinctive anthropogenic effect can be found there. However, the avalanche sites included in the investigation are not under heavy pressure at the moment. The alteration of the topography takes place to the north of the avalanche path 23, having completely changed avalanche path 14 in the last forty years. The only possible effect of the mining activities for the selected avalanche paths in terms of hazard potential is seismic loadings, which occurred from the open pit and underground mine explosions. This impact will be not covered in the present research, leaving apart the artificial component in avalanche triggering.

3.4.5 Summary

Results of the studies in the Khibiny Mountains have shown the significance of the following meteorological factors for release of avalanches that hit the traffic axes:

- snowstorm activity;
- precipitation;
- temperature, which is especially important during spring thaws.

Another important parameter correlated with avalanche release is accumulated snow on the ground, expressed as total snow height [cm]. This value could be a good indicator if it has been recorded closer to avalanche sites. Whereas, the data on total snow heights, observed at the "Central'naya" meteorological station, can only provide a rough idea of possible snow accumulation in the study area.

3.5 Methodology: development and adjustment

The proposed methodology aims to evaluate the dynamics in avalanche risk. The assessment was tailored to two main components: change in avalanche hazard and spatio-temporal development of assets at risk. The methodology is grounded on the approach developed by Wilhelm (1998) and follows local-scale studies, implemented for the traffic axes in Europe (Kristensen et al. 2003; Hendrix and Owens, 2008; Wastl et al. 2011). The analyses are carried out for the road and railway sections in the Khibiny Mountains (see chapter 3.1) and account only for avalanche risk, neglecting other risks from natural hazards in the area. The performed analyses were done for the current situation with consideration of present infrastructure and settlement arrangement and existing protection measures.

The main goal is towards the adaptation of the transferred methodology for specific functions of traffic routes, different climatic settings and data availability. The obtained results intend to highlight the significance of the dynamics in avalanche risk assessment and reflect the realistic situation in the area in terms of avalanche situation and avalanche risk. Moreover, findings of the research are a proper foundation for risk-based road management, introducing a new approach in Russia.

For the stated purposes, the risk assessment is done in two different timeframes:

- long-term risk assessment (temporal resolution of year);
- short-term risk assessment (temporal resolution of day).

The possible variables and limitations of the proposed methodology are:

1. the performed risk assessment was done for dry snow avalanches, which are the majority of snow avalanches in the area;
2. the simulation of avalanche dynamic parameters by the ELBA plus model was done only for dense flow, while powder part was not considered in the hazard potential calculations;
3. the methodology accounts for spontaneous natural snow avalanches and neglects the artificially triggered avalanches;
4. the short-term risk assessment is done for the railway section.

3.5.1 Research data

The study is based upon both digital data and detailed avalanche records from the avalanche cadastre produced by the CAS. The input data for the project includes:

- avalanche cadastre records with detailed information of released avalanches;
- records from the meteorological station “Central’naya” for the period from 1964 till 2012:
    1. mean daily temperature [ºC]
    2. mean daily precipitation [mm in water equivalent]
    3. type of precipitation
    4. duration of snowstorms [h]
    5. duration of sunshine [h]
- snow depth measurements at the meteorological station “Central’naya” between 1997 and the beginning of 2012;
- snow height observation measured for the avalanche sites 13-23 measured on snow stakes for the avalanche season 2010-2012;
- information about wind direction and wind speed during snowstorms measured at the “Central’naya” meteorological station for the period between 1997 and 2011;
- georeferenced topographic map for the area at the scale of 1:50,000;
- georeferenced satellite image from IKONOS with a resolution of 0.8 m for the study area;
- digital contour lines for the slope of interest with intervals of 5 m;
- information about socio-economic indices in the region:
    1. vital statistics for the period 2007-2015
    2. economic statistics for the period 2007-2010

3. tourist season and tourist flow for the period 2007-2010
4. development plan for the city 2012-2014

- daily traffic density for the road section.

The input data concerning location of traffic routes and other elements at risk was derived from topographic maps and was checked along with the recent satellite image because of the steady changes in the area. The data about the terrain was acquired by field observation coupled with analyses of the DEM, produced from digital contour lines with interval of 5 m. This DEM provided the basis for modelling of avalanche processes and analyses of the specific physical characteristics of avalanche flow. The sources of data for the research are summarized in Table 7.

Table 7: Sources of data for the research

Type of data	Source
Avalanche cadastre (1968-2012)	Center of Avalanche Safety, JSC “Apatit”
Meteorological data, meteorological station "Central'naya" (1964-2012)	Center of Avalanche Safety, JSC “Apatit”
Blizzards, snow height, meteorological station "Central'naya" (1997-2012)	Center of Avalanche Safety, JSC “Apatit”
Data on snow heights, snow stakes (seasons 2010-2012)	Center of Avalanche Safety, JSC “Apatit”
Topographic map (1:50,000)	Moscow State University, Faculty of Geography
Orthophoto for the area	Moscow State University, Faculty of Geography
Digital contour lines (interval 5 m)	Moscow State University, Faculty of Geography
Information on the tourist season and tourist flows (2007-2010)	Municipal Authority “Administration of Kirovsk town, Murmansk oblast”
Vital and economic indices (2007-2015; 2007-2010)	Municipal Authority ”Administration of Kirovsk town, Murmansk oblast”
Development plan for Kirovsk town (2012-2014)	Municipal Authority ”Administration of Kirovsk town, Murmansk oblast”

3.5.2 Risk assessment

To calculate risk and consequently to evaluate the direct effect of avalanches on the endangered elements, the studied railway and road were divided into sections according to avalanche sites situated above to illustrate the prioritized stretches.

3.5.2.1 Avalanche situation

Analysis of the registered events shows that during the observation period 94 avalanches hit the transport axes. The majority are represented by small (volumes ≤ 25,000 m³) dry snow avalanches, which can block the railway with more than 2 m of snow (in the extreme cases a blockage of up to 4 m may occur).

A comparison with meteorological conditions shortly before and on the day of release revealed that:

- 87.5 % of naturally released avalanches hit the railway or/and road released during or one day after heavy snowfalls and a blizzards;
- 10 % originated without the contribution of heavy snowfalls and usually happened due to blizzard activity;
- 2.5 % occurred under temperatures different from mean in the previous days, being usually avalanches of long-term development (metamorphism) in the old snow cover.

Besides, the classification of the analyzed avalanches according to the position of a sliding surface is presented in Figure 21.

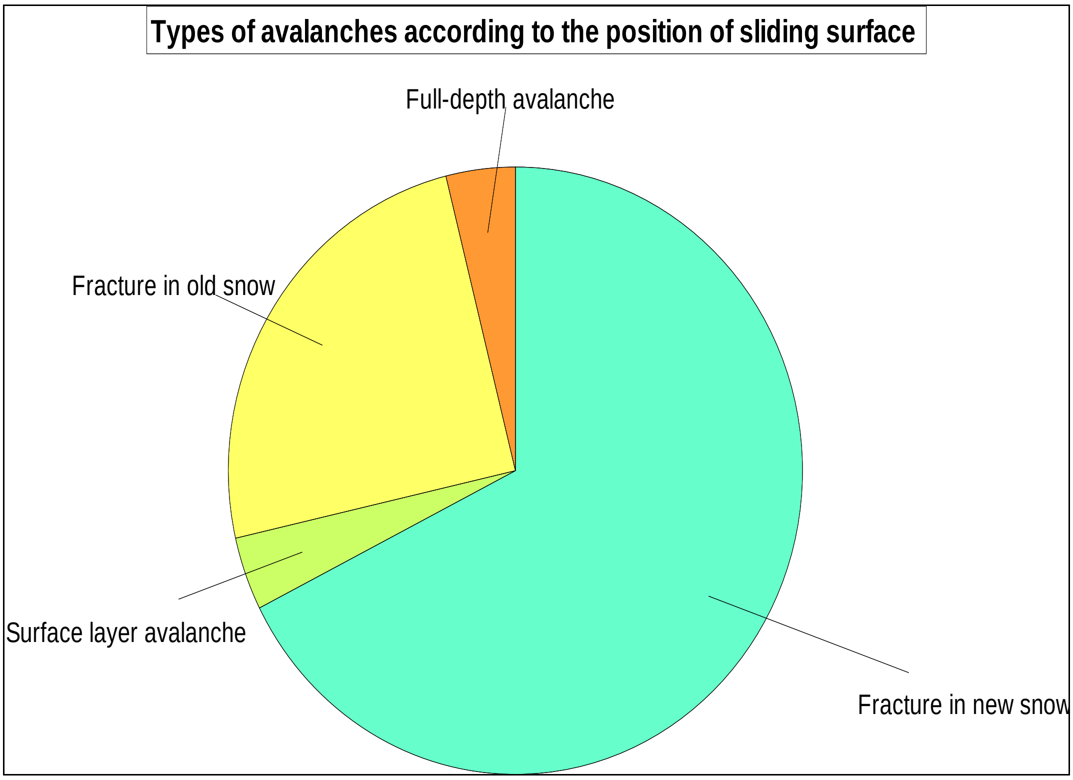

Figure 21: Types of avalanches that hit the traffic axes according to the position of sliding surface (Avalanche cadastre)

The artificially released avalanches (14 avalanche events in total) were excluded out of consideration, assuming that the mortar shooting is an additional and in some cases the main factor to affect the snow stability.

Spatial and temporal distribution of avalanche release varies among the studied avalanche paths and within the avalanche hazardous period[6]). To illustrate these flactuations, the recorded avalanche events were subsequently analyzed with respect to:

- number of avalanche events (total number of avalanches registered for every avalanche site, number of avalanches hitting the traffic axes);
- seasonal dynamics;
- possible diurnal changes in avalanche release based on different genetic types and slope expositions.

Figure 22 illustrates the distribution of avalanches for an individual avalanche path.

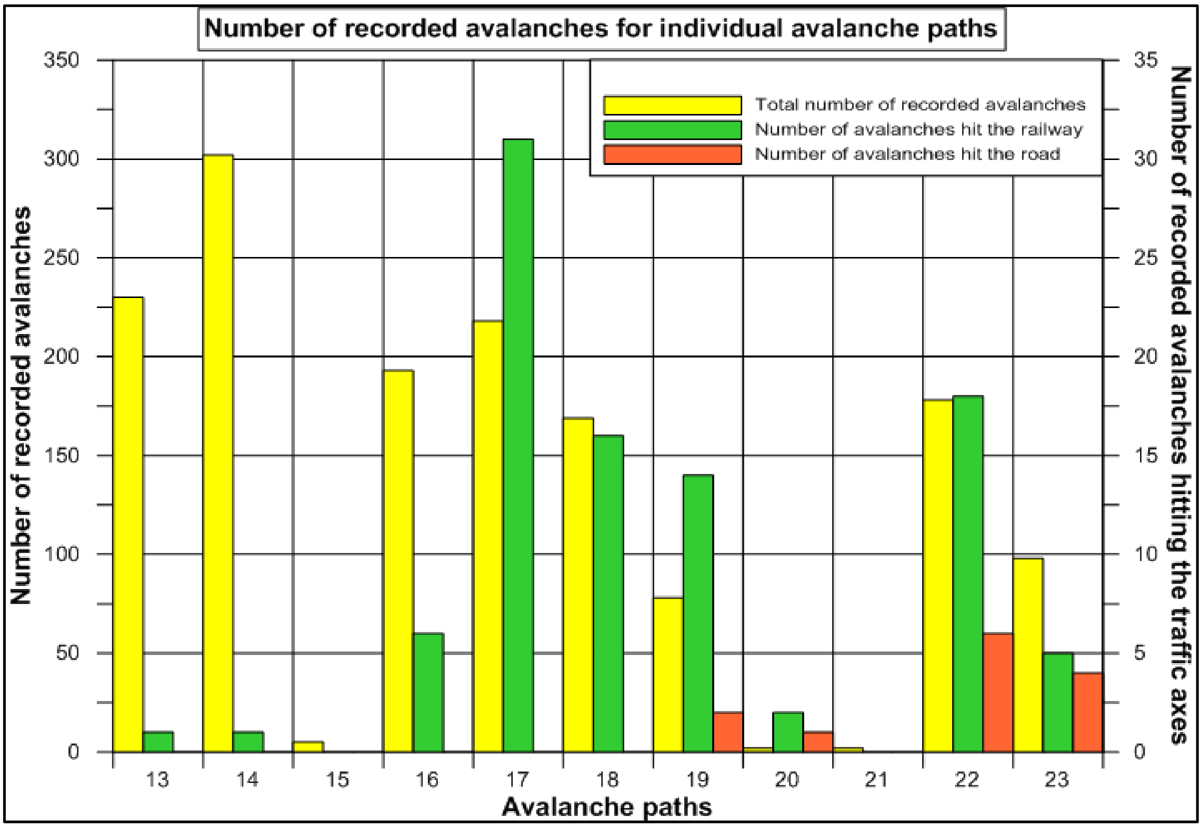

Figure 22: Number of avalanche events in a single avalanche path for the time period 1965-2011

[6]According to avalanche cadastre developed at the CAS, the avalanche hazardous period in the area lasts from October to mid June.

The evaluation denotes the avalanche paths 13 and 14 as those with the maximum number of the avalanches released within the period of observation. In contrast, avalanche paths 20 and 21 contribute the minimum numbers of total avalanche accidents. The most “active” avalanche path in terms of number of avalanches hit the railway is path 17, while the maximum number of avalanches hit the road has been registered from the path 22.

With respect to seasonal fluctuations, two distinct peaks can be allocated depending on the type of avalanches and local meteorological conditions:

- the first peak is associated with the heavy snowstorms in January and February;
- the second peak coincided with the increase of air temperature and solar radiation in March and April.

These peaks can be clearly observed in the temporal variability of avalanche release, both for the total number of recorded avalanche events and for the sample of avalanches hitting the traffic axes (Figure 23 and Figure 24).

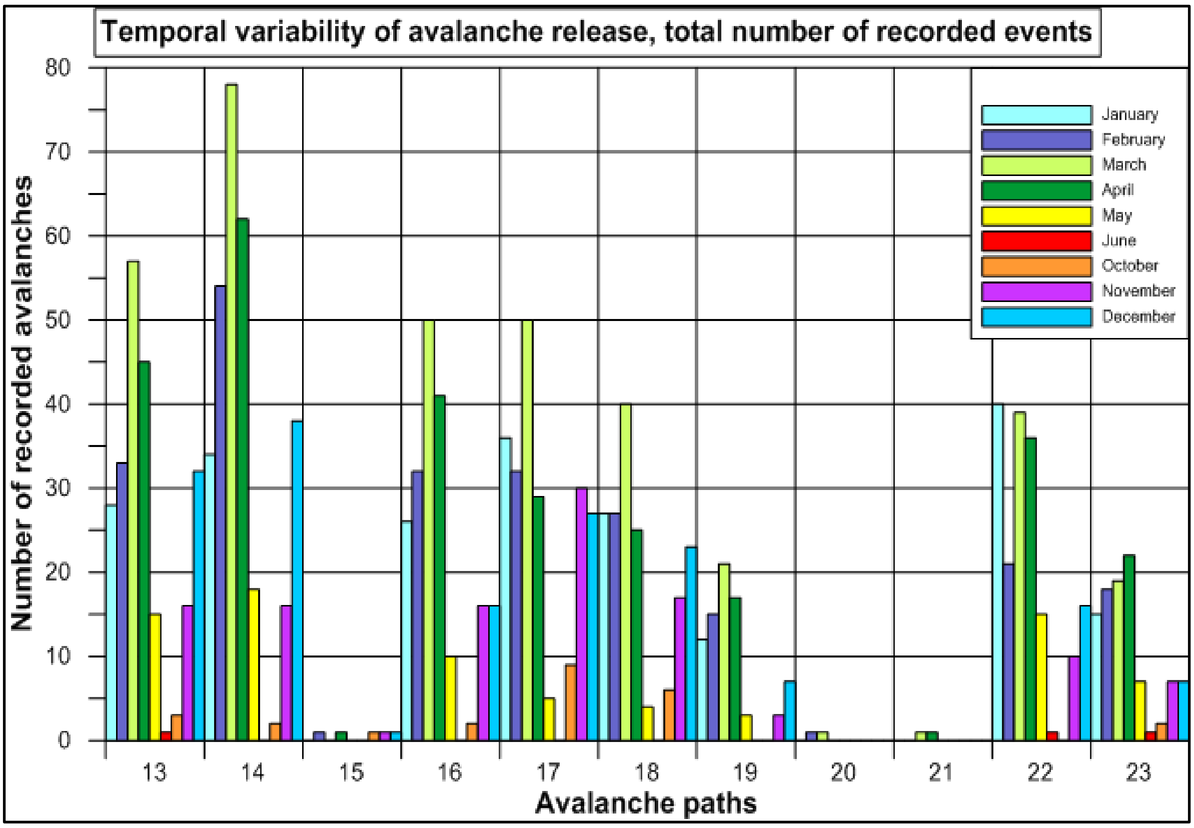

Figure 23: Temporal variability of avalanche release for the time period 1965-2011 (total number of the recorded avalanche events)

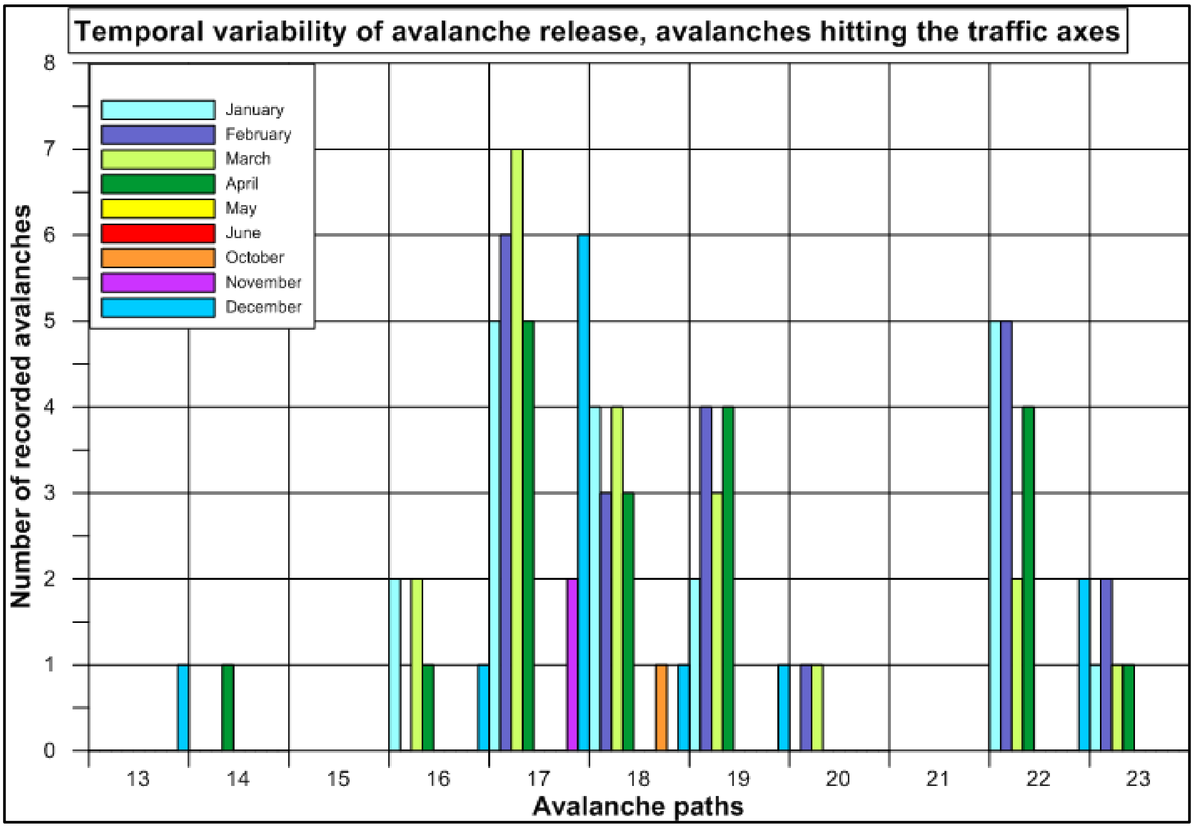

Figure 24: Temporal variability of avalanche release for the time period 1965-2011 (avalanches that hit the traffic axes)

In every case, the largest number of the released avalanches was associated with the stated peaks:

- in terms of frequent avalanches, there is a predominance of spring release for all the avalanche paths (despite the exposition);
- for large events, which block the transport axes in the run-out, spring peak is of equal significance except for the paths with northwestern exposition.

Diurnal changes of avalanche release time are presented in Figure 25. It is evident that avalanche releases mostly contribute to the period with the highest traffic values, increasing the damage potential. Moreover, it is apparent that the observed avalanches on the northwestern slope occurred mostly in a day time. The possible reason can be that most of the recorded avalanches hitting the traffic routes were artificially triggered, and thus were released during a day time under good visibility conditions.

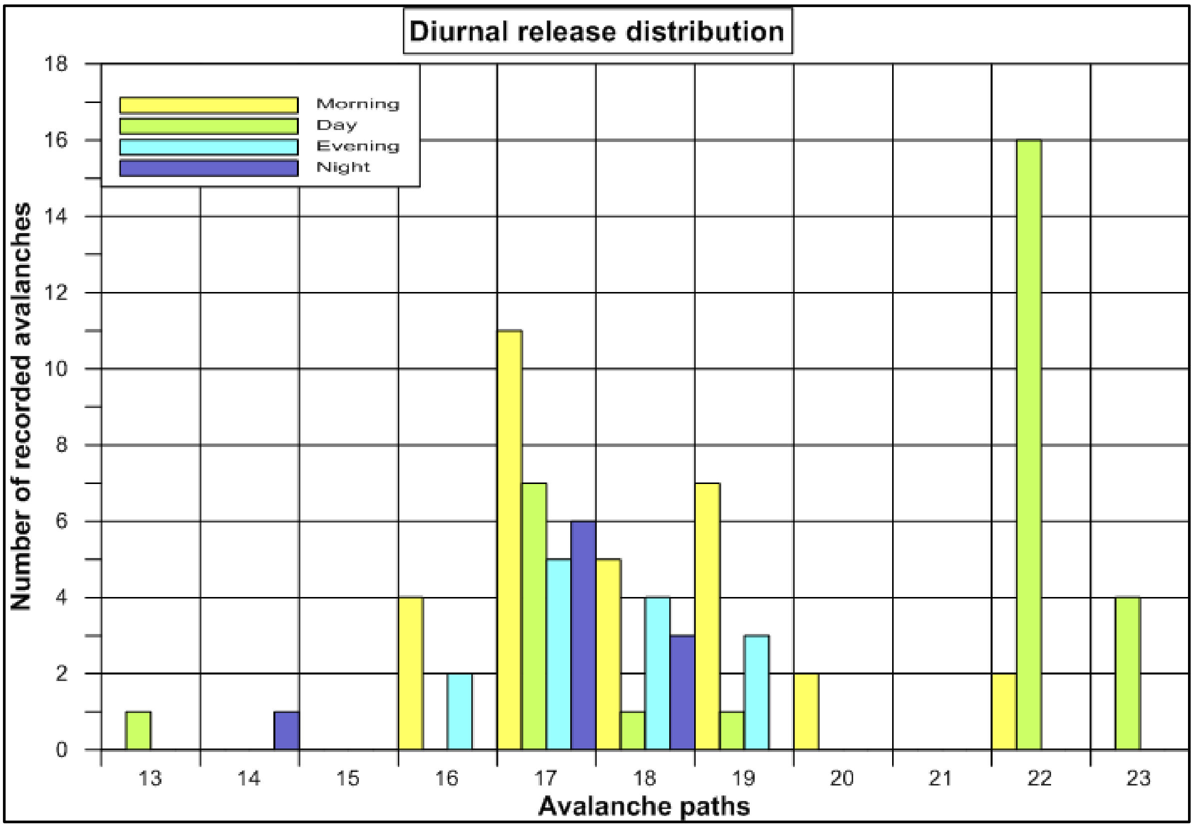

Figure 25: Diurnal distribution of avalanche release for the time period 1965-2011 (avalanches that hit the traffic axes)

3.5.2.2 Damage potential

Damage potential for this case study is addressed separetely for the road and railway sections due to different functions of these transportation routes.
The studied road is not a pass road in the valley but serves as:

- traffic artery between town districts;
- major route to the sanitarium for the employees of the JSC "Apatit";
- transport of workers to the mine and factory complex, situated on the northwestern slope of the Yukspor Mountain.

