"ECONOME-RAILWAY"

A NEW CALCULATION METHOD AND TOOL FOR COMPARING THE EFFECTIVENESS AND THE COST-EFFICIENCY OF PROTECTIVE MEASURES ALONG RAILWAYS

Michael Bründl[1], Cornelia Winkler[2] and Reto Baumann[3]

ABSTRACT

Limited financial resources require the evaluation of mitigation measures against natural hazards concerning their effectiveness and their economic efficiency. In Switzerland, the online calculation tool "EconoMe" allowing for analysing the benefit-cost-ratio of mitigation measures is in operational use since the beginning of 2008. Since specific requirements to risk assessments along railway are not completely fulfilled by "EconoMe", several railway companies in Switzerland decided to develop "EconoMe-Railway". In this paper we present the general concept and the methodologies implemented in "EconoMe-Railway" and show its application by an example. The results of the presented case study indicate, that risk to persons are contributing to the overall risk at most, while economic factors like e.g. interruption costs have a less significant influence on the results of a risk analysis. However, this conclusion might be case-specific and cannot be transferred to other examples.

Keywords: risk assessment, benefit-cost-analysis, railway

INTRODUCTION

Public money is used to finance the protection of human life, of material assets and of the environment against natural hazards. This limited resource should be used in a way that achieves the maximum possible effect by minimizing as many risks as possible. Hence, every decision-maker faces the question as to the areas in which resources should be used. Cost-benefit analyses (CBA) are recognized instruments for determining the economic efficiency of investments and mitigation measures. However, a workshop with Swiss natural hazard experts has indicated that risk analyses, conducted by different consultants using a calculation tool allowing the user to change calculation factors, cannot be compared to each other. The results strongly depend on selected methods, assumptions, parameters and input variables. When system boundaries, methods and variables differ too much, the comparability of CBA deteriorates. The conclusion was that a tool for comparable risk assessment and CBA was needed (Krummenacher et al., 2006).

In the beginning of 2008, "EconoMe 2.1", an online tool for the evaluation of the effectiveness and the efficiency of mitigation measures, was introduced to practice by the Federal Office for the Environment for prioritising subsidised mitigation projects (BAFU, 2011a). With the introduction of "EconoMe 2.1", the results produced by the older Microsoft Excel ® tool used by the Swiss Railway Company SBB since 2005 (Burkard and Winkler, 2005) were no longer comparable. The development of a new calculation tool became necessary.

The main driving factor for developing "EconoMe-Railway" was the comparability of risk analyses and benefit-cost-analyses of mitigation measures. The new tool should be compatible with "EconoMe 2.1". Additionally, it should address specific requirements of railway companies to risk analyses. One important factor is the availability of a railway route. The closure of an important railway route can cause more financial loss than damage to railway infrastructure. Thus, "EconoMe-Railway" should

[1] Dr. Michael Bründl, WSL Institute for Snow and Avalanche Research SLF, Flüelastrasse 11, 7206 Davos-Dorf (e-mail: bruendl@slf.ch)
[2] Cornelia Winkler, NATUR.ING, Sebastianplatz 1, 3900 Brig-Glis (e-mail: c.winkler@naturing.ch)
[3] Reto Baumann, Federal Office for the Environment FOEN, 3003 Bern (e-mail: reto.baumann@bafu.admin.ch).

allow for estimating interruption costs (Winkler, 2011) and integrating them into the resulting risk; a factor, which is not regarded in “EconoMe 2.1”.
In this paper we provide an overview on the online tool “EconoMe-Railway (BAFU and BAV, 2001). After a brief introduction into the general approach of “EconoMe”, we will present the methodology implemented in “EconoMe-Railway”. In the second part we will illustrate the application of EconoMe-Railway in practice. Finally, we will discuss the results and the difficulties that come across in a risk assessment for traffic routes and we will give some conclusions.