The key objectives corresponding to the resultant damage potential are the number of endangered persons (human lives are approached as elements at risk) and their distribution in space, represented by a traffic density (Wilhelm 1997; Borter 1999a,b; Zischg 2005a). For the investigated road section no traffic data was available. Thus the traffic density was calculated in-situ, during one week for different time intervals to include possible variations in transport flow on weekends. The output takes into account traffic for different time stretches in both directions with total number of vehicles (including private cars, buses, mini buses and special transport for mining) and passengers passing along the studied slope (the detailed calculation is presented in Appendix E).

The studied road can be characterized as one with a high intensity of traffic during the day. Figure 26 presents the overall statistics, highlighting the highest peaks in traffic density in the morning, after midday and in the evening with a successive decrease after the end of working day. The same tendency is observed in terms of total number of passengers, where the peaks are correlated to the work flow to the town and the shifts at the mine during the day. The shifts at the mine are:

- 7:00 - 13:00;
- 13:00 - 19:00;
- 19:00 - 01:00;
- 01:00 - 07:00.

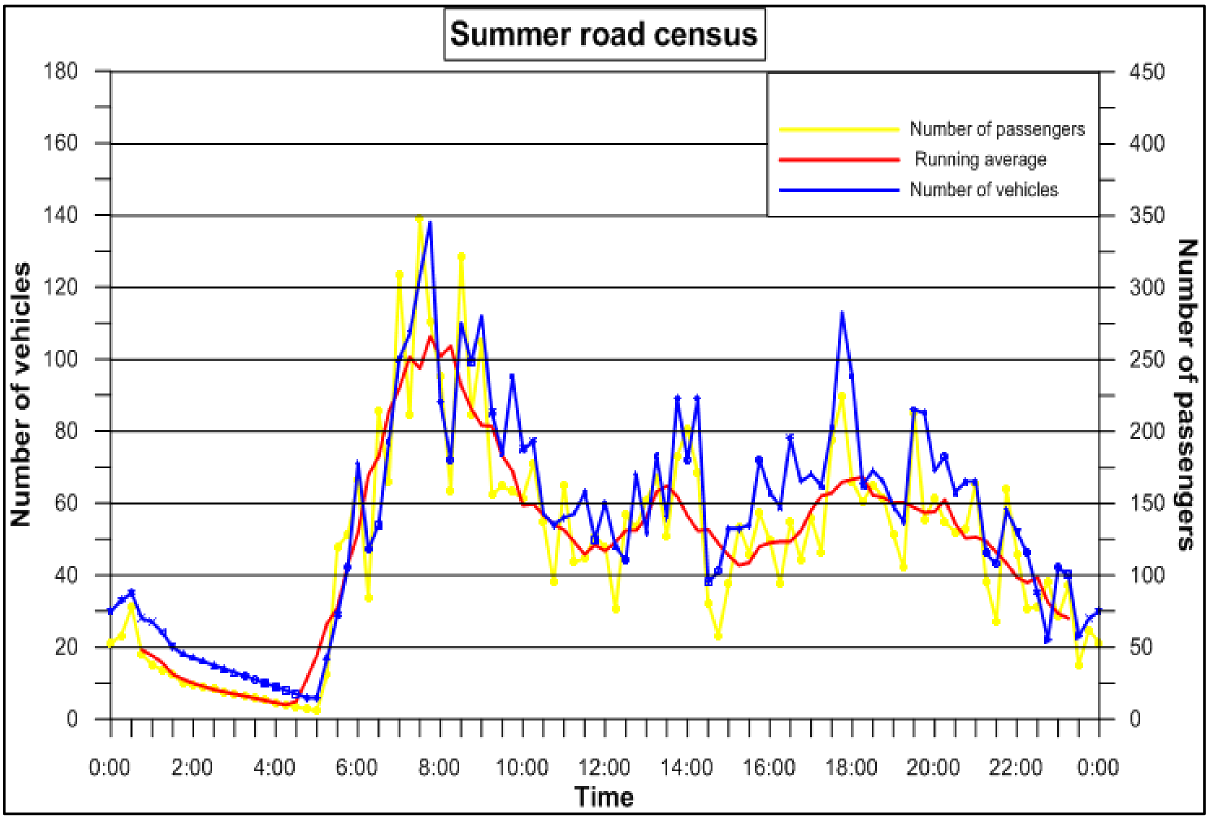

Figure 26: Traffic census for the road section for the summer season

While the peaks in total number of passengers are as following:

- 06:30 - 08:00;
- 13:00 - 14:00;
- 17:30 - 18:00 and 19:00 - 19:30;
- 00:30 - 01:00.

According to the results, the average daily traffic density and the occupancy rate for the summer road are:

- 5,295 vehicles per day;
- 2.2 persons/vehicle.

The mean speed of the vehicles was assumed as 60 km/h and is a constant along the studied road section.

The derived values were further adapted for the avalanche hazardous season (October - mid June). To obtain a realistic situation, the mean daily traffic was increased for the period November - mid May, which corresponds to the Alpine skiing, mountaineering and backcountry skiing season when the inspected road serves as:

- transport artery to access the ski touring and snowmobile touring areas in the Kukisvumchor valley;
- main route to the Kukis slope for off piste and Alpine skiing;
- main connection between the 23rd Kilometre Station and ski resorts (a case for those Alpine skiers renting the property in the 23rd Kilometre Station).

According to data in Table 8, the sum of the highest recorded daily numbers of tourists for all categories provides the maximum expected daily increase in passengers for a high season. The maximum number of the Alpine skiers implies that about one third out of the observed daily maximum could possibly use the road, including those tourists, who:

- rent accommodation in the 23rd Kilometre and use the road to get to the ski resorts in Kirovsk town;
- ski on the Kukis Mountain slopes and use the road to get to the ski area.

However, the biggest proportion of the tourists are accommodated in Kirovsk town in the vicinity of major ski resorts (“Local Tourist Information Center”, expert assessment).

Table 8: Tourist flow (Vikulina 2009)

Category of activity	Annual maximum [persons]	Season (peak season)	Maximum [persons/day]
Alpine skiing	10,000	November - May (New Year, February, beginning of May)	1,500 Ski resort, end of March
Ski touring	8,000	November - May (end of January-April)	500 Kukisvumchor valley, end of March
Snow mobile tours	1,000	December-May (New Year, February-May)	100 Kukisvumchor valley, March
Off piste, crosscountry skiing	500	Mid February - mid April	40 Kukis slope, end of February
Mountaineering	300	February - May (March-April)	30 Ganeshin cirque, beginning of April

Taking into account the stated facts, proposed number of tourists and previously calculated mean occupancy rate, mean daily traffic during the hazardous season or winter daily traffic is increased by 8% in average and equals 5,714 vehicles/day.

According to local conditions (polar twilight phenomenon) and most probable travelling time of tourists, the day is divided into two time stretches:

- “active” period from 08:00 till 19:00 with an increase in traffic of 10%;
- “passive” period from 19:00 till 08:00 with traffic increased by 5%.

This calculation provides a possible winter daily traffic density for the studied road, which is presented in Figure 27. Analyzing the given traffic distribution, the major input contributes to the flow of employees between two town districts. The highest number of passengers originates from the transportation of workers to mine facilities or factory and depends on the schedule of shifts.

The peak number of vehicles correlates more with the general working time and is observed in the morning, in the lunch break and in the evening. Whereas tourist activity plays a secondary role at the moment, being responsible for a slight increase in traffic during winter time.

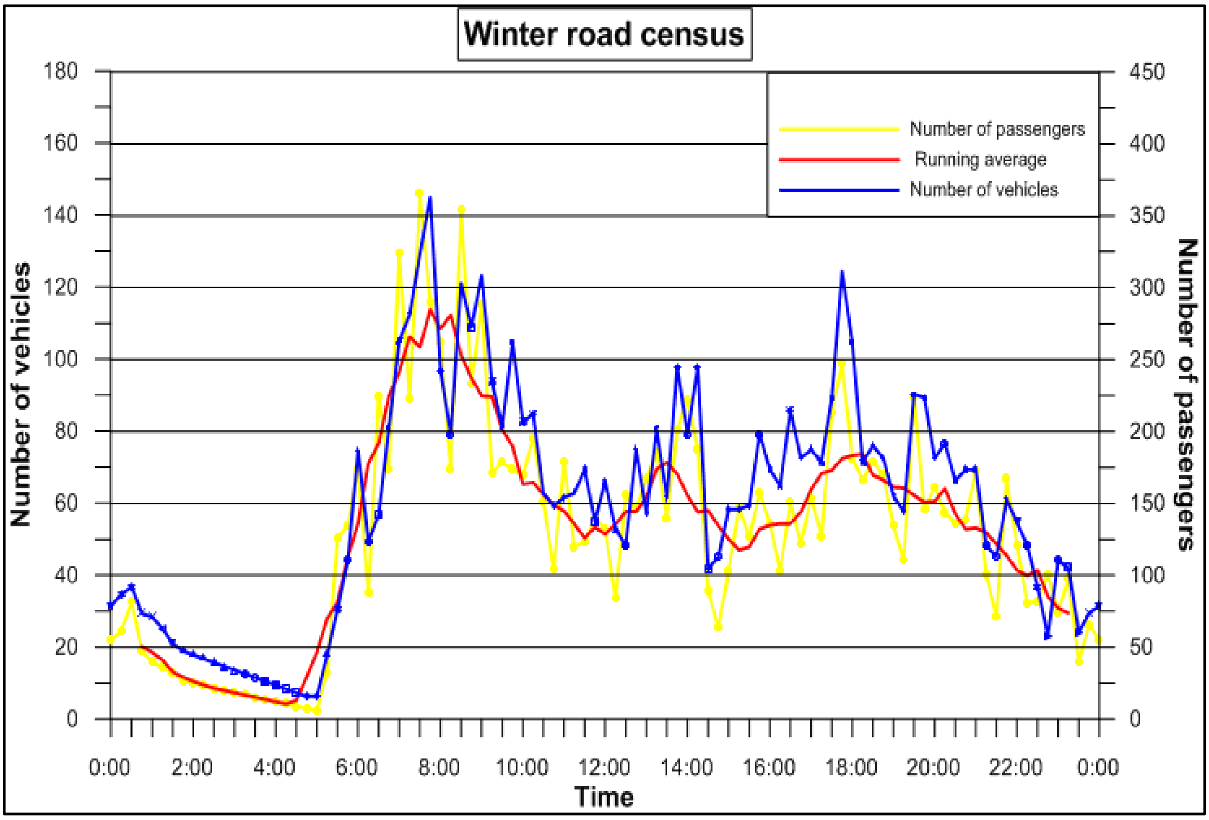

Figure 27: Traffic census for the road section for the winter season

In contrast, for the railway section damage potential is approached as total economic losses in the case of a specific avalanche situation. The railway is an additional single-track branch line, used for fuel and ore transport to the factory. It is planned to become a main route for ore transportation in the near future due to planned restoration works for the tunnel (Chernous 2012, personal communication). Following this development plan, damage potential for the railway is calculated in accordance with the schedule of ore transportation, which was assessed during the field season 2012:

- one full train to the factory every hour;
- one empty train to the mine every hour.

The implemented method accounts for direct losses including the monetary value of the transported ore and the cost of the train itself, as well as for indirect losses as a possible profit of the mining company. Figure 28 presents a typical freight train for ore transportation. The train is built of 25 open carriages with a maximum capacity of 105 tonnes of ore per carriage resulting in 2,625 tonnes of material in total.

Figure 28: The freight train with ore (Pukhtel 2012)

3.5.3 Hazard modelling

The modelling part of the work aims to determine the maximum run-out distances and the width of the railway/road blocked by a given avalanche. The 2D model “Elba plus” was selected to fit the stated purposes. The simulation model, with its initial focus on the dense flow avalanches, relies upon the modified version of the Voellmy model for friction calculation. The modification refers to the variable in time and space turbulent friction coefficient (ξ), which is calculated with an adapted Colebrook-White equation (ELBA plus HANDBUCH 2005).

$$a = g\left[(sin\,\psi - sign(v) \times \left[\mu \times cos\,\psi + \frac{v^2}{\xi \times h}\right]\ \right] \qquad (3).$$

$$\xi = 8g \times \left[-2 \times log\,10\left[\frac{k_s}{12h}\right]\right]^2 \qquad (4).$$

a - acceleration of the avalanche [m/s²]

g - gravitation [m/s²]

h - flow height [m]

k_s - roughness length [m]

μ - dry friction parameter []

ψ - slope angle [°]

v - velocity [m/s]

ξ - dynamic friction parameter [s^2/m]

The selected dynamics model was calibrated by back calculation of the extreme snow avalanches[7] observed at every avalanche path. The focus of the calibration was on a maximum possible fit of the modelled avalanches with the observed events by two criteria:

- the maximum run-out distance;
- the width of the railway/road blocked by a certain avalanche.

The major input parameters required for the calibration of the model are represented by:

- release area(s);
- fracture depth;
- friction coefficients;
- snow entrainment;
- roughness of the terrain;
- snow density (for the release area, for the flowing phase and for the entrainment).

The release areas were digitized using the information about the recorded avalanche events from the avalanche cadastre, such as: the highest release and the lowest deposition altitudes; the maximum width of the avalanche front; as well as sketches of the observed avalanche events (for the most catastrophic avalanches). The lateral extent and possible lower boundary of the release areas were checked with the topographic map and high resolution IKONOS image.

As an input fracture depth, values of the maximum fracture line thickness from the cadastre were used, being the most reliable data, in order to avoid unreliable assumptions about possible snow accumulation in the avalanche sites. The maximum fracture depth of 3 m was

[7] To meet objectives of the study, extreme events were allocated by the longest recorded run-out distance.

recorded for the avalanche site 22, while the average for all the sites was about 1.5 m. The smallest values corresponded to avalanche sites 18 and 20.

In terms of the friction coefficients, the ELBA plus model offers a possibility to adjust the dry friction parameter (μ), which is either constant or variable depending on the model chosen. For the calibration procedure the modified Voellmy model with constant dry friction (μ) was selected, as one provided the best fit for the run-out distances under the set of applied parameters. The calibration of the dry friction parameter (μ) was done on the basis of the Swiss Guidelines (SLF 1999) for the parameters, such as:

- size of the recorded avalanches, represented by volume;
- type of the path in the tranzit zone (unchannelled; channelled; gully).

The return period has been roughly estimated based on the recurrence interval of the events that hit the traffic routes during the period of observation, as no records are available for the period prior to the settlement establishment. Thus main focus during calibration was on the avalanche path type and the avalanche volume.

According to the mass balance law, volume of the modelled avalanche events was aimed to be equivalent to the volume of deposition of the recorded avalanches, assuming rather high entrainment rate and growth of the volume due to the entrained snow. An exception was made for small avalanches (volume less than $2*10^3$ m^3), where in some cases the released volume was modelled two times larger than the deposited, assuming that avalanche did not show erosion of snow in the avalanche path (Barbolini and Cappabianca 2002).

The analysis of planar curvature for the possible starting zones (slope angle in a range of 30° (28°) to 50°) is presented in Figure 29, adopting the recommendation used for the RAMMS simulation model and is classified as:

- open slope;
- channel;
- gully.

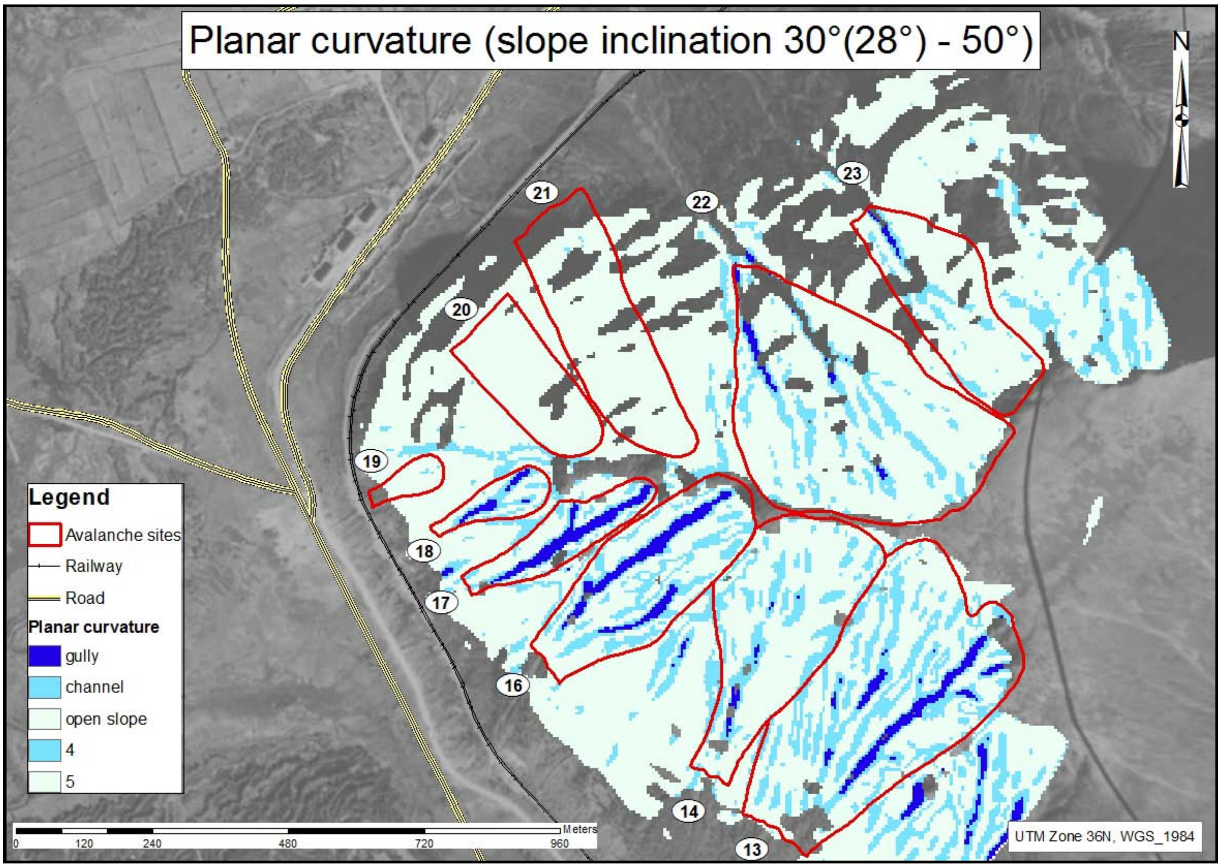

Figure 29: Planar curvature of the possible release areas

The resultant values derived for the studied avalanche paths during the calibration are:

- 0.2 for the channelled avalanches of a mean size (25,000 - 60,000 m³), which typically occur on the northwestern slope of the Yukspor Mountain;
- 0.2 for the open-slope avalanches of a small size (< 25,000 m³);
- 0.25 for the channelled avalanches of a small size (< 25,000 m³);
- 0.3 for the gully avalanches of a small size (< 25,000 m³).

In all of the cases, the determined values of the dry friction parameter (μ) are lower than the values recommended for the respective conditions by the Swiss Guidelines (SLF 1999). However, they lie in a range of values practically used for dense flow avalanche modelling in Switzerland, summarized by Gubler (2013) (see Appendix F). The default values of the friction parameter (μ) equals 0.155 and the entrainment rate of 0.1 m provided good fit for channelled avalanches exceeding volume of $1*10^3$ m^3 in terms of the width, but demonstrated short run-outs. Besides, the above-cited values were not applicable for very small avalanches with volumes less than $1*10^3$ m^3.

Apart from the friction parameter, another important factor found to be influential in the calibration process, was a snow entrainment rate. It greatly affects the mass balance of a snow avalanche and the behavior of a flow. Generally, entrainment depends on the depth of erodible snow in the avalanche path to a proportion from 0.5 to 0.75 of the release depth (Sovilla 2004), depending on the size of an avalanche and local snow conditions. The bigger is the avalanche, the more snow can be picked up in the avalanche path (Volk and Kleemayr 1999); in extreme cases avalanches can entrain new snow cover nearly to the whole depth (Barbolini and Cappabianca 2002). According to the size of avalanches, the applied entrainment rates were set as:

- 0.2 m for avalanches of a small size (< 25,000 m^3);
- 0.25 m for avalanches of a mean size (25,000 - 60,000 m^3).

The proposed entrainment rates fall in range of the recommended and practically applied values for the Austrian Alps (ELBA plus HANDBUCH 2005). Values for roughness, critical flow depth and snow density in different phases were kept as default in the model. The applied values for model calibration are listed in Table 9.

Table 9: Input parameters for the model calibration

Parameter	Value	Adaptation
Entrainment of snow [m]	0.2-0.25	adapted
Roughness []	0.1	default
Snow density in the release area [kg/m³]	200	default
Snow density in flowing phase [kg/m³]	300	default
Snow density in entrainment [kg/m³]	135	default
Dry friction coefficient μ []	0.2 - 0.3	adapted
Minimum flow depth [m]	0.1	default

To illustrate the applicability of the proposed values, simulation of two avalanche events of different volumes are given below. The first avalanche event was recorded in the avalanche path 18 on the 14^{th}-15^{th} March 1983 and is presented in Figure 30, being modelled with the adapted value of dry friction parameter (μ) of 0.3 and entrainment rate of 0.2. The recorded avalanche blocked the railway section for 60 m with the mean depth of avalanche deposits equivalent to 0.24 m and total deposition volume of $2.0*10^3$ m^3. The simulated avalanche is wider in the transit zone mainly due to topography. However, in the deposition the differences are not considerable, being 8 m wider than the observed event. The depth of the deposits in the area of railway blockage is also very close to the real values recorded.

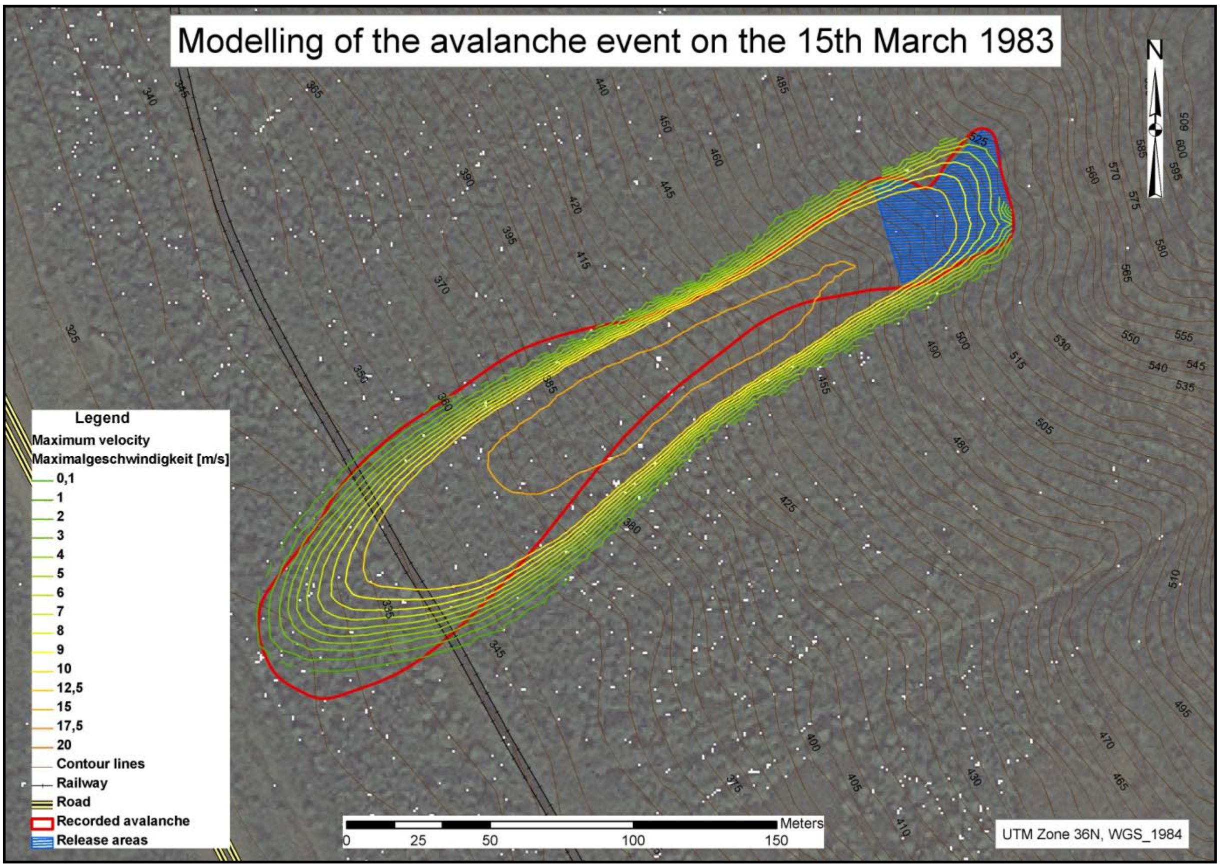

Figure 30: Modelling of the avalanche event on the 14th-15th March 1983

The second avalanche event happened in the avalanche path 23 on the 5th April 1985 and is presented in Figure 31; being simulated with the adapted value of dry friction parameter (μ) of 0.2 and proposed entrainment rate of 0.25 m. The recorded avalanche had deposition volume of $36.6*10^3$ m^3 and blocked the railway section for 133 m, and the road section for 120 m. According to the avalanche cadastre this avalanche event was released after a heavy snowfall and blizzard, which resulted in huge snow accumulation in the avalanche starting zone. The mortar shooting on this day was an additional impulse. The released avalanche had several fracture lines and was reported to entrain snow up to the ground in some areas. This information was used during the simulation procedure, where one major release area was designed with a total release volume of $32.3*10^3$ m^3; other fracture lines were taken into account by the increased entrainment. The modelled avalanche had a wider width of blockage for the railway, if compared with the actual event, being 165 m. For the road section the width of blockage was equivalent to the actual one (120-122 m), but shifted; while the depth of deposits were equivalent.

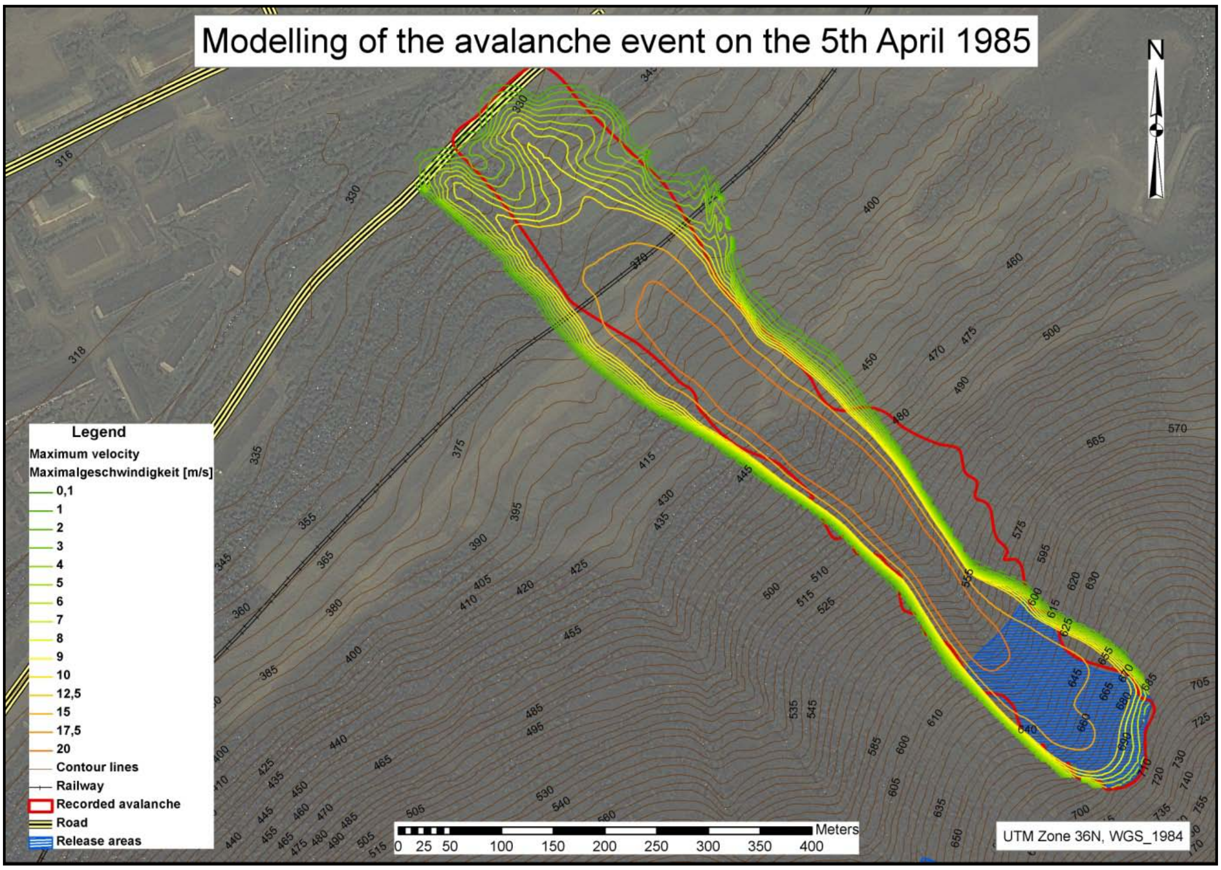

Figure 31: Modelling of the avalanche events on the 5th April 1985

Summing up, the model selected for the calibration could be used for the dynamics modelling of the avalanches of different volumes and various avalanche path types in the studied area. It provides fair results in terms of a run-out distance and a depth of deposition. The modelled width of blockage of the traffic routes is wider in most of the cases. To improve the results of model validation, return period can be incorporated for a more detailed calibration. In addition, for proper results of modelling the following should be considered:

- definition of the release zone(s) is fundamental for the three-dimension terrain;
- applied release depth is important in the light of a volume driven model;
- application of high entrainment rate shows numerical instabilities;
- width of the transit and deposition zones demonstrate a high dependency on the topography;
- model provides a wide run-out in the relatively flat terrain independent of the applied friction coefficient and simulation regime.

4. RESEARCH RESULTS

4.1 Long-term risk development

Long-term development of avalanche risk is based on general topographic and climatic conditions of a site. It is represented by mean risk and is based on a return period calculated from the number of documented historical events for every avalanche path. In the following study the long-term avalanche risk is expressed by:

- individual risk;

Selected as a criterion to judge on safety for different road sections and determine possible segments with an individual death risk exceeding the critical values.

- collective risk;

Collective risk, subsequently summed up for all avalanche paths, illustrates the overall avalanche hazard situation for the specific road. It is calculated based on the assumption that the studied road stays open during whole winter season.

- total economic losses for the railway under a specific scenario.

The total economic losses reflect the situation for the studied railway section, being calculated for both, indirect and direct losses. The resulted values are used as a foundation for the selection of mitigation measures from a cost-benefit perspective.

4.1.1 Individual and collective risk for the road section

Individual and collective risk is calculated for the road section following equation 5 and equation 6:

$$r = \frac{z}{24h} \sum_{i=1}^{n} \frac{g_i + t_{car}}{T_i \times v_i} \times \lambda_i \qquad (5).$$

$$R_o = \frac{WDT \times \beta}{24h} \sum_{i=1}^{n} \frac{g_i + t_{car}}{T_i \times v_i} \times \lambda_i \qquad (6).$$

g_i - mean width of road blockage in the avalanche path i [km]

t_{car} - stopping distance of a car [km]

v_i - mean speed of the car in the avalanche path i [km/h]

z - number of passages within a day for an individual person []

β - degree of occupancy [persons/car]

λ_i - mean death rate in cars involved in avalanches in the avalanche path i []

T_i - return period of the avalanche in the avalanche path i [years]

WDT - winter daily traffic [cars]

The stopping distance, added to an average width of avalanche blockage, is used to account for the vehicles that can not brake before collision (Kristensen et al. 2003). It is calculated by the methodology from the Inspectorate for Road Traffic Safety of Russia and is presented in the equation below, assuming the road is cleaned from snow (C = 0.7):

$$t_{car} = K \times v_i \times \left(\frac{v_i}{1000}\right) \times 254B \quad (7).$$

v_i - mean speed of the car in the avalanche path i [km/h]

B - coefficient for cohesion with a road []

K - braking coefficient []. K = 1 in the case of a car

Other input values used for computation are summarized in Table 10.

Table 10: Input values for risk assessment

Avalanche path	Number of passages	Mean width of blockage[km]		Braking distance [km]	Mean vehicle speed [km/h]	Mean occupancy rate [persons]	Mean death rate	WDT [vehicles]	
		Railway	Road					Summer road	Winter road
13	2	0.050	0.000	0.02	60.0	2.2	0.18	5,295	5,714
14	2	0.007	0.000	0.02	60.0	2.2	0.18	5,295	5,714
15	2	0.000	0.000	0.02	60.0	2.2	0.18	5,295	5,714
16	2	0.037	0.000	0.02	60.0	2.2	0.18	5,295	5,714
17	2	0.028	0.000	0.02	60.0	2.2	0.18	5,295	5,714
18	2	0.033	0.000	0.02	60.0	2.2	0.18	5,295	5,714
19	2	0.037	0.078	0.02	60.0	2.2	0.18	5,295	5,714
20	2	0.075	0.065	0.02	60.0	2.2	0.18	5,295	5,714
21	2	0.000	0.000	0.02	60.0	2.2	0.18	5,295	5,714
22	2	0.108	0.150	0.02	60.0	2.2	0.18	5,295	5,714
23	2	0.114	0.100	0.02	60.0	2.2	0.18	5,295	5,714

Taking into account the major function of the road as a connection route between two town districts, individual risk focuses on the commuters and adopts the hypothesis of two passages per day: a way from home to work, and a way back home. The mean death rate is grounded on the statistical data from the Swiss Alps derived for the period between 1946 - 1999 and is equivalent to 18% (Wilhelm 1997). Mean width of blockage for a single avalanche path was calculated based on the data in the avalanche cadastre and supported maps, as well as on the modelled width of blockage from the simulation model ELBA plus.

The avalanche hazardous period comprises of both, winter and summer seasons with different traffic values. Thus for a long-term risk evaluation, the average daily traffic was determined from the weighted input of both periods:

- winter daily traffic was used for the period from November till mid of May, corresponding to 6.5 months of the avalanche period (76.5%);
- summer daily traffic was used for avalanche-free period in October and time from mid May till mid June, embracing 2 months in total (23.5%). The input of the above-presented values results in a mean daily traffic of 5,587 vehicles.

The mean return period is calculated following the concept of the recurrence interval separately for road and railway and is shown in Table 11. For the avalanche paths with no documented events, the return period was assumed to be longer than the period of observation.

Table 11: Return period of avalanches for a single avalanche path

Avalanche path	Period of record [years]	Number of recorded events		Return period T[years]	
		Railway	Road	Railway	Road
13	46	1	0	46	> 46.00
14	46	1	0	46	> 46.00
15	46	0	0	> 46	> 46.00
16	46	6	0	7.67	> 46.00
17	46	31	0	1.48	> 46.00
18	46	16	0	2.88	> 46.00
19	46	14	2	3.29	23.00
20	46	2	1	23.00	46.00
21	46	0	0	> 46	> 46.00
22	46	18	6	2.56	7.67
23	46	5	4	9.2	11.50

The resultant individual and collective risks for the road section are illustrated in Figure 32. Generally, the studied road is impacted by four avalanche paths: avalanche path 19, 20, 22 and 23 with a corresponding number of the recorded avalanche events equals two, one, six and four.

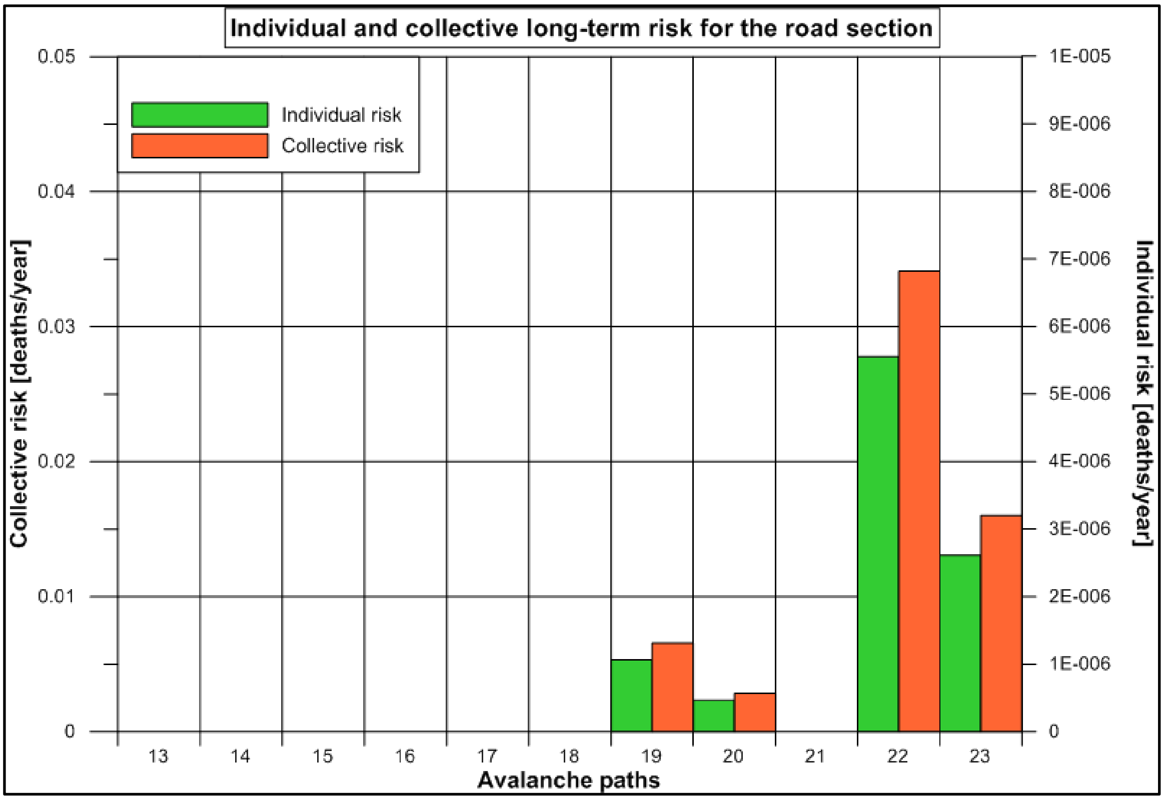

Figure 32: Individual and collective long-term avalanche risk for the road section

According to the Russian Ministry of Emergency Situations, calculated risk is classified as acceptable for the avalanche path 20, and as admissible for the avalanche paths 19, 22, 23 (Vorobiev 2005). The avalanche path 19 has an individual death risk equivalent to $1.1{*}10^{-6}$, which is slightly higher than the threshold value for an acceptable risk of $1{*}10^{-6}$. The calculated value for the avalanche path 22 is equal $5.6{*}10^{-6}$, being the highest value for the investigated road section; avalanche path 23 has a death risk of $2.7{*}10^{-6}$.

Cumulative collective risk for the studied road equals $5.9{*}10^{-2}$ fatalities per year, which would manifest as one death in 16.8 years, in other words. The major input in terms of calculated risks is done by the avalanche path 22 with values 12 times higher than the respective values of individual and collective risks for the avalanche path 20.

4.1.2 Long-term economic losses for the railway section

The calculation of total economic losses for the railway section is based on three major components:

- the hazard release probability;
- the annual probability of the freight train being hit by an avalanche;
- the consequences quantified in terms of value and vulnerability of elements at risks.

The likelihood of an avalanche release is presented by a inverse value of the mean return period T [years] for a single avalanche path. The probability of a freight train being hit is adopted from the proposal of Wilhelm (1999) and is reflected by:

- number of passages during the day (schedule of ore transportation);
- width of avalanche blockage for the railway;
- train speed.

Moreover, the train factor is included to account for the increased chance for a train to be hit by an avalanche, as the train length is higher than the width of an avalanche blockage. In mathematical form the evaluation is presented in equation 8.

$$R_{mon} = \left(\frac{z_{emp}}{24h} \times V_{emp} + \frac{z_{full}}{24h} \times V_{full}\right) \sum_{i=1}^{n} \frac{g_i}{T_i \times v_i} \times \gamma_i \qquad (8).$$

g_i - mean width of railway blockage in the avalanche path i [km]

u_i - mean speed of the train in the avalanche path i [km/h]

z_{full} - number of passages within a day for a full train []

z_{empty} - number of passages within a day for an empty train []

γ_i - parameter to account for length of the train (Bahnfaktor) []

T_i - return period of the avalanche in the avalanche path i [years]

V_{full} - monetary damage for the freight train with ore [RUB]

V_{empty} - monetary damage for the freight train without ore [RUB]

$$V_{full\ or\ empty} = C_{train} + C_{labour} \qquad (9).$$

C_{train} - cost of damaged carriages (assuming that they are not repairable) and ore [RUB]
C_{labour} - labour costs for technical service and snow cleaning up works [RUB]

In the case of an empty train, the economic losses for the train include only the cost of the damaged carriages and railway track maintenance.

γ_i – is the parameter to account for the length of the train (Bahnfaktor). The calculation of the factor is given in equation 10 below.

$$\gamma_i = \left(\frac{l_t}{b_i}\right) + 1 \qquad (10).$$

l_t - length of a train [km]
b_i - mean width of railway blockage in avalanche path i [km]

The consequences are evaluated on the scenario basis, addressing possible effects of the collision between a train and a snow avalanche with certain resultant losses. As it is discussed in the case study for Pass Lueg by Pürstinger et al. (2003), the major impacts of an avalanche flow from the horizontal impact are forces differentiated into (Figure 33):

- force resulting from the avalanche flow core (F_{dh});
- force resulting from the accumulated snow (F_{stau});
- force resulting from the backfilled snow.($F_{hinterfüllt}$).

The acting forces depend on several avalanche dynamic characteristics:

- avalanche impact pressure;
- height of an avalanche flow;
- avalanche velocity.

From the train parameters, weight and speed of the train play an important role for the consequences of a collision. A collision with an avalanche usually results in the breakage of several train wheelbases, the derailment of carriages and the railway track damage. In addition, the carriage(s) can be overturned when the overturning moment exceeds the resisting moment (Lindamood et al. 2003).

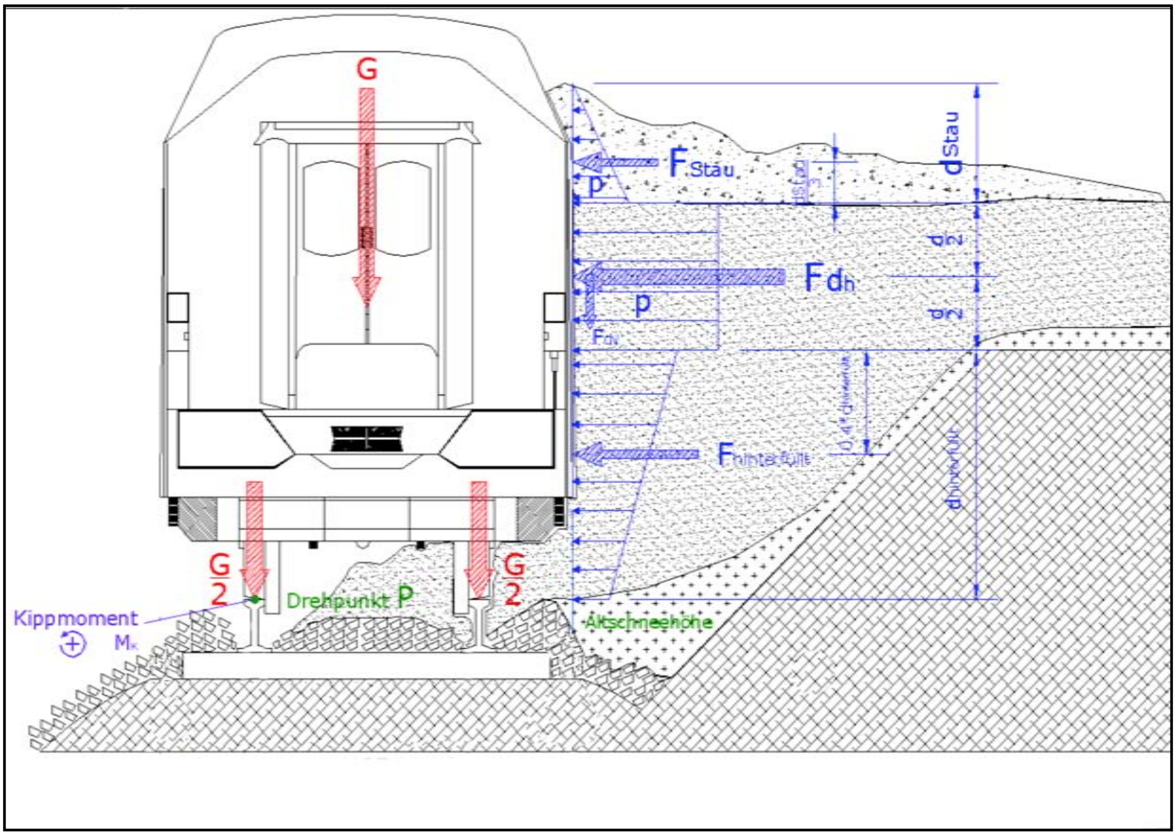

Figure 33: Sketch of a collision between a snow avalanche and a train (Pürstinger et al. 2003)

Following these statements, three scenarios are proposed[8]:

1. the worst-case scenario implies the assumption that several carriages are derailed, overturned and severely damaged; the railway track is destroyed because of the derailment. In the case of a full train, transported material is lost. The required technical service includes emergency response crew to uncouple the damaged carriages and to fix the railway track; the intact carriages are pulled away. Subsequently the railway snowplough is used for the snow removal operations from the railway track.
2. the average-case scenario assumes the situation that several carriages are derailed within the collision with an avalanche, but stay on the track and do not destroy it. Consequently, in the case of a full train, transported ore is not lost in the accident. The required technical service includes emergency response crew to uncouple the damaged carriages and to clean up the railway track. The intact carriages are pulled away. Subsequently the evacuation train rights the derailed carriages and pulls them away.

[8] The proposed scenarios do not consider the possible collision between a locomotive including a driver and a snow avalanche.

3. the average-case scenario, including indirect losses. It assumes the same outcome of the collision, when several carriages are derailed, but stay on the track and do not destroy it (transported ore is not lost in the accident). The required technical service includes emergency response crew to uncouple the damaged carriages and to clean up the railway track. The intact carriages are pulled away. Subsequently the evacuation train rights the derailed carriages and pulls them away. The consequences of the collision are quantified in an alternative way, including indirect losses for a better understanding of a real economic impact to the mining company. The indirect economic losses arise from the blockage of the railway track by the hit train and suspension in the ore dressing at the factory, applying minimum number of trains that are blocked.

The computed evaluation accounted for one type of carriages; carriage type “2BC-105” is typically utilized for ore transportation in the area. The sketch of the carriage is given in Figure 34.

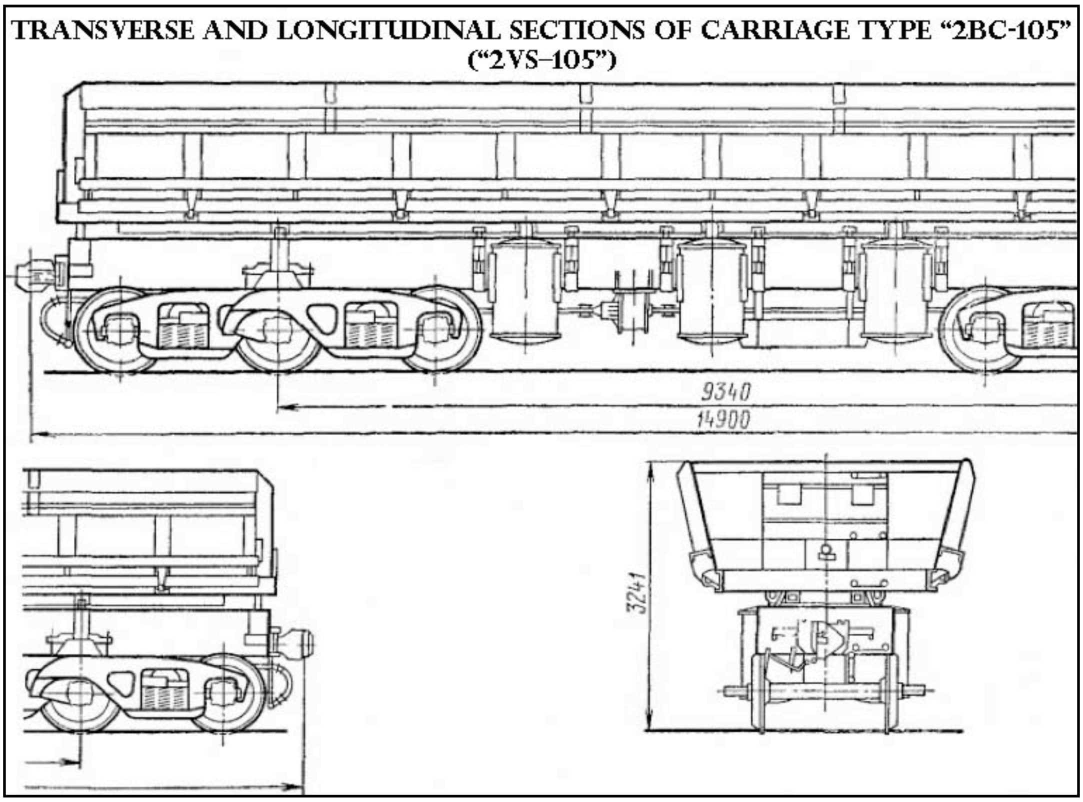

Figure 34: Sketch of the typical carriage used for ore transportation (SCBIST railways forum 2013)

The carriage type "2BC-105" ("2VS–105") is 14.9 m in length when measured along the clutch axes; mean speed is assumed as 40 km/h. The cost of the carriage of a similar type is RUB 3.25 million[9] (sale price of the OOO "Prom-Standard" 2013). The total length of the train is estimated to be 400 m, being built of 25 carriages and 1 locomotive of 29 m long. Two-section locomotive of type "2TЭ116-1" ("2TE116–1") was applied for calculations; the sketch of the locomotive is presented in Figure 35.

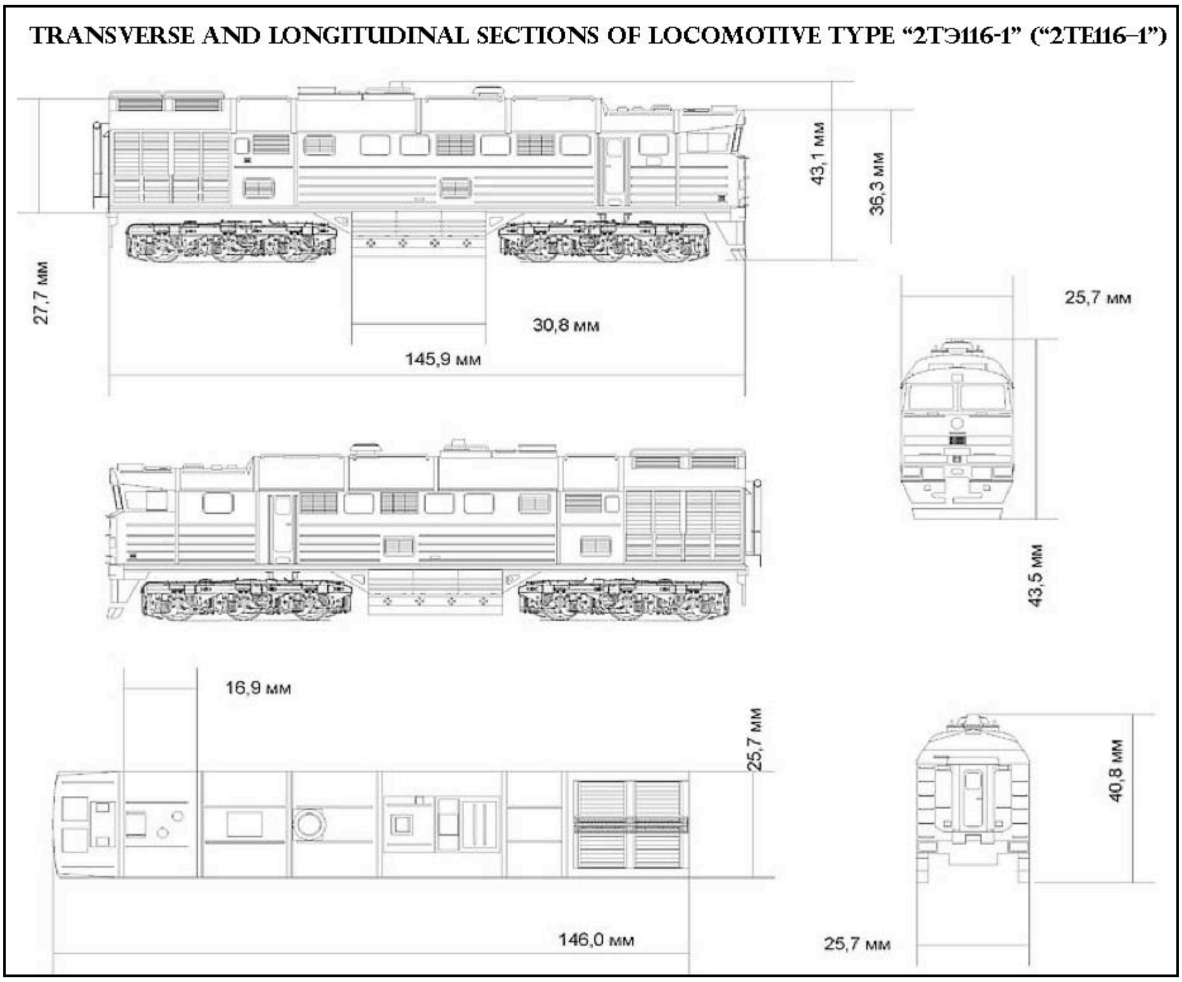

Figure 35: Sketch of the typical locomotive used for ore transportation (SCBIST railways forum 2013)

Input values for the transported ore were obtained from information available online. The cost of the transported ore was estimated as possible revenue from production of two main goods: apatite and nepheline concentrates. According to the published data in the annual report of "PhosAgro" (2011), a tonne of apatite concentrate for export (90% of sales), which is a product of apatite-nepheline ore dressing by flotation, is estimated to be RUB 8,475.

[9] For currency conversion from RUB to EUR, mean reference exchange rate of EUR 1 = RUB 40 is applied.

According to “РБК daily” (“RBC daily”) (2011), cost for one tonne of nepheline concentrate is RUB 735. The outcome of apatite concentrate for the last three years is reported to be about 29.38%; the outcome of nepheline concentrate is 3.18% (details in Table 12); which results in the price of RUB 2,513 per tonne of the transported material. The estimated values consider labour costs for mining operations and concentrate production, which are already included in the market price. However, the secondary gain from sales of other minerals in the ore tenor is not taken into account.

Table 12: Production and dressing of apatite-nepheline ore (Annual report of the "PhosAgro")

Production and dressing of apatite-nepheline ore [million tonne]				
Year	**2009**	**2010**	**2011**	**Mean**
Apatite-nepheline ore	23.9	27.1	26.6	25.9
Apatite concentrate	7.0	8.1	7.7	7.6
Nepheline concentrate	0.5	1.0	1.0	0.8

According to the scenarios, main losses for the worst-case scenario are associated with the lost ore and the damaged carriages. While for the average-case scenario, the direct, or first order losses, originate from the labour costs for putting the carriage back on track and snow removal works. The indirect losses for the average-case scenario arise from the possible profit of the mining company.

The labour costs for the snow cleaning up works are adopted from the tariff used for roads in another region and are estimated to be RUB 1,780 for $1*10^{-4}$ km^2 (100 m^2) of the railway (Ministry of Transport, Tver Oblast 2013). The train services are evaluated as a ratio of spent working time, applying a hypothesis that an emergency response brigade of 12 persons spend on average two hours to reach the place of accident and uncouple one derailed carriage, and three hours to uncouple one derailed carriage and fix the railway track (Russian Railways 2013, expert assessment).

The monthly working hours are taken as 174 hours, with an average monthly salary estimated to be RUB 30,767.4 for 2012 (Municipal Authority “Administration of Kirovsk town, Murmansk oblast” 2011). In addition, snow removal by a snowplough is included in calculations of labour costs. Assuming two hours of work are needed for the cleaning up the railway track (snowplough “СДП - М” (“SDP - M”) was used as an example), including shift and fuel costs as well as depreciation, the cost is RUB 2,790 (Russian Railways 2013, expert assessment). The overall equation for labour costs, including snow cleaning up works, is shown in equations 11 for the worst-case scenario and equation 12 - for the average-case scenario.

$$C_{labour} = 12S\left(\frac{3}{174}\right) \times \sum_{i=1}^{n} w_i + C_{snowploug\ h} \quad (11).$$

$$C_{labour} = 12S \times \left(\frac{2}{174}\right)\sum_{i=1}^{n} w_i + \sum_{i=1}^{n} Q_i \times 0{,}01C_{snow} + C_{snowploug\ h} \quad (12).$$

w_i - number of carriages to be arranged back to the railway track []
C_{snow} - costs for the snow cleaning up works by emergency response crew [RUB]
$C_{snowplough}$ - cost of the snow cleaning up works by a snowplough [RUB]
S - average monthly salary for Murmansk Oblast' [RUB]
Q_i - area of blockage for a single avalanche path [km^2]

The number of the affected carriages was obtained comparing mean width of blockage for a single avalanche path with the length of a carriage (equation 13).

$$w_i = \frac{g_i}{m_c} + 1 \quad (13).$$

With the condition: $w_i = round(x)$

g_i - width of railway blockage for a single avalanche path [km]
m_c - length of a carriage [km]

The calculated economic losses are presented in Figures 36 and Figure 37.

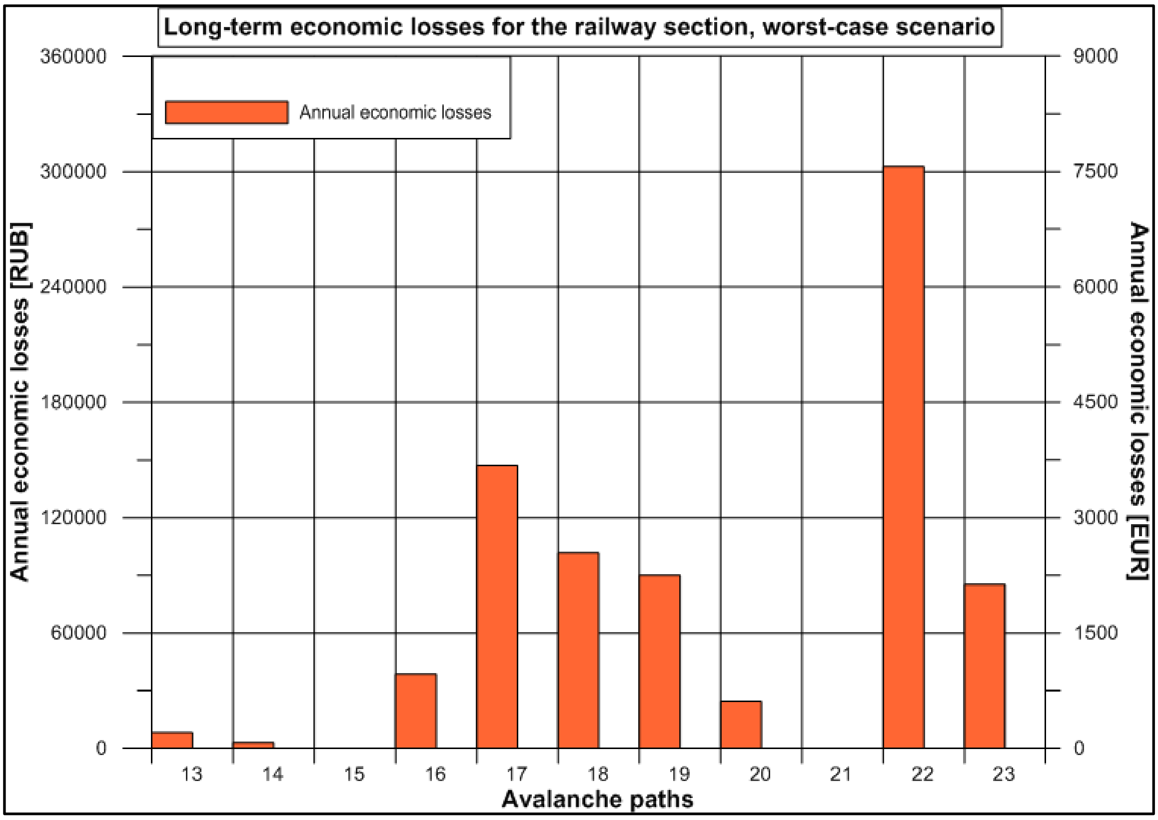

Figure 36: Total economic losses for the railway section, the worst-case scenario

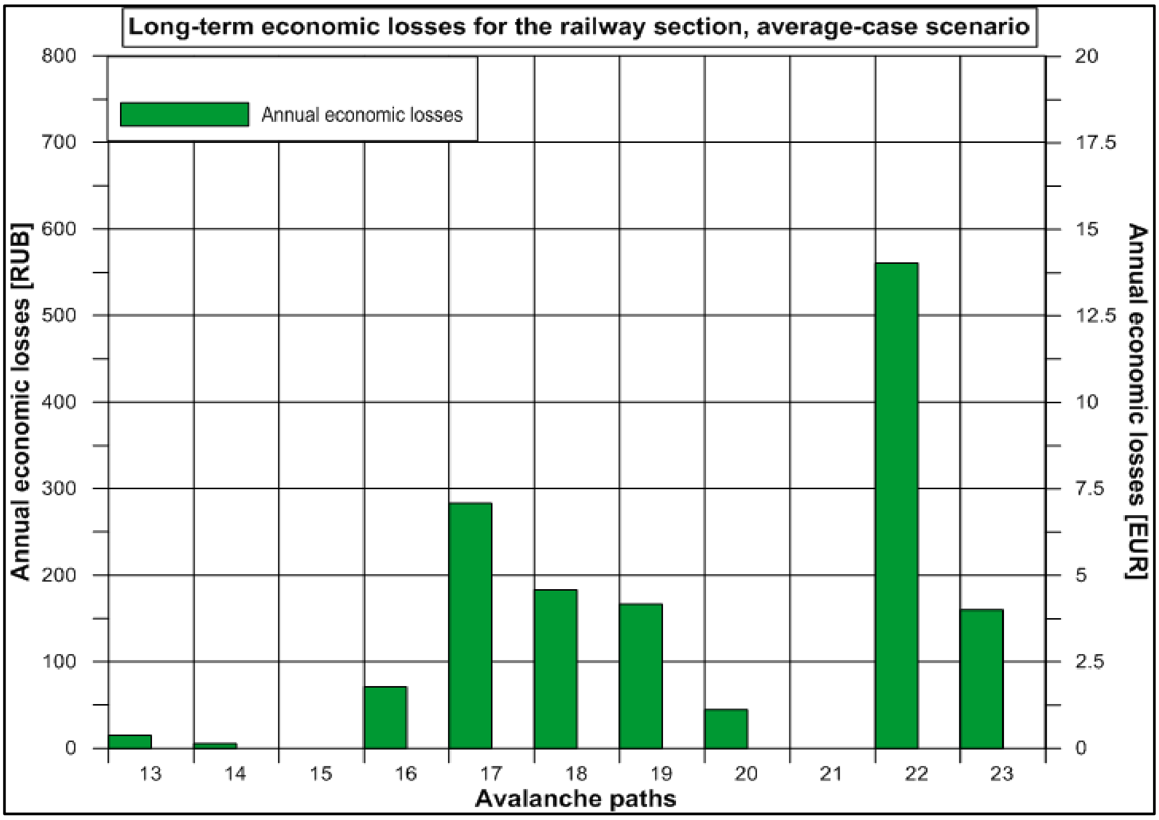

Figure 37: Total economic losses for the railway section, the average-case scenario

The economic risk, expressed as direct annual economic losses, is separately calculated for the worst-case and the average-case scenarios. The indirect economic losses for the average-case scenario are calculated on the same basis, with the only difference for the consequences estimation and the total number of passages, accounting for both, full and empty trains. The overall equation is presented below:

$$R_{ec.indir} = \frac{z_{train}}{24h} \times \frac{g_i}{u_i \times T_i} \gamma_i \times P_i \qquad (14).$$

g_i - width of railway blockage for a single avalanche path [km]
u_i - mean speed of the train in the avalanche path i [km/h]
z_{train} - number of passages within a day for a train, accounting for full and empty train []
γ_i - parameter to account for length of the train (Bahnfaktor) []
T_i - return period of the avalanche in the avalanche path i [years]
P - possible profit [RUB]

The consequences are quantified based on possible profit of the mining company for the ore, which could be transported during the repair works on the railway section. The time needed for the recommence of normal railway work regime is calculated from: time spent to uncouple the damaged carriages, and time spent to clean up the avalanche deposits. The assumption of 1/2 working hour spent by a brigade for cleaning 100 m² of avalanche deposits is used.

$$P_{full\ or\ empty} = C_{ore} \times (w_i \times H_{unc} + 0.005 Q_i) + C_{labour} \qquad (15).$$

w_i - number of the affected carriages []. For the calculation procedure see equation 13.
C_{ore} -cost of the transported ore per one train [RUB]
C_{labour} - labour costs for the average-case scenario [RUB]. See equation 12.
H_{unc} - time needed to uncouple one damage carriage [h]
Q_i - area of blockage for a single avalanche path [km^2]

The estimated economic losses, including indirect damage are illustrated in Figure 38.

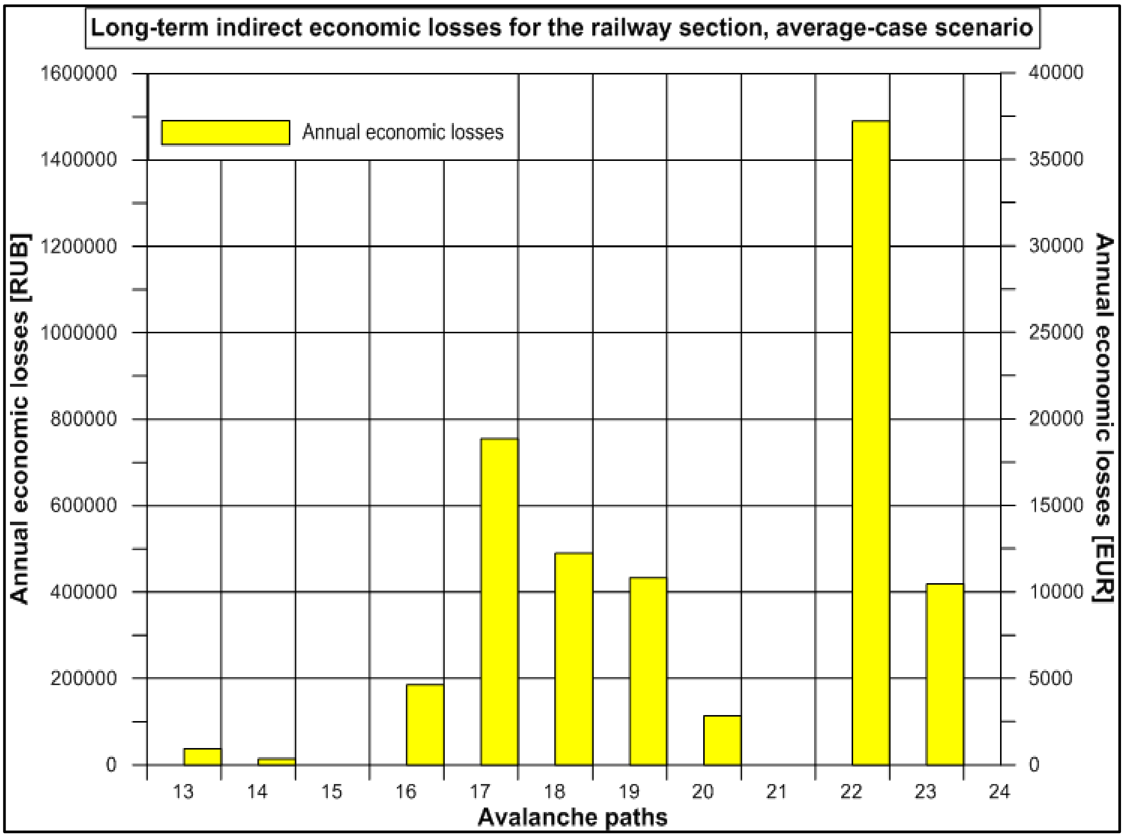

Figure 38: Total indirect economic losses for the railway section, the average-case scenario

Analyzing the computed long-term economic risk calculations, the highest monetary losses in all the cases are calculated for the avalanche path 22, resulting in RUB 1.44 million and is 100 times higher than the quantified consequences for the avalanche path 14 (the smallest annual economic risk). High contributions for the estimated annual losses also originate from the avalanche paths 17 and 18, which are the most frequent avalanche paths in terms of number of avalanche events hitting the railway. The economic risk, quantified in monetary losses, is the following (in descending order):

- the economic losses for the average-case scenario, including indirect losses was estimated to be RUB 3.71 million;
- the worst-case scenario, where several carriages are derailed and overturned, results in total monetary damage for the studied railway section of RUB 801,433;
- the average-case scenario, where several carriages are derailed and block the railway track, avalanche risk is quantified as RUB 1,489.

The calculated values provide an idea of possible consequences and illustrate the worst-case and the average-case losses. The worse-case scenario can occur only under extreme conditions with very high pressure of avalanche flow, and therefore it is not considered further. For the average-case scenario, which is the most possible under local avalanche conditions, the calculated economic risk differs depending on the way to quantify the consequences. The average-case scenario accounting for the first order losses presents the minimum annual economic risk, being approximately 2500 times lower than the economic risk for the average-case scenario including indirect losses. However, it is not capable to represent the real economic impact from the railway blockage. Taking into account the major role of the railway as a freight route, the average-case scenario accounting for the economic losses to the mining company, is more representative. Thus it is selected as a basis for economic loss calculation in the short-term risk, as well as for the cost-benefit analysis to justify proposed countermeasures. To get the feeling of the calculated value, the risk arisen from the average-case scenario including indirect losses is quantified as:

- $1.6 * 10^{-3}$ % of GRP (Gross Regional Product) of Murmansk Oblast (Federal Service of State Statistics in Murmansk Oblast 2010);
- 1.4 % of the net monthly profit of the JSC “Apatit” (Annual report of the profits and losses 2011 in the Appendix I).

4.2 Short-term risk development

A short-term development of avalanche risk aims at illustrating the temporal variability of avalanche hazard potential and the fluctuation of elements at risk in the diurnal timeframe. In the presented research the short-term risk is evaluated for dry snow avalanches, which present the majority at the site, and is conducted for the railway section, due to the facts that:

- the created sample of avalanches hitting the traffic routes[10] includes only one avalanche event, which blocked the road. This fact makes the designed sample statistically non-representative for further analysis on avalanche events hitting the road;
- the information about the tourist flow on a weekly or a daily resolution is not available for the study area.

The hazard potential is represented by the possibility of an avalanche release in a daily timeframe and the width of railway blockage. The damage potential is determined by the freight traffic and is calculated for the average-case scenario including indirect losses. The

[10] The avalanche events from 1998 are used due to wind speed data availability, which is the main criterion for blizzard activity. The avalanche events are presented in Appendix G.

conducted assessment accounts for both, current freight traffic and scenario with the increased freight intensity.

4.2.1 Hazard potential

Practically, the release probability for dry snow avalanches is frequently substituted by an occurrence probability of a special meteorological event; usually a snowfall of certain intensity is taken (Wilhelm 1997). For the investigated site no measurements of new snow are available, thus other statistically significant meteorological parameters (see discriminant analysis in chapter 3.3) have been analyzed in terms of their influence on avalanche release. Four scatter plots were derived to inspect the relationship between the number of the recorded avalanches and the respective meteorological parameter. Individual observed avalanche events are scattered widely in all the plots, and thus a weak dependency on a single meteorological parameter can be concluded. There is a slightly positive trend, namely that an increase in the number of avalanches is correlated with an increase in each meteorological parameter, such as wind speed, snow height, mean daily temperature and precipitation within 24 hours. Moreover, a very low coefficient of determination can be reported, illustrating nonlinear dependency (Figure 39, Figure 40, Figure 41 and Figure 42).

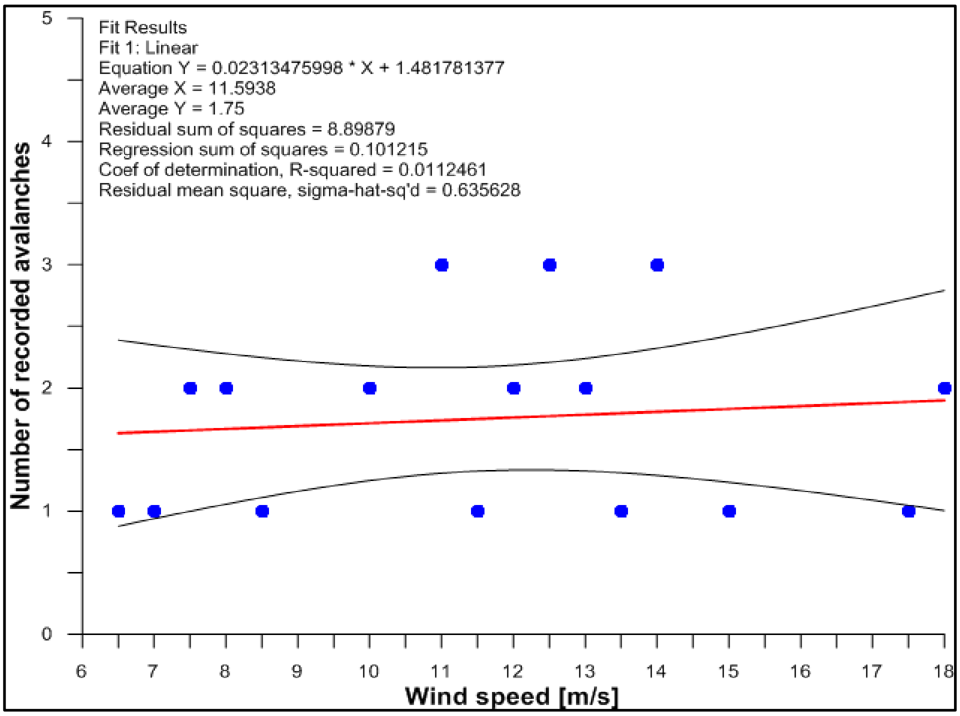

Figure 39: Scatter plot with a regression line for wind speed [m/s]

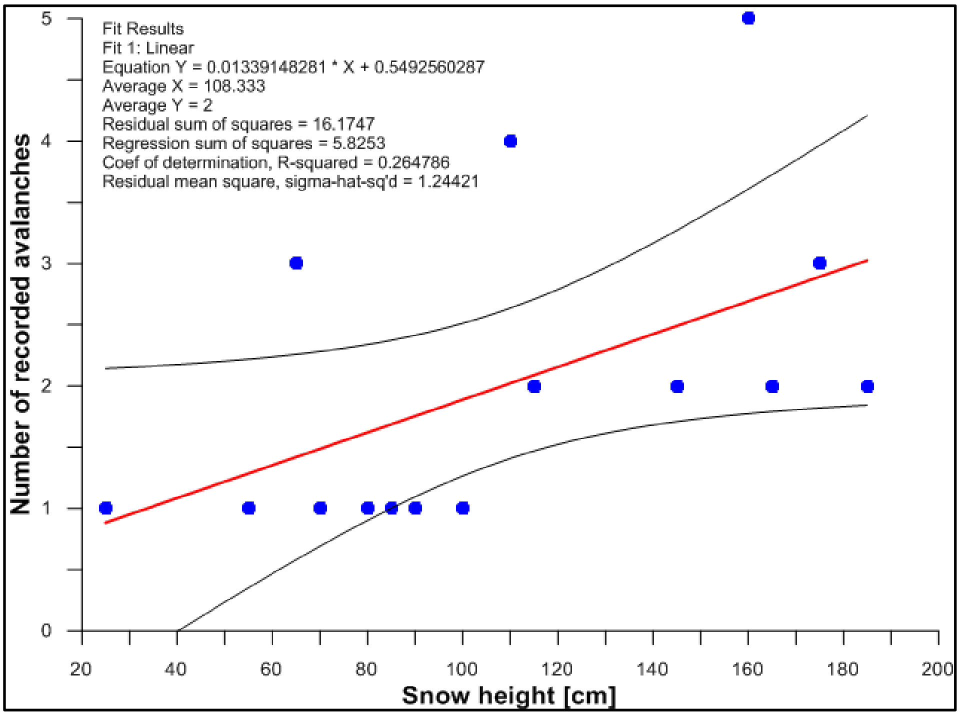

Figure 40: Scatter plot with a regression line for snow height [cm]

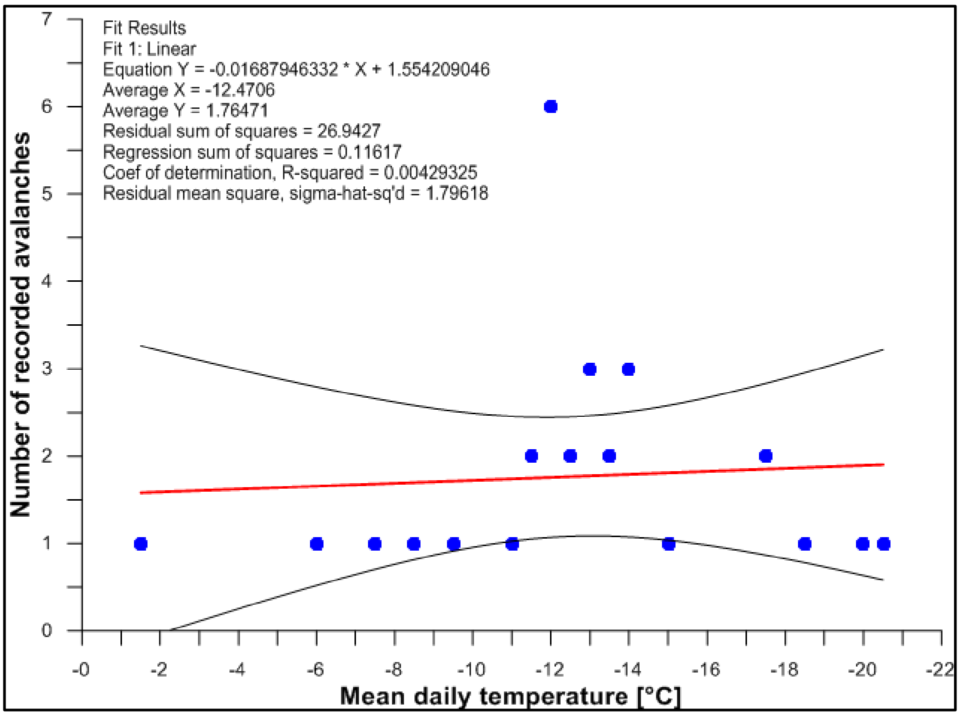

Figure 41: Scatter plot with a regression line for mean daily temperature [°C]

Thus, the short-term variability of avalanche release is grounded on a fuzzy logic model, which allows accounting for a nonlinear relationships and a combination of meteorological parameters. In addition, the output of a fuzzy logic model is presented in a simple and understandable way. As a basis for the developed method, a case study of the Sulden road in the Italian Alps was selected (Zischg et al. 2005b). The proposed fuzzy logic model is built upon the available measurable meteorological parameters, derived from the meteorological station “Central’naya”.

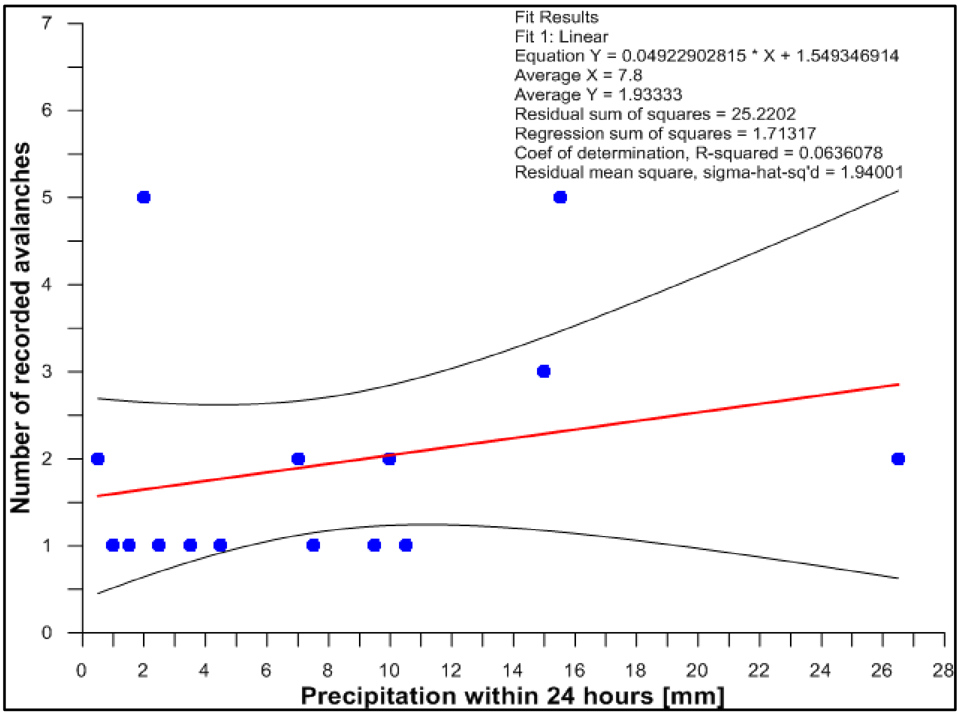

Figure 42: Scatter plot with a regression line for precipitation within 24 hours [mm]

According to the recorded events and meteorological data, triggering of dry snow avalanches hitting the transport axes frequently occurs because of additional loads of snow shortly after heavy snowstorms (chapter 3.5.2.1). Thus blizzard activity, represented by wind speed during snowstorms and precipitation within 24 hours, plays the most important role in the further developed rule-base system.

Temperature is considered as an influential parameter only at its extreme values, which are either below or above average daily temperatures registered for the area. Snow heights, measured at the meteorological station “Central’naya”, reflect the amount of snow on the ground, possibly available for avalanche formation, but do not illustrate the situation in the studied avalanche paths. Therefore, the data about snow heights is not used in the fuzzy logic system.

This simplified background is summarized in the fuzzy logic rule-base model, designed upon if conditions - then conclusion rules of the Mamdani type for all input values. The rules are presented in Table 13, where a degree of truth illustrates the importance or weight of a specific rule.

Table 13: Rule base of the expert system

Rule number	IF-clause	THEN-clause	Degree of truth
1	IF "mean daily precipitation" IS "heavy" AND "wind speed" IS blizzard	THEN "variable release" IS "avalanche expected"	1
2	IF "mean daily precipitation" IS "heavy" AND "mean daily temperature" IS "extremely cold" AND "wind speed" IS "blizzard" AND	THEN "variable release" IS "avalanche expected"	1
3	IF "mean daily precipitation" IS "heavy" AND "mean daily temperature" IS "extremely warm" AND "wind speed" IS "blizzard"	THEN "variable release" IS "avalanche expected"	1
4	IF "mean daily precipitation" IS "heavy" AND "mean daily temperature" IS "average" AND "wind speed" IS "blizzard"	THEN "variable release " IS "avalanche expected"	1
5	IF "mean daily precipitation" IS "moderate" AND "mean daily temperature" IS "extremely cold" AND "wind speed" IS "blizzard"	THEN "variable release " IS "avalanche expected"	1
6	IF "mean daily precipitation" IS "moderate" AND "mean daily temperature" IS "extremely warm" AND "wind speed" IS "blizzard"	THEN "variable release" IS "avalanche expected"	1
7	IF "mean daily precipitation" IS "moderate" AND "mean daily temperature" IS "average" AND "wind speed" IS "blizzard"	THEN "variable release" IS "avalanche expected"	1
8	IF "wind speed" IS "blizzard" AND " mean daily temperature" IS "extremely cold"	THEN "variable release" IS "avalanche expected"	0.8
9	IF "wind speed" IS "blizzard" AND " mean daily temperature" IS "extremely warm"	THEN "variable release" IS "avalanche expected"	0.8
10	IF "mean daily precipitation" IS "moderate" AND "mean daily temperature" IS "average" AND "wind speed" IS "blizzard"	THEN "variable release" IS "no avalanche expected"	0.8
11	IF "wind speed" IS "no blizzard"	THEN "variable release" IS "no avalanche expected"	1
12	IF "mean daily precipitation" IS "light" AND "mean daily temperature" IS "average" AND "wind speed" IS "blizzard"	THEN "variable release" IS "no avalanche expected"	1

The quantitative input variables for the designed rule-base system were anticipatorily transformed into linguistic variables by membership functions (Figures 43, Figure 44 and Figure 45). A certain degree of membership identified the degree to which a value belongs to the fuzzy set. The border values for the designed classes of the input variables are based on the observations of environmental parameters and existing thresholds from the previous studies (Bozhinskiy et al. 2001; Zyuzin 2006).

Wind speed is grounded on values of wind speed for initiation of snowstorms in the area, which are equivalent to border values of:

- 4-5 m/s for the deflation in the upper layer of the fresh-fallen snow;
- 6-7 m/s for the settled snow surface (Zyuzin 2006).

The results from the scatter plot also illustrates that no avalanches were recorded with the wind speed lower than 6.5 m/s.

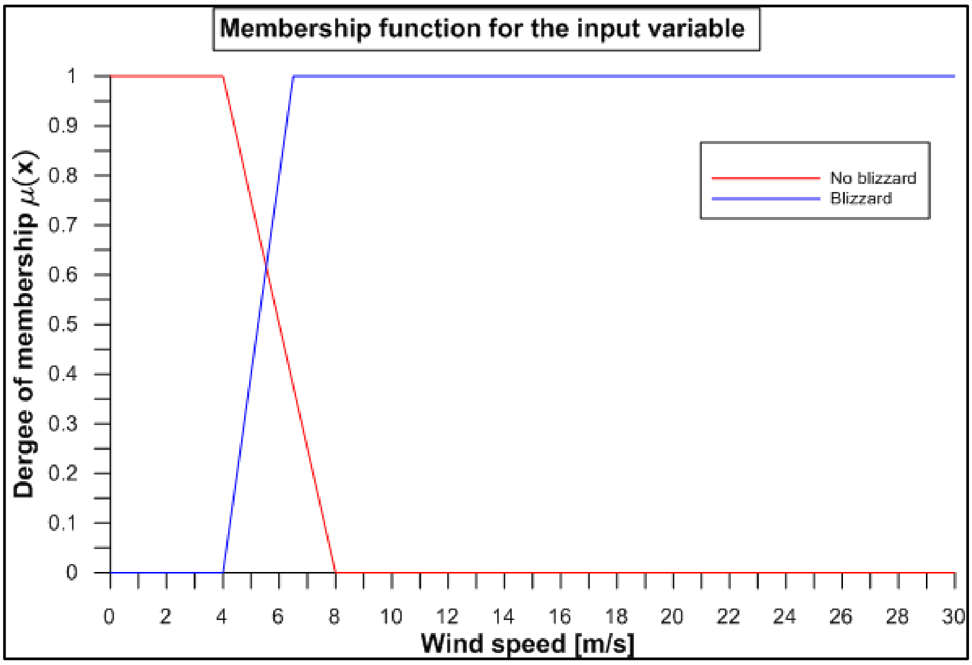

Figure 43: Membership function for wind speed [m/s]

The same procedure was implemented for all selected environmental parameters resulting in the threshold values for mean daily temperature and precipitation within 24 hours. In the case of mean daily temperature, the comparison of mean daily temperature for days with the recorded avalanches and days with no avalanche events was used to derive approximate values of average and “extreme” temperatures. The developed classes represent average and “extreme” temperature as follows:

- average (between - 20 °C and - 2 °C);
- “extreme” (extremely cold ≤ - 20 °C; extremely warm ≥ - 4 °C).

For precipitation, the classes are formed with respect to the border value of 0.5 mm, which reflects a possibility of a blizzard occurrence. The value of 0.5 mm is also seen as the lowest value of precipitation within 24 hours for avalanche occurrence from the respective scatter plot. The upper border is the value of solid daily critical precipitation for avalanche formation from the fresh-fallen snow, which is 10 mm in water equivalent (Bozhinskiy et al. 2001).

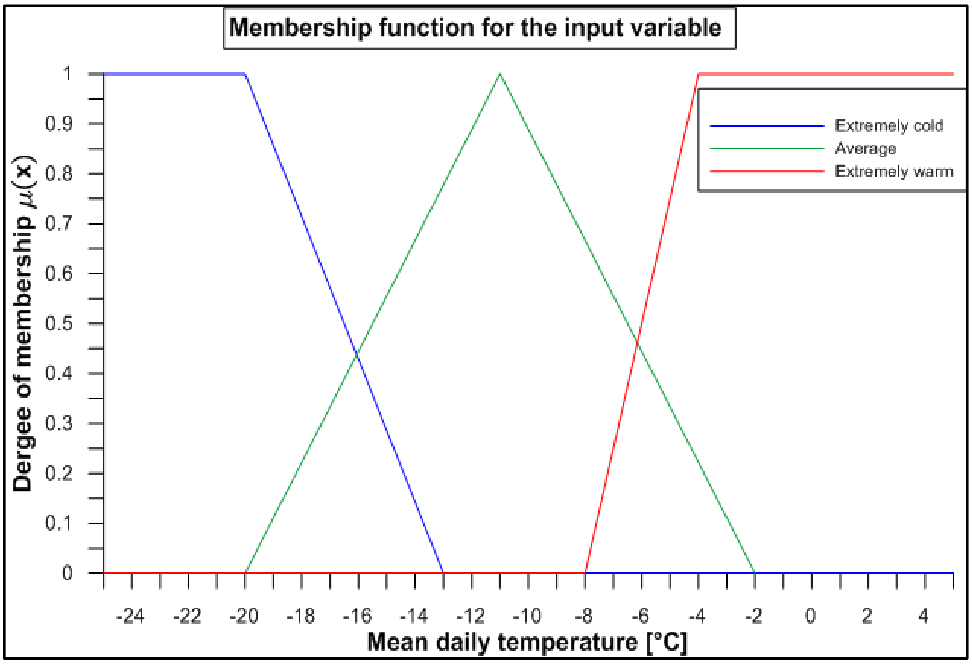

Figure 44: Membership function for mean daily temperature [°C]

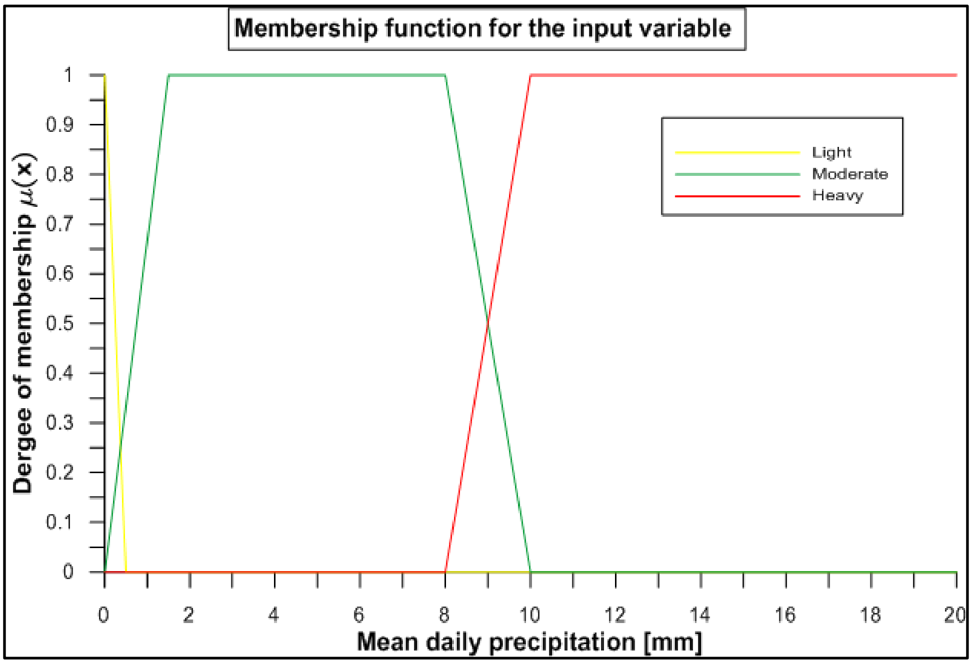

Figure 45: Membership function for mean daily precipitation within 24 h [mm]

During the inference procedure single input variables in the IF-clauses were combined by a logical AND-operator, which uses the minimum function. The aggregation step was used instead of a defuzzification of the results. This provides a membership value for the whole rule from all relative membership values of the single parameters of the respective rule (equation 16).

$$\mu_{\text{avalanche release /no avalanche release}} = \min(\mu_w ; \mu_t ; \mu_p) \quad (16).$$

μ_w - degree of membership of wind speed []
μ_t - degree of membership of mean daily temperature []
μ_p - degree of membership of mean daily precipitation []

In the case of several rules being applicable for the input data, the maximum membership value was used, resulting in the accumulated degree of membership for the statement "avalanche release expected" and "no avalanche release expected" for an individual day. The accumulated degree of membership quantifies the grade that a specific day belongs to days with avalanche release and days with no avalanche release, based on combination of the meteorological parameters, and can be used to illustrate a temporal variability of avalanche release.

As an example, the short-term risk was calculated for a two-month period during the winter season 2010 applying the meteorological parameters for every day. The results of the analysis are presented in Figure 46[11]. During this period three avalanche events hitting the railway were registered in the avalanche path 17, in the avalanche path 18 and in avalanche path 19. The results of the implemented fuzzy logic model are generally in a good agreement with the observed events. The days with the recorded avalanches hit the railway on the 17th February 2010 and on the 3rd- 4th March 2010 have a membership degree of 1 for the conclusion "avalanche release expected" and degree of membership equal 0.1 and 0 for the conclusion "no avalanche expected", demonstrating a significant difference between the membership

[11] The detailed calculation of the variable hazard potential for every day is presented in Appendix H. The recorded avalanche events that hit the railway are highlighted in bold; and recorded avalanche events stopped in the slope are highlighted in italics.

degrees. In addition to the above stated days, considerable membership degree differences with high values for avalanche release, was computed for two days. In one case, on the 24th February 2010 the elevated membership degree for the conclusion “avalanche release expected” was registered when the avalanche, which stopped in the slope, occurred. Whereas on the 23rd February 2010 a high membership value for the conclusion “avalanche release expected” was observed one day prior the avalanche event. For all other days during the validation period, high membership degree for the conclusion “avalanche release expected” was complemented by rather high value (> 0.6) of membership degree for the conclusion “no avalanche expected”, pointing inconsiderable difference between the concurrent rules.

According to the results, no avalanches were registered for the days with an explicit value of 1 for “no avalanche release expected” and 0 for “avalanche release expected” conclusions. In one case, on the 9th January 2010, a high membership degree of 0.88 for no avalanche release was computed for the day with the avalanche event, which stopped in the slope.

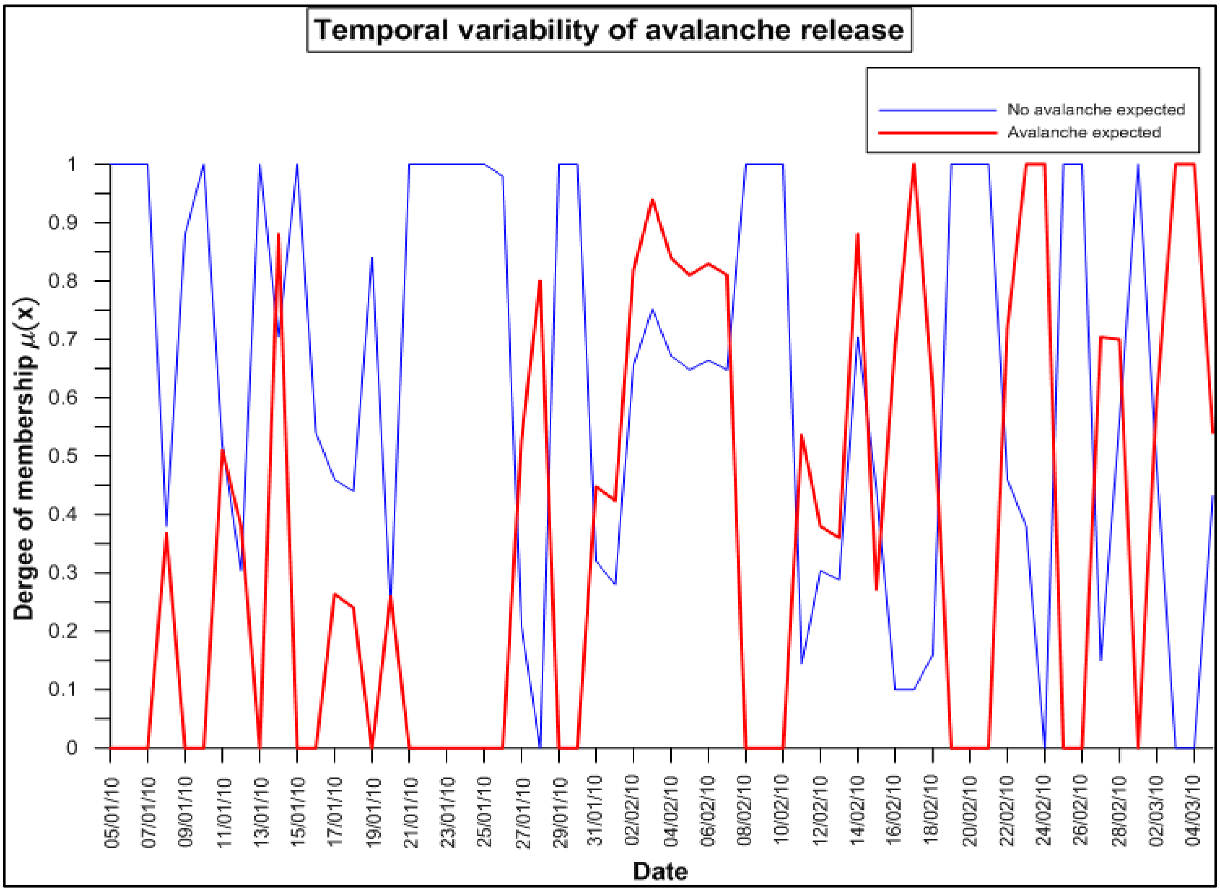

Figure 46: Variable hazard potential estimated within the validation period between 05.01.2010 and 05.03.2010

On the whole, the designed fuzzy logic system can model the temporal variability of avalanches hit the railway in the study area, but generates plausible results for the days with avalanche events, which stopped in the slope. For the days with avalanche events, which stopped in the slope, inconsiderable differences between the membership degrees of the concurrent statements are observed. This illustrates an equivocation and simplicity of the developed rules. To improve accuracy of the results, additional meteorological parameters and snow characteristics should be incorporated to fully represent the system behavior.

4.2.2 Damage potential

According to the average-case scenario including indirect losses, the damage potential is quantified as possible economic losses to the mining company from the railway blockage. As daily freight traffic on the studied railway stretch is constant, variability of damage potential is reflected by various width of blockage in different avalanche paths and corresponding different number of the affected carriages. The variability of damage potential depends on number of avalanche release(s) and avalanche path, where the avalanche(s) occur under current meteorological conditions and snowpack characteristics. Due to the lack of forecasting information and data on snow cover properties, the spatial interpolation of damage potential was possible only for the days:

- with the registered avalanche events, which stopped in the slope;
- with the registered avalanche events, hit the railway;
- day with high membership degree for the conclusion "avalanche release expected" prior the avalanche events, where an avalanche release in the same avalanche path was adapted.

The resultant variable damage potential was calculated according to the equation 17 and is presented in Figure 47.

$$d_{ec.indir} = \frac{z_{train}}{24h} \times \sum_{i=1}^{n} \frac{g_i}{u_i} \gamma_i \times P_i \quad (17).$$

g_i - width of railway blockage for a single avalanche path [km]

u_i – mean speed of the train in the avalanche path i [km/h]

z_{train} - number of passages within a day for a train, accounting for full and empty train []

γ_i - parameter to account for length of the train (Bahnfaktor) []

P - possible profit [RUB]

The membership degree for the conclusion "avalanche release expected" was used as a possibility of a certain extent of damage to occur (Zadeh 1978).

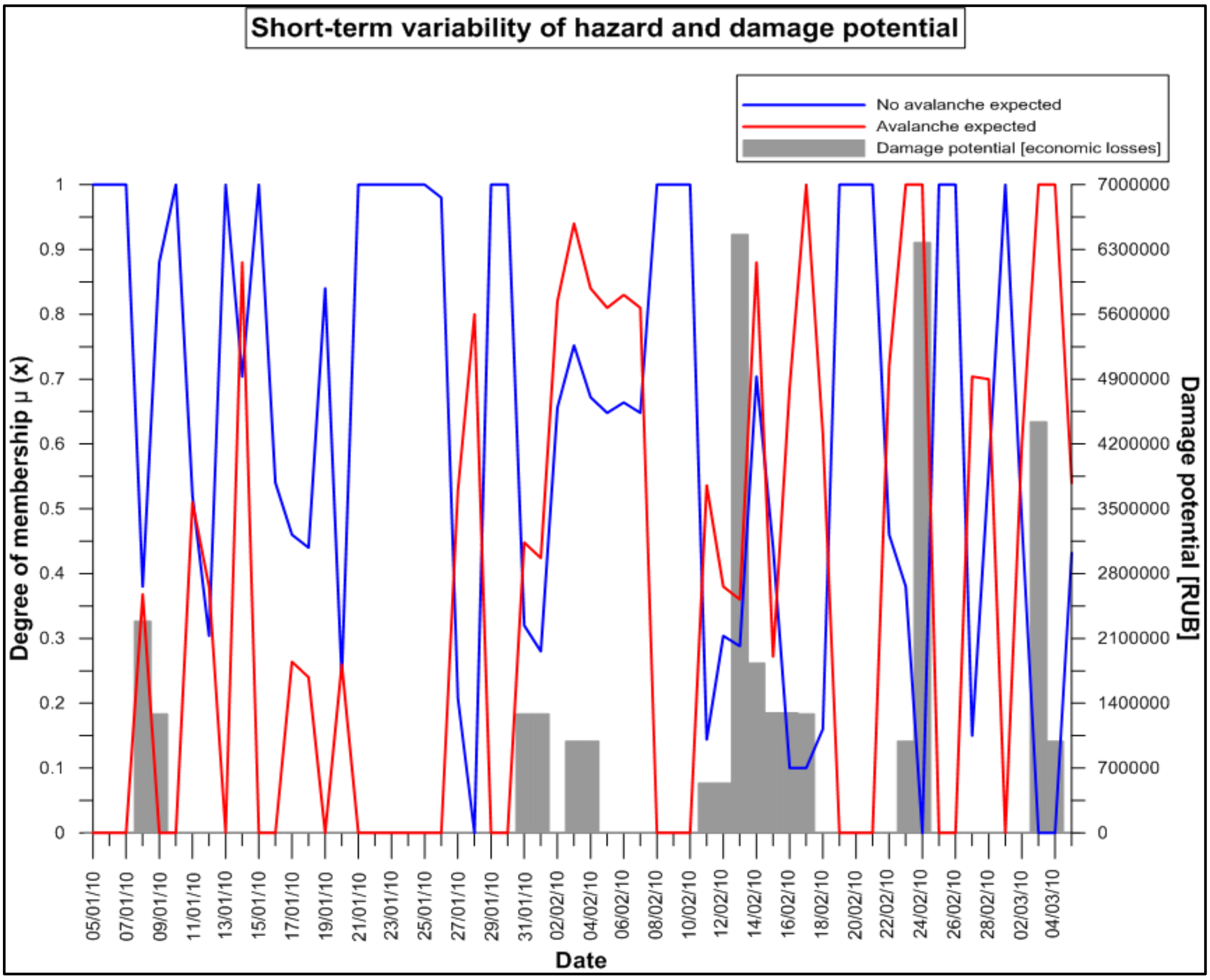

Figure 47: Variable damage potential estimated within the validation period between 05.01.2010 and 05.03.2010

The damage potential for the days with avalanches hit the railway was determined as RUB 1.28 million for the 17th February 2010; RUB 989,748 for the 4th March and RUB 1.29 million for the 3rd March. The damage potential for the last case could be doubled if the avalanche released in the avalanche path 16 hit the railway. In all the cases, the recorded damage potential was calculated to occur with a possibility of 1, demonstrating the highest hazard potential.

The peaks of damage potential, quantified as RUB 6.46 million and RUB 5.98 million, was calculated for the 13th and the 24th February 2010. On the 13th February three avalanches were released in the avalanche paths 13, 17 and 22. None of the recorded avalanches hit the railway, stopping in the slope; degree of membership for the conclusion “avalanche release expected” was equivalent to 0.36. On the 24th February three avalanches, which stopped in the slope in the avalanche paths 16, 17 and 22, were recorded. For this date membership degree of the conclusion “avalanche release expected” was calculated as 1; membership degree for the concurrent conclusion was 0. The lowest damage potential was estimated for the 11th and 12th February, when avalanche event happened in the avalanche path 14. The changes in the calculated damage potential for the selected period are up to 1200 %, demonstrating a high spatio-temporal variability, depending on the avalanche paths that pose threat to the railway in a particular day.

Analyzing the computed results, it becomes apparent that risk peaks arise when a larger number of avalanches occur, being correlated with the spatial distribution of hazard potential. Thus, it is of vital importance to incorporate spatial interpolation in the developed fuzzy logic model to predict a behavior of the system “dry snow avalanche - railway section”. It can be done by adding snow cover characteristics to identify the avalanche paths to pose a threat to the railway in a given day. Moreover, adding rules for the avalanches hit the road will enable adaptation of the designed fuzzy logic model for the system “dry avalanche - road”, where variable seasonal and daily traffic flow can complement to the calculated damage variability.

4.2.3 Scenario building

The variability of damage potential due to increase in elements at risk and increase in hazard potential for a particular day is addressed on the scenario basis. The built scenarios are applied for the avalanche event recorded on the 17th February 2010 in the avalanche path 18, where resultant economic losses for a single scenario are further compared with actual economic losses. The proposed scenarios focus on:

- increase in hazard potential and unaltered number of elements at risk calculated for the current conditions;
- increase in elements at risk (represented by the increase in freight traffic) and unaltered hazard potential;
- combined increase in both, freight traffic intensity and hazard potential.

The hazard potential of snow avalanches to the greatest extent relies on snowiness and lateral extent of release areas. The maximum snow accumulation values, recorded in the study area, represent considerable temporal variability with a slight increase in annual values in the past decades. However, comparison of the averaged values for longer periods, as a possible indicator of climate change, reveals no statistically significant trend (Zaika and Vikulina 2009). Based on these findings, the first scenario represents the most unfavourable conditions using maximum snow depth recorded within the period of observation without referring to future avalanche situation from a climate change perspective. The maximum possible accumulation of snow recorded for the studied avalanche path is 1.5 m.

To allocate possible lateral extent of release areas in the case of maximum possible snow depth, topographic characteristics, including critical slope angle combined with curvature, were analyzed in ArcGIS system (Figure 48). Slope angles in a range between 30° (28°) to 50° were considered in determination of release areas for spontaneous snow avalanches on the studied slopes. The curvature was divided into concave (less than - 0.2); flat (between - 0.2 and 0.2) and convex (more than 0.2).

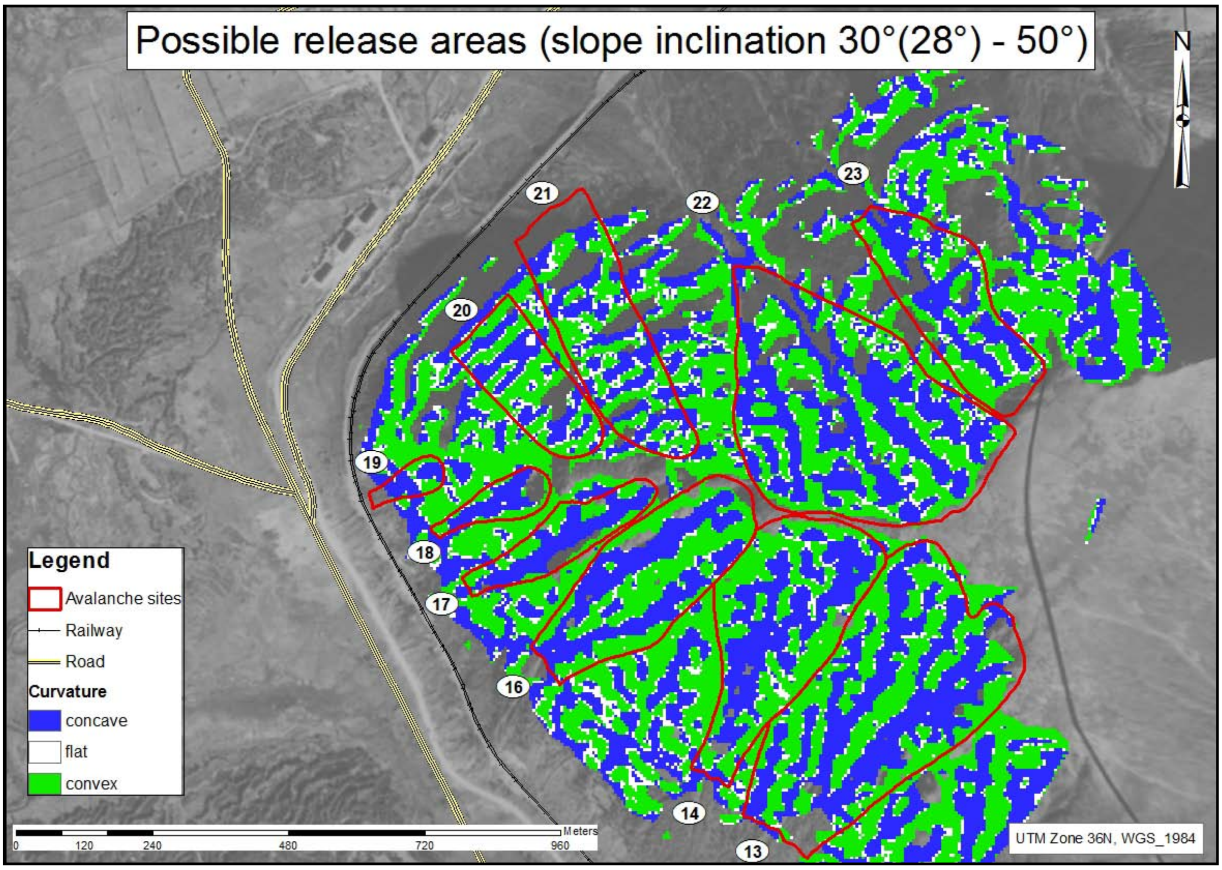

Figure 48: Possible release areas based on a curvature and a slope inclination analysis

The release area of the designed event was increased, if compared with the previously recorded avalanches, and a simultaneous release in the neighboring avalanche path 17 was proposed. This reflects a realistic picture when under unfavourable conditions larger areas can be released, and simultaneous occurrence of avalanche events can happened in the neighboring avalanche paths.

The designed avalanche events block the railway section for 75 m in the avalanche path 17 and for 85 m in the avalanche path 18, with an average deposition depth equal 0.5 m for the avalanche path 17 and 0.75m for the avalanche path 18. The modelled avalanche events are illustrated in Figure 49.

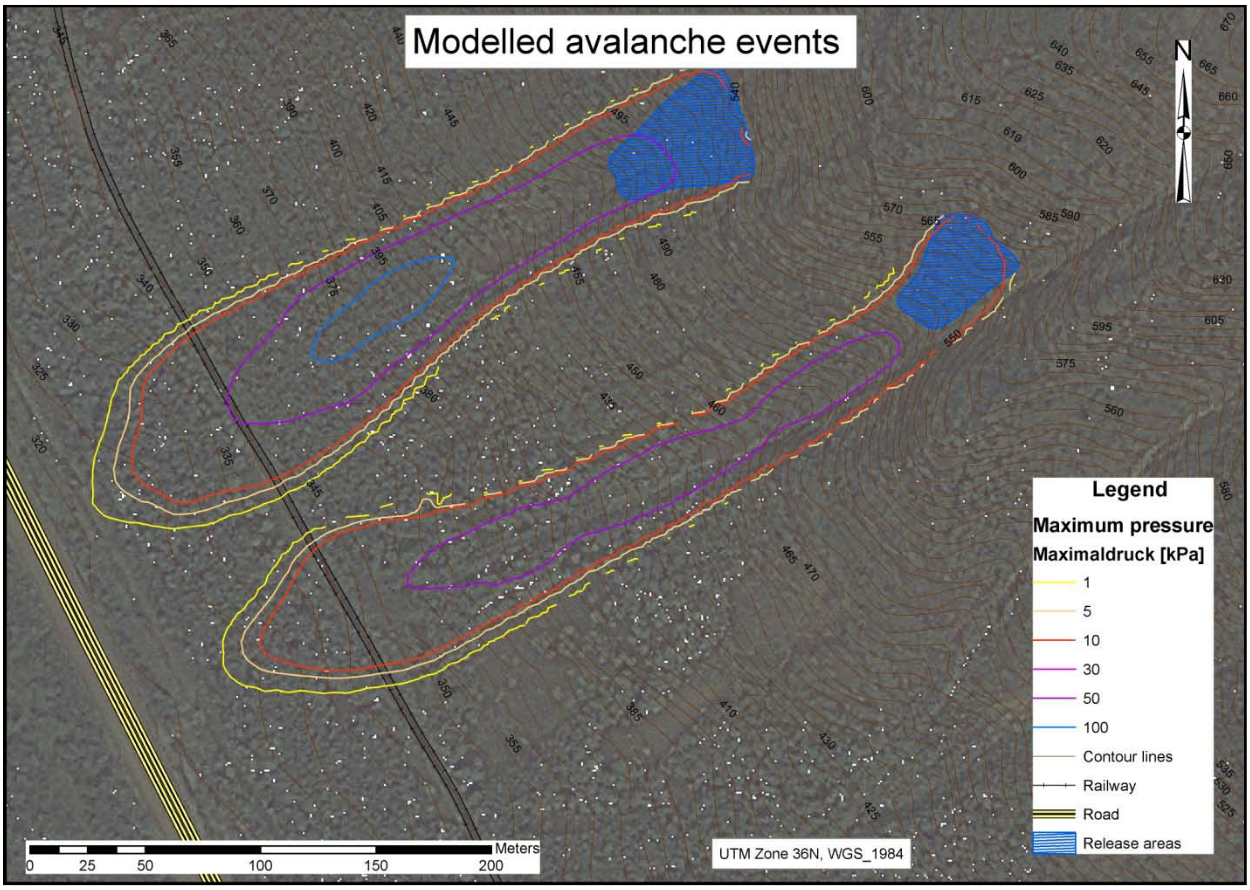

Figure 49: Designed avalanche event occurred in the avalanche path 17 and avalanche path 18

The second scenario focuses on the increase in elements at risk and applies a doubled freight frequency. This results in:

- two full trains to the factory every hour;
- two empty trains to the mine every hour.

The third scenario illustrates the situation with a double increase in freight traffic, as well as at the design release of two avalanches blocking the railway for 160 m. The scenario aims demonstration of the worst possible consequences for the selected site.

The results of each scenario and actual economic losses for the recorded avalanche event are illustrated in Figure 50, being expressed as economic damage including indirect losses. It can be foreseen as a distinct increase in economic damage with the increased hazard or/and increased number of elements at risk. The comparison with the initial state reveals a change of 200% for the scenario with the increased elements at risk, and 570% for the designed situation with the increased hazard potential. The combined scenario results in a dramatic increase of 1142%.

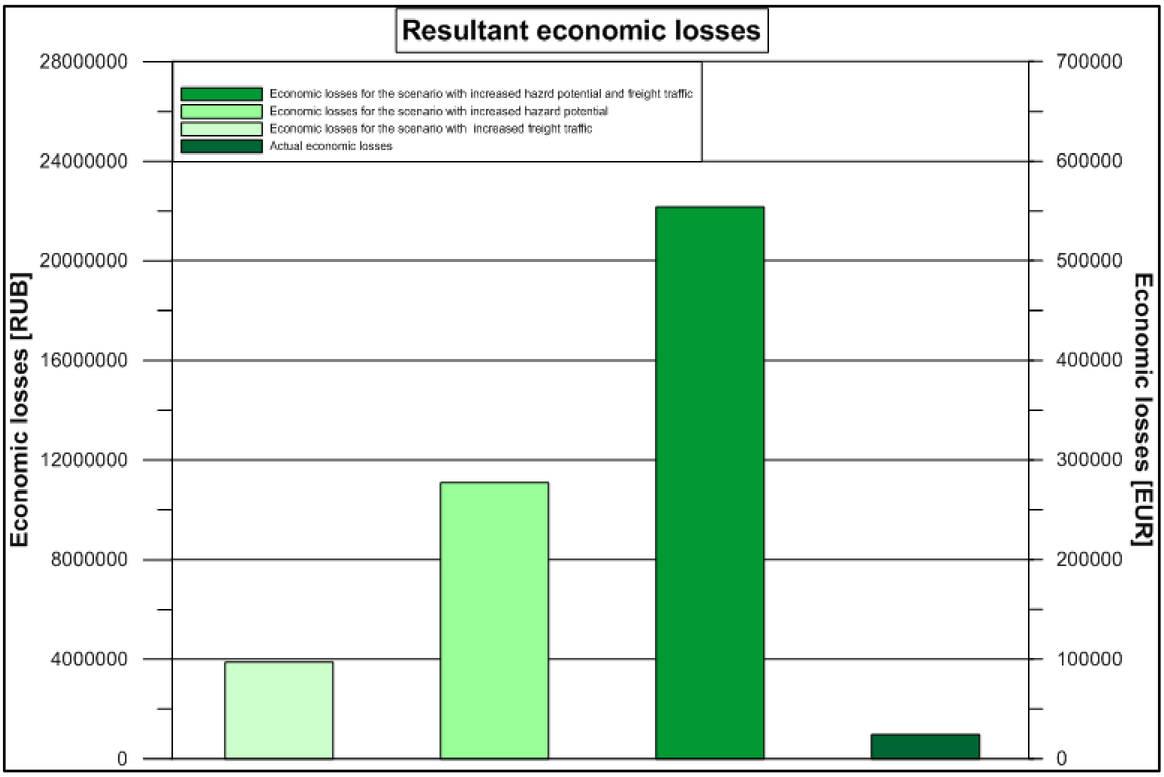

Figure 50: Indirect economic losses for three different scenarios and an actual avalanche event on the 17th February 2010

Additionally, to point out the effect of the variability of damage potential and proper timeframe for risk assessment, resultant economic losses are weighted against the long-term annual losses for the respective avalanche path. The annual economic losses for the avalanche path 18 were estimated as RUB 446,028, using mean width of blockage and probably of avalanche release calculated from the return period. This value is 4.34 times lower than the actual economic damage occurred during the avalanche event.

5. CONCLUSIONS AND IMPLICATION

5.1 Recommendation for the mitigation strategies

The recommendations on probable mitigation strategies for the investigated road and railway sections are based on the risk assessment and local conditions. The procedure includes:

- weighting of the calculated long-term individual risk against the level of acceptance;
- incorporation of long-term economic losses to identify avalanche paths posing the highest threat to the railway;
- cost-benefit analysis for the selected alternatives.

The investigated road is impacted by four avalanche paths: the avalanche path 19, 20, 22 and 23. The value of death risk for an individual exceeds acceptable risk for three of them, excluding the avalanche path 20. It is classified as an admissible level of risk, which requires considerable investments in the large-scale avalanche protection programs (Vorobiev 2005). But keeping in mind that the level of acceptable risk is a general recommendation; the obtained values of individual death risk are further compared with other types of everyday risks, as discussed in Cappabianca et al. (2008) and Fuchs (2009). For the present study average traffic risks are selected. According to the statistical data, traffic risk in terms of fatality risk equals $1.07*10^{-4}$ for Murmansk Oblast' (Inspectorate for Road Traffic Safety 2012), which is 1900% smaller than the highest value of the avalanche death risk for the studied road section calculated for the avalanche path 22. The result of such a comparison highlights an issue of a tolerable level of risk for the study area and questions a need in mitigation measures for risk reduction. Due to the lack of any information or research on tolerable risk in Russia, in this specific project the decision was made to base a selection of mitigation measures on economic losses and approach a risk reduction of a death to individual as a complementing task.

Analyzing economic losses from the avalanche release in different avalanche paths, the highest economic impact originate from the avalanche path 22 and is quantified as RUB 1.44 million annually. In addition, considerable damage is calculated for the avalanche paths 17 (RUB 669,749); the avalanche path 18 (RUB 446,028); the avalanche path 19 (RUB 394,601) and the avalanche path 23 (RUB 423,992). For other avalanche paths the estimated economic losses are relatively small ranging from RUB 169,223 to RUB 11,680. In all cases, the presented monetary damage originates from the indirect losses for the railway closure; the input from the direct losses, such as repair service and labour cost for snow removal, is very low and can be neglected.

In terms of mitigation measures, the possible alternatives can be:

- implementation of the organizational measures;

Here a temporal closure of the railway and road during the days with high hazard potential can be suggested.

- permanent protection measures;

From the alternatives, the best option will be supporting structures in the avalanche starting zone, which eliminate snow movement from creeping and sliding. Whereas protection measures in the avalanche deposition zone, such as catching or deflecting dams, cannot be considered due to a limited space in the valley.

- artificial avalanche release.

In the study area mortar shooting has been in use in the past, but cannot be implemented now due to the current legislation issues.

The first mitigation option includes preventive railway and road closure and focuses on the reduction of probability of presence of elements at risk. The effectiveness of this measure heavily depends on the number of closure days. It can demonstrate a 100% risk reduction if the traffic routes are kept open only during the days with a low hazard potential (Margreth et al. 2003). To estimate number of closure days for the study area, information on the development of hazard potential from the fuzzy logic system is used. According to the results of the analysis performed in a short-term timeframe, heavy precipitation and “extreme” temperatures were the governing input variables in the rule-base system. Therefore, these parameters are selected as a basis to calculate days of closure. The only adjustment was done for the “extreme” temperatures, applying a temperature gradient as a factor influencing avalanche formation processes (Prirodnye usloviya Khibinskogo uchebnogo poligona 1986).
The sum of these days is equivalent to 15, 14 of which are days with mean daily solid precipitation exceeding 10 mm in water equivalent and 1 day with a critical temperature gradient more than 10°C (Avalanche cadastre). Being expressed in economic losses, the calculated number of closure days means RUB 2.37 billion.

For the second mitigation option, snow nets for the avalanche paths 17, 18 and 19 and an artificial avalanche release for the avalanche paths 22 and 23, 16 and 20 are proposed. For the avalanche path 22 and 23 artificial avalanche release is selected as an additional measure for the already existing earth dams, which will decrease the investments in structural protection and improve the reliability of the present countermeasures. The avalanche paths 13 and 14 are excluded from consideration due to the fact that no avalanche events hitting the railway occurred after the structural measures, such as concrete fences and terracing of the slope, were implemented there.

The snow nets for the selected avalanche paths are installed below the highest recorded fracture line for slab avalanches (SLF 2007) and are positioned in continuous rows in the starting zones of the 17th, 18th and 19th avalanche paths. The location of snow nets is presented in Figure 51.

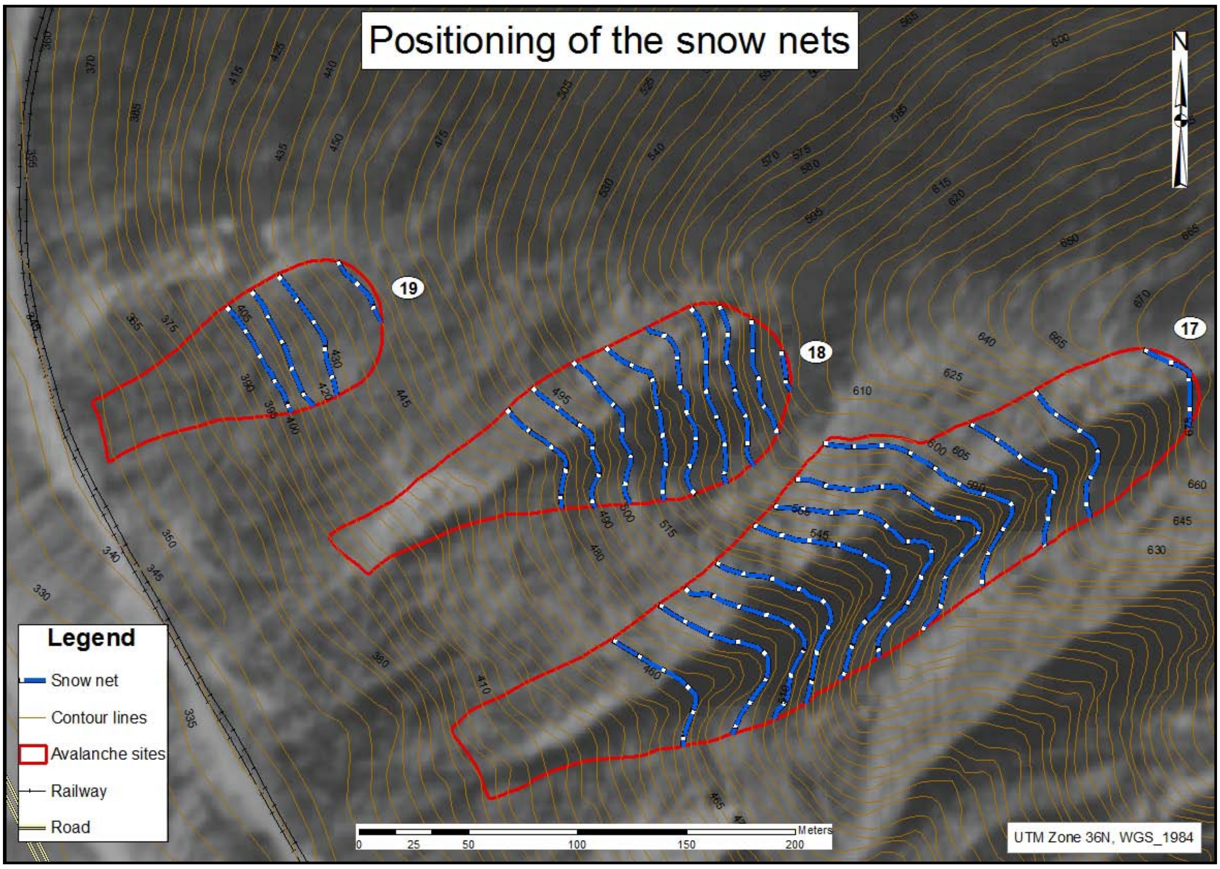

Figure 51: Sketch for the positioning of snow nets in the avalanche paths 17, 18 and 19

The distance between structures was calculated based on the maximum snow height and the slope inclination to cover a given starting zone to a full length. The height of the structure is equal to the maximum snow height in a given area, being 2.5 m for the avalanche paths 17 and 18, and 1.5 m for the avalanche path 19. The equation for calculation the distance between structures is given below.

$$L = f_l \times H_k \qquad (17).$$

L - distance between structures [m]
f_l - distance factor []
H_k - height of the structure [m]

The lower border of the starting zone was selected as the lowest altitude, at which avalanche hit the railway occurred. This will ensure that no avalanches posing threat to the railway can develop below the supporting structures.

The economic cost of the second mitigation option was calculated from the cost of snow nets and artificial triggering of avalanches. The average market cost of 1 m of a snow net is RUB 50,000 (Geobrugg Russia, personal communication), including installation. After recalculation for a lifetime of the construction[12], annual investments needed for the designed snow nets are RUB 3.27 million. The expenditures for the artificial avalanche triggering were estimated by:

- mean annual number of previously recorded mortar shootings done for the avalanche paths 22 and 23;
- mean annual number of the observed avalanches for the avalanche paths 16 and 20, assuming that all of them would be triggered artificially in future.

On average, 2.3 avalanches are artificially triggered during a year for the avalanche paths 22 and 23 and 6.5 for the avalanche paths 16 and 20. To conduct an artificial release in the study area, a compressed air canon “Avalancheur” is selected as an alternative for a mortar shooting. Depending on the snow conditions, usually from one to ten shots are needed to release an avalanche. Therefore, two ranges are proposed for the calculation:

- 2 shots in terms of triggering relatively small avalanches shortly after the snowfall;

[12] The lifetime of a snow net was taken as 30 years.

- 4 shots for either avalanches of a medium size, or for delayed artificial triggering operations.

Accordingly, the cost for the shooting ranges from RUB 230,912 to 461,824. Here the cost of one explosive load is applied as RUB 13,120 (Stoffel 2013).

The third mitigation option aims at artificial release of rather small avalanches, which stop in the slope and decrease snow accumulation and formation of big avalanches capable to hit the studied railway and road sections. The intensity of artificial release for the studied area was calculated assuming that shooting is performed for the days with a high hazard and adopts number of days when railway and road closure is recommended. For the number of required shots, the same assumption, used in the second mitigation option, is applied. The total costs for the mitigation option lies in a range RUB 3.54 million to RUB 6.3 million, including the cost of the canon.[13]

The cost-benefit analysis together with an expected risk reduction for each alternative is summarized in Table 14. The expected risk reduction level was estimated under the assumption that the artificial release is made in proper time, and the number of days with road closure is sufficient.

Table 14: Cost-benefit analysis for the selected alternatives

Alternative	Annual cost [million RUB]	Expected risk reduction
1. Temporal closure of the railway and road	2370.00	High
2. Snow nets and artificial avalanche release	3.5 – 3.73	High
3. Artificial avalanche release	3.54 – 6.30	High

From the above-listed mitigation options, the most cost-effective solutions are structural measures and artificial avalanche release, where the costs are lower than the annual economic losses equal RUB 3.71 million. However, the cost-effectiveness of the mitigation option with structural protection is doubted to fit the purposes of the study area. It is planned that the investigated railway will become a main route for ore transportation for the period of the restoration works for the tunnel (Chernous 2012, personal communication), which makes the investment in permanent construction not feasible. Thus, artificial triggering is recommended

[13] The cost of the canon is approximately RUB 2.37 million (Stoffel 2013). The guaranteed lifetime of the canon is three years.

as a protection alternative. The cost-effectiveness of this option is insured under the condition that the required shooting is done shortly after the snowfalls, and utilize therefore minimum number of explosive charges. In terms of risk reduction for the road, all the proposed options demonstrate a high level of reduction.

5.2 Discussion and outlook

To draw a conclusion about avalanche risk for an exposed object, a study of spatio-temporal variability in hazard and damage potential is essential. To incorporate a dynamic component into a risk analysis procedure, a proper scale combined with a representative temporal resolution is required. For road and railway stretches, large scale is feasible to conduct investigation of hazardous processes and assess a spatial distribution of elements at risk in both, long-term and short-term timeframes.

In the case of the presented study, a long-term risk development mirrors a general situation in the area and is a basis to identify the most dangerous spots. A separate assessment for the road and railway sections provides risk estimation expressed in terms of fatality risk and economic losses. The results of the long-term risk assessment have been further used for the discussion on mitigation strategies and for the selection of the most cost-effective countermeasure. In a short timeframe with a daily temporal resolution, the avalanche risk assessment has been conducted only for the railway section. The short-term risk dynamics is assessed through two components: hazard and damage potential. The variations in hazard potential are modelled by the fuzzy logic system, using available meteorological parameters of mean daily temperature, mean wind speed and precipitation within 24 hours. Damage potential development is addressed through the width of the railway blockage and the number of the affected carriages. In the framework of the thesis, damage potential is assessed for the recorded avalanches on the basis of information from the avalanche cadastre. In general, the designed model demonstrates good results with regards to the avalanches hit the traffic routes, but needs a certain improvement to enable prognosis of avalanches, which stopped in the slope. In addition, a spatial interpolation of the hazard potential can be done by introduction of snow cover properties and additional topographic parameters to provide more detailed information on a possible damage potential for an individual day. Of further interest is temporal variability in damage potential for the road section, where seasonal and daily variability in daily traffic could be studied. This will be of a special importance in terms of the tourism development and the expected increase in tourists in future (Administration of Kirovsk town).

For the development of the proposed methodology on risk assessment, a research of artificially triggered avalanches and additional seismic load, as well as incorporation of wet snow avalanches can be recommended. Moreover, information about snow distribution, which can be processed as a new snow height measurements at the meteorological station or a laser scanning of the slopes, will be a powerful tool for avalanche dynamics modelling and avalanche forecasting.

5.3 Conclusion

The case study from the Khibiny Mountains shows that the adapted methodology is capable to model avalanche risk development in different timeframes, and can be implemented for snow avalanche risk assessment for traffic routes in a large-scale. Furthermore, the developed methodology can serve as a basis for dynamic risk assessment on a large-scale in Russia and be exported to another region with the required adaptation to the available data.

In the present research the dynamics of avalanche risk was addressed through a daily variability of the hazard and damage potential. According to the developed fuzzy logic system, an individual day with a certain set of meteorological parameters was simultaneously classified by a membership degree as a day with “no avalanche release expected” and a day with “avalanche release expected”. A difference in membership degrees served a basis for a decision on risk management. The damage potential was calculated for the recorded avalanche events. The dynamics in damage potential was modelled using variable number of avalanche releases and different resulting width of the railway blockage during an individual day. In addition, three scenarios were modelled with the validated avalanche dynamics model ELBA plus. The designed scenarios outline a high effect of the increased hazard as well as the elevated number of the elements at risk on the resulting monetary losses.

The results highlight the importance of the spatio-temporal variability of hazard and elements at risk. Furthermore, the findings of the conducted research represent the current situation in the region and offer a basis for the development and implementation of decision-making processes in respect to the avalanche risk.

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8. APPENDIX

Appendix A: *International morphologic avalanche classification*

Zone	Criteria	Alternative characteristics and avalanche classification	
Starting zone	Manner of starting	**A1**	Starting from a point (loose-snow avalanche)
		A2	Starting from a line(slab avalanche)
		A3	Soft slab avalanche
		A4	Hard slab avalanche
	Position of sliding surface	**B1**	Within snow cover (surface-layer avalanche)
		B2	New snow fracture
		B3	Old snow fracture
		B4	On the ground (full-depth avalanche)
Tranzit zone	Liquid water in snow	**C1**	Absent (dry snow avalanche)
		C2	Present (wet snow avalanche)
	Form of path	**D1**	Unconfined avalanche
		D2	Channelled avalanche
	Form of movement	**E1**	Cloud of snow dust (powder avalanche)
		E2	Along the surface of slope (flowing avalanche)
Deposition zone	Surface roughness of deposits	**F1**	Coarse (coarse deposits)
		F2	Angular blocks (debris)
		F3	Rounded clods
		F4	Fine (finedeposits)
	Liquid water in snow debris at time of deposition	**G1**	Absent (dry avalanche deposits)
		G2	Present (wet avalanche deposits)
	Contamination of the debris	**H1**	No distinct contamination (clean avalanche)
		H2	Presence of contamination
		H3	Bedrock fragments
		H4	Trees, tree branches

Appendix B: *The most destructive events in the area*

Avalanche site	**Date**	**Resulting damage**
16	24.04.34	The railway is blocked with the locomotive and one open goods truck being overthrown.
	05.12.35	The locomotive is derailed.
17	27.02.36	The railway is blocked with one person from the railway service being buried.
	16.03.37	The railway is blocked with one member of railway service being injured.
18	18.01.35	The railway is blocked with 6 members of railway service being injured.
	14.01.62	The road is blocked with 1 car being hit.
22	07.05.34	The traffic light is destroyed with total length of 240m of railway affected.
	20.01.65	4 power line posts are destroyed with 2 car garages being buried.
	08.12.81	The railway and road are blocked with 3 car garages being destroyed.
	05.04.85	The railway and road are blocked with 6 car garages and heating pipeline being destroyed.
	09.02.87	The railway and road are blocked with 1 car garage and heating pipeline being destroyed.
23	27.11.34	The locomotive and 4 open goods trucks are buried.
	05.12.35	The locomotive is hit with 1 house being destroyed and 1 person buried and 3 injured.
	17.01.84	The railway and road are blocked with 3 car garages being destroyed.

Appendix C: *Findings of the MANOVA test*

Box's Test of equality of covariance matrices

Box's M	122.609
F	2.020
df1	56
df2	7,566.994
Sig.	0.000

The assumption of homogeneity of variance-covariance was violated, thus the Pillai's Trace test is used further to check the significance.

Multivariate tests

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta squared	Noncent. parameter	Observed power(a)
Intercept	Pillai's Trace	0.314	210.269	7.000	3,220.000	0.000	0.314	1,471.884	1,000
	Wilks' Lambda	0.686	210.269	7.000	3,220.000	0.000	0.314	1,471.884	1,000
	Hotelling's Trace	0.457	210.269	7.000	3,220.000	0.000	0.314	1,471.884	1,000
	Roy's Largest Root	0.457	210.269	7.000	3,220.000	0.000	0.314	1,471.884	1,000
Avalanche release	Pillai's Trace	0.041	9.711	14.000	6,442.000	0.000	0.021	135.950	1,000
	Wilks' Lambda	0.959	9.797	14.000	6,440.000	0.000	0.021	137.154	1,000
	Hotelling's Trace	0.043	9.883	14.000	6,438.000	0.000	0.021	138.358	1,000
	Roy's Largest Root	0.041	19.038	7.000	3,221.000	0.000	0.040	133.269	1,000

Appendix D: *Summary from the discriminant analysis*

Parameters	Avalanche release	Mean	Std. Deviation	N
Precipitation within 24 h [mm]	1	2.728	4.6455	2.968
	2	4.020	5.0713	241
	3	5.320	6.2863	20
	Total	2.840	4.7047	3.229
3 days precipitation sum [mm]	1	8.478	9.8833	2.968
	2	9.428	9.4226	241
	3	11.365	9.1944	20
	Total	8.567	9.8485	3.229
Mean wind speed [m/s]	1	4.987	5.1188	2.968
	2	7.707	4.9829	241
	3	10.618	4.7792	20
	Total	5.225	5.1727	3.229
Snow height [cm]	1	92.39	52.786	2.968
	2	111.20	47.590	241
	3	108.75	51.743	20
	Total	93.89	52.641	3.229
Snow addition 24h [cm]	1	1.13	2.676	2.968
	2	1.17	2.729	241
	3	0.60	1.789	20
	Total	1.13	2.676	3.229
Mean temperature [°C]	1	-8.201	6.0052	2.968
	2	-9.668	5.5351	241
	3	-12.723	4.7865	20
	Total	-8.338	5.9856	3.229
Temperature gradient [C°]	1	0.045	2.6872	2.968
	2	-0.108	2.9695	241
	3	-0.214	2.6889	20
	Total	0.032	2.7087	3.229

Eigenvalues

Function	Eigen value	% of Variance	Cumulative %	Canonical Correlation
1	0.041	96.3	96.3	0.199
2	0.002	3.7	100.0	0.040

Wilks' Lambda test

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 2	0.959	135.841	14	0.000
2	0.998	5.173	6	0.522

Appendix E: *Summary for the traffic census*

Time	Total number [vehicles]	Total passengers	Time	Total number [vehicles]	Total passengers
00:00	30	53	12:15	48	76
00:15	33	58	12:30	44	142
00:30	35	78	12:45	68	133
00:45	28	45	13:00	52	152
01:00	27	38	13:15	73	168
01:15	24	34	13:30	56	127
01:30	20	31	13:45	89	183
01:45	18	25	14:00	72	202
02:00	17	23	14:15	89	171
02:15	16	22	14:30	38	81
02:30	15	21	14:45	41	58
02:45	14	19	15:00	53	94
03:00	13	18	15:15	53	134
03:15	12	16	15:30	54	115
03:30	11	14	15:45	72	143
03:45	10	13	16:00	63	124
04:00	9	12	16:15	59	94
04:15	8	10	16:30	78	137
04:30	7	8	16:45	66	111
04:45	6	7	17:00	68	140
05:00	6	6	17:15	65	116
05:15	17	31	17:30	81	194
05:30	29	120	17:45	113	224
05:45	42	128	18:00	95	165
06:00	71	166	18:15	65	151
06:15	47	84	18:30	69	163
06:30	54	214	18:45	66	154
06:45	77	165	19:00	59	128
07:00	100	309	19:15	55	105
07:15	107	212	19:30	86	213
07:30	123	348	19:45	85	139
07:45	138	276	20:00	69	154
08:00	88	238	20:15	73	137
08:15	72	158	20:30	63	130
08:30	110	322	20:45	66	132
08:45	99	212	21:00	66	164
09:00	112	262	21:15	46	96
09:15	85	156	21:30	43	68
09:30	74	162	21:45	58	160
09:45	95	158	22:00	52	115
10:00	75	154	22:15	46	77
10:15	77	178	22:30	35	78
10:30	57	137	22:45	22	96
10:45	54	95	23:00	42	71
11:00	56	163	23:15	40	93
11:15	57	109	23:30	23	38
11:30	63	112	23:45	28	62
11:45	50	127	00:00	30	53
12:00	60	120			

Appendix F: *Proposed values for the dry friction coefficient*

Recommendations for the friction coefficients (SLF 1999)

Large avalanches (60,000 m^3)		**300-year**		**30-year**	
	Altitude (m a.s.l.)	μ	ξ	μ	ξ
unchannelled	above 1500	0.16	2500	0.17	2000
	1000-1500	0.18	2000	0.19	1750
	below 1500	0.20	1750	0.21	1500
channelled	above 1500	0.20	1750	0.21	1500
	1000-1500	0.25	1500	0.26	1500
	below 1500	0.30	1200	0.31	1200
gully	above 1500	0.30	1000	0.31	800
	1000-1500	0.34	750	0.35	600
	below 1000	0.38	500	0.39	400
Mean size avalanches (25,000 - 60,000 m^3)	**Altitude (m a.s.l.)**	**300-year**		**30-year**	
unchannelled	above 1500	0.20	2000	0.21	1750
	1000-1500	0.24	1500	0.25	1500
	below 1500	0.28	1200	0.29	1200
channelled	above 1500	0.26	1200	0.27	1200
	1000-1500	0.29	1200	0.31	1200
	below 1500	0.33	1000	0.34	1000
gully	above 1500	0.33	1000	0.34	800
	1000-1500	0.37	800	0.38	600
	below 1500	0.40	500	0.41	400
Small avalanches (< 25,000 m^3)	**Altitude (m a.s.l.)**	**300-year**		**30-year**	
unchannelled	above 1500	0.30	1500	0.31	1200
	1000-1000	0.32	1200	0.33	1200
	below 1500	0.34	1200	0.35	1000
channelled	above 1500	0.32	1200	0.33	1000
	1000-1500	0.34	1000	0.35	800
	below 1000	0.36	800	0.37	600
gully	above 1500	0.36	800	0.37	600
	1000-1500	0.40	500	0.41	400
	below 1000	0.42	500	0.43	400

Swiss avalanche-dynamics procedures for dense flow avalanches (Gubler 2013)

Dry friction coefficiemt (μ)	**Conditions**
	Extreme avalanches (rare avalanches) with very large volumes > $1*10^6$ m^3
	Higher altitudes, dry cold snow
0.155	Flow depth > 1 to 2 m
	As above but for dry snow at higher temperatures
0.20	Lower altitudes
	Smaller avalanches with lower mean return periods and volumes $1*10^4$ m^3
	Flow depth 1 to 2 m
0.25 - 0.30	Independent of snow type
0.30	Wet snow avalanches of any size

Appendix G: *Recorded avalanche events hit the traffic routes*

Avalanche event	Precipitation 24 h [mm]	Class	Snow height [cm]	Class	Mean wind speed [m/s]	Class	Mean temperature [°C]	Class	Number of events
04.03.1970	7.2	7.0	124	125			-12.6	-12.5	1
15.04.1971	4.3	4.5	127	125			-12.3	-12.5	1
20.04.1971	16.9	17.0	142	140			-10.3	-10.5	1
22.02.1974	6.0	6.0	148	150			-7.0	-7.0	1
23.02.1974	19.7	19.5	155	155			-4.2	-4.0	1
26.02.1974	3.4	3.5	160	160			-7.4	-7.5	4
13.03.1975	2.1	2.0	181	180			-2.7	-2.5	1
13.04.1975	2.4	2.5	190	190			-5.8	-6.0	1
14.04.1975	17.8	18.0	182	180			-10.0	-10.0	2
15.04.1975	23.5	23.5	184	185			-12.5	-12.5	1
08.04.1976	11.3	11.5	101	100			-10.3	-10.5	1
28.02.1977	2.5	2.5	103	105			-17.9	-18.0	2
24.10.1978	33.6	33.5	84	85			-6.9	-7.0	1
21.01.1979	9.0	9.0	108	110			-14.2	-14.0	1
17.11.1979	2.2	2.0	85	85			-8.9	-9.0	1
11.01.1980	5.5	5.5	112	110			-8.0	-8.0	1
14.01.1981	13.1	13.0	84	85			-13.2	-13.0	1
06.12.1981	11.5	11.5	82	80			-12.2	-12.0	1
08.12.1981	24.1	24.0	79	80			-14.8	-15.0	1
09.12.1981	13.5	13.5	72	70			-17.2	-17.0	1
15.03.1983	2.7	2.5	126	125			-11.6	-11.5	3
17.01.1984	8.1	8.0	100	100			-9.6	-9.5	2
06.02.1984	2.5	2.5	128	130			-12.1	-12.0	2
04.04.1985	12.4	12.5	131	130			-8.9	-9.0	1
05.04.1985	7.8	8.0	132	130			-11.3	-11.5	4
02.01.1986	17.4	17.5	81	80			-11.1	-11.0	1
09.02.1987	1.8	2.0	167	165			-19.0	-19.0	1
24.02.1988	3.3	3.5	60	60			-15.5	-15.5	2
15.03.1988	4.2	4.0	68	70			-12.0	-12.0	1
22.03.1988	0.4	0.5	77	75			-7.0	-7.0	1
03.01.1989	0.6	0.5					-7.5	-7.5	1
26.01.1989	3.7	3.5					-4.9	-5.0	1
21.03.1991	1.6	1.5	58	60			-14.1	-14.0	1
15.12.1991	12.1	12.0	123	125			-15.4	-15.5	3
01.04.1992	23.6	23.5	240	240			-15.3	-15.5	1
03.12.1992	13.6	13.5	50	50			-5.3	-5.5	1
28.02.1994	6.5	6.5	41	40			-15.0	-15.0	1
03.01.1995	6.4	6.5	94	95			-15.1	-15.0	1
24.01.1995	11.5	11.5	92	90			-14.0	-14.0	1
05.04.1997	8.1	8.0	158	160			-13.8	-14.0	3
05.03.1998	*2.2*	*2.0*	*109*	*110*	*11.2*	*11.0*	*-17.3*	*-17.5*	*2*
19.12.1998	*15.3*	*15.5*	*111*	*110*	*11.4*	*11.5*	*-7.5*	*-7.5*	*1*
16.12.1999	*9.5*	*9.5*	*63*	*65*	*6.6*	*6.5*	*-12.6*	*-12.5*	*1*
21.01.2000	*1.9*	*2.0*	*116*	*115*	*18.0*	*18.0*	*-13.7*	*-13.5*	*2*
05.03.2000	*15.0*	*15.0*	*160*	*160*	*12.5*	*12.5*	*-13.0*	*-13.0*	*3*
09.03.2000	*7.1*	*7.0*	*167*	*165*	*8.0*	*8.0*	*-11.9*	*-12.0*	*2*
03.04.2000	*26.5*	*26.5*	*184*	*185*	*7.3*	*7.5*	*-14.0*	*-14.0*	*2*
20.12.2000	*2.5*	*2.5*	*100*	*100*			*-9.4*	*-9.5*	*1*
17.01.2001	*0.6*	*0.5*	*109*	*110*			*-8.3*	*-8.5*	*1*
12.01.2003	*1.2*	*1.0*	*23*	*25*	*13.8*	*14.0*	*-18.6*	*-18.5*	*1*
21.01.2004	*10.2*	*10.0*	*88*	*90*	*15.0*	*15.0*	*-12.0*	*-12.0*	*1*
16.02.2004	*4.3*	*4.5*	*84*	*85*	*8.3*	*8.5*	*-15.0*	*-15.0*	*1*

Appendix G: *Recorded avalanche event hit the traffic routes (continued)*

Avalanche event	Precipitation 24 h [mm]	Class	Snow height [cm]	Class	Mean wind speed [m/s]	Class	Mean temperature [°C]	Class	Number of events
20.02.2007	*0.5*	*0.5*	*159*	*160*	*17.4*	*17.5*	*-20.0*	*-20.0*	*1*
14.02.2008	*15.3*	*15.5*	*143*	*145*	*13.0*	*13.0*	*-12.1*	*-12.0*	*2*
29.12.2008	*3.3*	*3.5*	*177*	*175*	*13.3*	*13.5*	*-1.3*	*-1.5*	*1*
31.12.2008	*15.7*	*15.5*	*176*	*175*	*12.2*	*12.0*	*-11.5*	*-11.5*	*2*
22.03.2009	*7.6*	*7.5*	*158*	*160*	*9.8*	*10.0*	*-12.2*	*-12.0*	*1*
17.02.2010	*1.6*	*1.5*	*65*	*65*	*7.1*	*7.0*	*-20.4*	*-20.5*	*1*
03.03.2010	*10.0*	*10.0*	*81*	*80*	*14.0*	*14.0*	*-10.9*	*-11.0*	*1*
04.03.2010	*10.5*	*10.5*	*67*	*65*	*14.2*	*14.0*	*-12.6*	*-12.5*	*1*
16.03.2010			*69*	*70*	*10.4*	*10.0*	*-13.8*	*-14.0*	*1*
12.11.2010	*2.1*	*2.0*	*56*	*55*	*10.8*	*11.0*	*-5.7*	*-5.5*	*1*

The avalanche events considered for the development of fuzzy logic model, used in short-term avalanche release calculation, is highlighted in italics.

Appendix H: *The time stretch for short-term risk calculation*

Date	Wind speed [m/s]	Mean daily temperature [°C]	Precipitation within 24 h [mm]	Snow height [cm]	μ_ no avalanche release	μ_ avalanche release
05.01.2010	0.0	-18.8	0.0	75	1.00	0.00
06.01.2010	0.0	-16.4	0.0	75	1.00	0.00
07.01.2010	0.0	-18.6	1.9	76	1.00	0.00
08.01.2010	*7.5*	*-16.1*	*0.0*	*76*	*0.38*	*0.37*
09.01.2010	*8.3*	*-12.0*	*0.0*	*75*	*0.88*	*0.00*
10.01.2010	0.0	-3.9	0.0	75	1.00	0.00
11.01.2010	8.9	-6.7	0.9	75	0.52	0.51
12.01.2010	8.8	-12.5	0.6	75	0.30	0.38
13.01.2010	0.0	-11.8	1.6	1	1.00	0.00
14.01.2010	7.4	-10.0	5.0	75	0.70	0.88
15.01.2010	0.0	-8.7	1,1	75	1.00	0.00
16.01.2010	10.7	-6.9	0,0	75	0.54	0.00
17.01.2010	11.0	-6.1	0,0	75	0.46	0.26
18.01.2010	12.6	-6.7	0,3	75	0.44	0.24
19.01.2010	14.4	-12.4	0,0	68	0.84	0.00
20.01.2010	13.5	-8.4	0,4	67	0.24	0.26
21.01.2010	0.0	-2.4	3.7	67	1.00	0.00
22.01.2010	0.0	-3.8	0.0	67	1.00	0.00
23.01.2010	0.0	-8.0	0.0	67	1.00	0.00
24.01.2010	0.0	-13.2	0.0	67	1.00	0.00
25.01.2010	0.0	-9.6	0.0	67	1.00	0.00
26.01.2010	19.1	-11.2	0.0	67	0.98	0.00
27.01.2010	23.1	-17.6	0.5	64	0.21	0.53
28.01.2010	16.6	-21.1	0.0	56	0.00	0.80
29.01.2010	0.0	-20.8	0.0	56	1.00	0.00
30.01.2010	0.0	-18.4	0.0	56	1.00	0.00
31.01.2010	6.6	-17.0	0.2	57	0.32	0.45
01.02.2010	*7.4*	*-16.7*	*0.6*	*58*	*0.28*	*0.42*
02.02.2010	9.4	-12.6	3.7	59	0.66	0.82
03.02.2010	7.5	-11.6	3.3	60	0.75	0.94
04.02.2010	*7.3*	*-12.4*	*5.4*	*61*	*0.67*	*0.84*
05.02.2010	8.4	-12.7	2.8	63	0.65	0.81
06.02.2010	9,3	-12.5	6.1	63	0.66	0.83
07.02.2010	7,5	-12.7	5.6	63	0.65	0.81
08.02.2010	0.0	-14.4	2.7	64	1.00	0.00
09.02.2010	0.0	-14.9	0.4	67	1.00	0.00
10.02.2010	0.0	-17.0	3.8	70	1.00	0.00
11.02.2010	8.4	-17.7	0.5	70	0.14	0.54
12.02.2010	*7.1*	*-12.8*	*0.6*	*69*	*0.30*	*0.38*
13.02.2010	*9.3*	*-7.1*	*0.5*	*68*	*0.29*	*0.36*
14.02.2010	*7.4*	*-12.0*	*4.4*	*67*	*0.70*	*0.88*
15.02.2010	8.3	-15.4	0.3	65	0.44	0.27
16.02.2010	*10.2*	*-19.2*	*0.0*	*65*	*0.10*	*0.69*
17.02.2010	**7.1**	**-20.4**	**1.6**	**65**	**0.10**	**1.00**
18.02.2010	9.2	-18.1	0.0	65	0.16	0.61
19.02.2010	0.0	-23.2	0.2	65	1.00	0.00
20.02.2010	0.0	-18.9	0.0	65	1.00	0.00
21.02.2010	0.0	-16.7	0.0	65	1.00	0.00
22.02.2010	6.1	-21.6	0.0	65	0.46	0.72
23.02.2010	6.5	-23.6	3.4	65	0.38	1.00
24.02.2010	*11.1*	*-20.5*	*2.3*	*65*	*0.00*	*1.00*
25.02.2010	0.0	-19.5	2.5	69	1.00	0.00
26.02.2010	0.0	-17.1	1.1	69	1.00	0.00
27.02.2010	7.4	-19.4	0.0	69	0.15	0.70
28.02.2010	5.9	-11.7	2.2	71	0.56	0.70
01.03.2010	0.0	-7.1	4.3	74	1.00	0.00
02.03.2010	7.8	-7.8	4.1	76	0.48	0.60
03.03.2010	**11.0**	**-10.9**	**10.0**	**81**	**0.00**	**1.00**
04.03.2010	**14.2**	**-12.6**	**10.5**	**67**	**0.00**	**1.00**
05.03.2010	7.6	-14.9	5.9	65	0.43	0.54

Appendix I: *The annual profit and loss statement for the JSC "Apatit"*

Отчет о прибылях и убытках

за январь - декабрь 2011 года

		Коды
	Форма по ОКУД	0710002
	Дата (число, месяц, год)	31 | 12 | 2011
Организация ***ОАО "АПАТИТ"***	по ОКПО	00203938
Идентификационный номер налогоплательщика	ИНН	5103070023
Вид экономической деятельности ***Добыча минерального сырья для химических производств и производства удобрений***	по ОКВЭД	14.30.00
Организационно-правовая форма/форма собственности ***открытое акционерное общество/смешанная российская собственность с долей федеральной собственности***	по ОКОПФ/ОКФС	47 | 41
Единица измерения: ***тыс. руб.***	по ОКЕИ	384

Поясне-ния	Наименование показателя	Код строки	За январь - декабрь 20 11 г.	За январь - декабрь 20 10 г.
3.14(пз)	Выручка	2110	35 155 338	36 219 895
6, 3.15(пз)	Себестоимость продаж	2120	(22 420 698)	(23 740 435)
	Валовая прибыль (убыток)	2100	12 734 640	12 479 460
6, 3.15(пз)	Коммерческие расходы	2210	(4 977 355)	(5 219 568)
6, 3.15(пз)	Управленческие расходы	2220	(2 580 608)	(2 391 550)
	Прибыль (убыток) от продаж	**2200**	**5 176 677**	**4 868 342**
3.16(пз)	Доходы от участия в других организациях	2310	1 986	10 172
3.16(пз)	Проценты к получению	2320	159 344	90 366
3.16(пз)	Проценты к уплате	2330	(5 788)	(6 900)
3.16(пз)	Прочие доходы	2340	8 996 619	12 682 543
3.16(пз)	Прочие расходы	2350	(10 165 400)	(13 680 584)
	Прибыль (убыток) до налогообложения	**2300**	**4 163 438**	**3 963 939**
3.11(пз)	Текущий налог на прибыль	2410	(960 136)	(1 127 177)
	в т.ч. постоянные налоговые обязательства (активы)	2421	127 448	334 389
	Изменение отложенных налоговых обязательств	2430	-	-
	Изменение отложенных налоговых активов	2450	-	-
3.16(пз)	Прочее	2460	17 642	2 440 743
	Чистая прибыль (убыток)	**2400**	**3 220 944**	**5 277 505**
	СПРАВОЧНО Результат от переоценки внеоборотных активов, не включаемый в чистую прибыль (убыток) периода	2510	214 469	216 683
	Результат от прочих операций, не включаемый в чистую прибыль (убыток) периода	2520	(82 753)	(97 966)
	Совокупный финансовый результат периода	2500	**3 352 660**	**5 396 222**
3.20(пз)	Базовая прибыль (убыток) на акцию (руб.)	2900	516	846
3.20(пз)	Разводненная прибыль (убыток) на акцию (руб.)	2910	516	846

Директор Кировского филиала ЗАО "ФосАгро АГ"
Генеральный директор ОАО "Апатит" _____ (подпись) К.В. Никитин (расшифровка подписи)

Главный бухгалтер ОАО "Апатит" _____ (подпись) Д.Г. Габдрахманов (расшифровка подписи)

27 марта 2012 г.

ОТКРЫТОЕ АКЦИОНЕРНОЕ ОБЩЕСТВО "АПАТИТ" МУРМАНСКАЯ ОБЛАСТЬ г. КИРОВСК РОССИЙСКАЯ ФЕДЕРАЦИЯ OPEN JOINT STOCK COMPANY "APATIT"

МЕЖРАЙОННАЯ ИФНС РОССИИ ПО КРУПНЕЙШИМ НАЛОГОПЛАТЕЛЬЩИКАМ ПО МУРМАНСКОЙ ОБЛАСТИ
30.03.12

9. LIST OF ABBREVIATIONS

ALARA - as low as reasonably achievable

a.s.l. - elevation above sea level [m]

CAS - Center for Avalanche Safety of the JSC “Apatit”

DEM - digital elevation model

DFA - discriminant function analysis

JSC - Joint-stock company

WTP - approach of willingness to pay

WTA - approach of willingness to accept

WDT - winter daily traffic, cars

UPPERCASE LETTERS

A - individual value of element at risk

B - coefficient for cohesion with road []

C_{train} - cost of damaged carriages (assuming that they are not repairable) and ore [RUB]

C_{labour} - labour costs for technical service and snow cleaning up works [RUB]

C_{ore} - cost of the transported ore in one train [RUB]

C_{snow} - costs for the snow cleaning up works by emergency response crew [RUB]

$C_{snowplough}$ - cost of the snow cleaning up works by snowplough [RUB]

F - F - ration, test statistic used in MANOVA and discriminant analysis

H_k – height of the structure [m]

H_{unc} - time needed to uncouple one damage carriage [h]

K - braking coefficient []

L – distance between structures [m]

N - total sample size []

P - possible profit [RUB]

R - risk

S - average monthly salary for Murmansk oblast [RUB]

T_i - return period of the avalanche in the avalanche path i [years]

Q_i - area of blockage [km^2]

V_{full} - monetary damage for the freight train with ore [RUB]

V_{empty} - monetary damage for the freight train without ore [RUB]

LOWERCASE LETTERS

a - acceleration of the avalanche [m/s²]

b_i - mean width of railway blockage in avalanche path i, [km]

c - resultant consequences

*d*f - degrees of freedom

$d_{ec.indirect}$ - variable economic losses [RUB]

f - function

f_l - distance factor []

g_i - width of avalanche blocking the road for avalanche path i

g - gravitation [m/s²]

h - flow height [m]

i - avalanche path, i=1, 2, 3,…, n

k_s - roughness length [m]

l_t - length of the train [km]

m_c - length of a carriage [km]

p - probability of occurrence

s - scenario

t_{car} - stopping distance for a car [km]

u_i - mean speed of the train in the avalanche path i [km/h]

v_i - mean speed of the car for avalanche path i [km/h]

v - avalanche velocity [m/s]

w_i - number of damaged carriages for a single avalanche path i []

z - number of passages within a day for an individual []

z_{train} - number of passages within a day for a train []

GREEK LETTERS

β - degree of occupancy [persons/vehicle]

Λ - Wilk's Lambda (the ration of error variance to total variance for each variable) []

λ - mean death rate in cars involved in avalanches []

χ^2 - chi-square test statistic (tests whether two categorical variables forming a contingency table are associated) []

p - statistical significance of the test []

ξ - turbulent friction coefficient [s²/m]

μ - dry friction (Coulomb friction) coefficient []

ψ - slope angle [°]

γ - Bahnfaktor []