GENERAL APPROACH IN ECONOME

“EconoMe-Railway” bases on the risk concept and the methodology as implemented in “EconoMe 2.1”, the online tool used by the Federal Office for the Environment (FOEN) for prioritising mitigation projects. The risk concept as applied for dealing with natural hazards in Switzerland is documented in the guideline RIKO (Bründl, 2009); it serves as the theoretical backbone for “EconoMe 2.1” (Bründl et al., 2009). “EconoMe 2.1” (BAFU, 2011a) enables planning engineers, investors and authorities responsible for the mitigation of avalanche, flood, slide, unconfined debris flow and rock fall processes to carry out comparative CBA. The benefit-cost-ratio is calculated as the ratio of annual risk reduction by mitigation measures and its annual costs. Risk is defined as a function of the probability of a process p_j in scenario j, the probability $p(s)_j$ that a process hits the object i in scenario j, the probability $p(e)_j$ of exposure of an object i, the number of objects N_i, the value of objects W_i, and the vulnerability of object i, $V_{i,j}$, in scenario j (eq. 1). The total risk is the sum of all object risks in all regarded scenarios j (eq. 2).

$$R_{i,j} = f(p_j, p(s)_j, p(e)_i, N_i, W_i, V_{i,j}) \tag{1}$$

$$R = \sum_j \sum_i R_{i,j} \tag{2}$$

The annual risk reduction $R(r)$ is calculated as difference of risk before mitigation measures $R(bm)$ and the remaining risk assumed to remain after realising mitigation measures $R(am)$. The costs of mitigation measures $C(y)$ are assessed as annuity value of the initial investment $I(0)$, the annual costs for maintenance $C(m)$ and operation $C(o)$, a residual value $L(n)$ after the lifetime n and an interest rate p for discounting this annuity value following Wilhelm (1999):

$$C(y) = C(m) + C(o) + \frac{I(0) - L(n)}{n} + \frac{I(0) + L(n)}{2} \cdot \frac{p}{100} \tag{3}$$

The benefit-cost-ratio is finally determined as:

$$BCR = \frac{R(r)}{C(y)} \geq 1, \tag{4}$$

with BCR greater or equal one expressing that the mitigation measure is economical efficient. The comparability of BCR is achieved by limiting the number of considered scenarios between three (minimum) and five scenarios (maximum) with typical return period of ≤ 10, 30, 100, 300 years and by using predefined values for calculating the risk. These values (e.g. vulnerability $V_{i,j}$) are defined as mean values aiming at comparability and not at producing precise results for a specific situation. In order to aggregate risk to persons and risks to assets to one risk value, the value of statistical life (VSL) is taken for monetising fatalities prevented by mitigation measures. According to existing values in the literature (e.g. Rheinberger, 2011; Hammitt and Robinson, 2011) Swiss authorities responsible for natural hazard management agreed to fix this value at CHF 5 million.
The workflow in “EconoMe 2.1” follows the risk concept as described in the guideline RIKO (Bründl, 2009) and guides the user step-by-step through risk analysis, risk evaluation and evaluation of an analysed mitigation project by its benefit-cost-ratio as described above. The workflow and the

structure of “EconoMe 2.1” served as the basis for the development of “EconoMe-Railway”, which will be presented in the following section.

METHODOLOGY ECONOME-RAILWAY

One important step of innovation of “EconoMe-Railway” was the collaboration of the Swiss Federal Office for the Environment (FOEN), the Swiss Federal Office of Transport (FOT), and the most important Swiss railway companies aiming at the development of a common tool for risk assessment and economic evaluation of mitigation measures along railways, which is compatible with “EconoMe 2.1”. Mitigation measures along railways in Switzerland are paid either to 100% by the railway company, or partly by the railway company, FOEN, FOT, and other beneficiaries. In many cases FOEN is partly subsiding mitigation measures along railways; therefore, it was interested in a high compatibility of EconoMe-Railway with “EconoMe 2.1”. Based on the risk concept (Fig. 1), “EconoMe-Railway” is able to deal with Alpine natural hazards like avalanches, rock fall and rock avalanches, flood, debris flow, spontaneous, shallow landslides and permanent landslides.

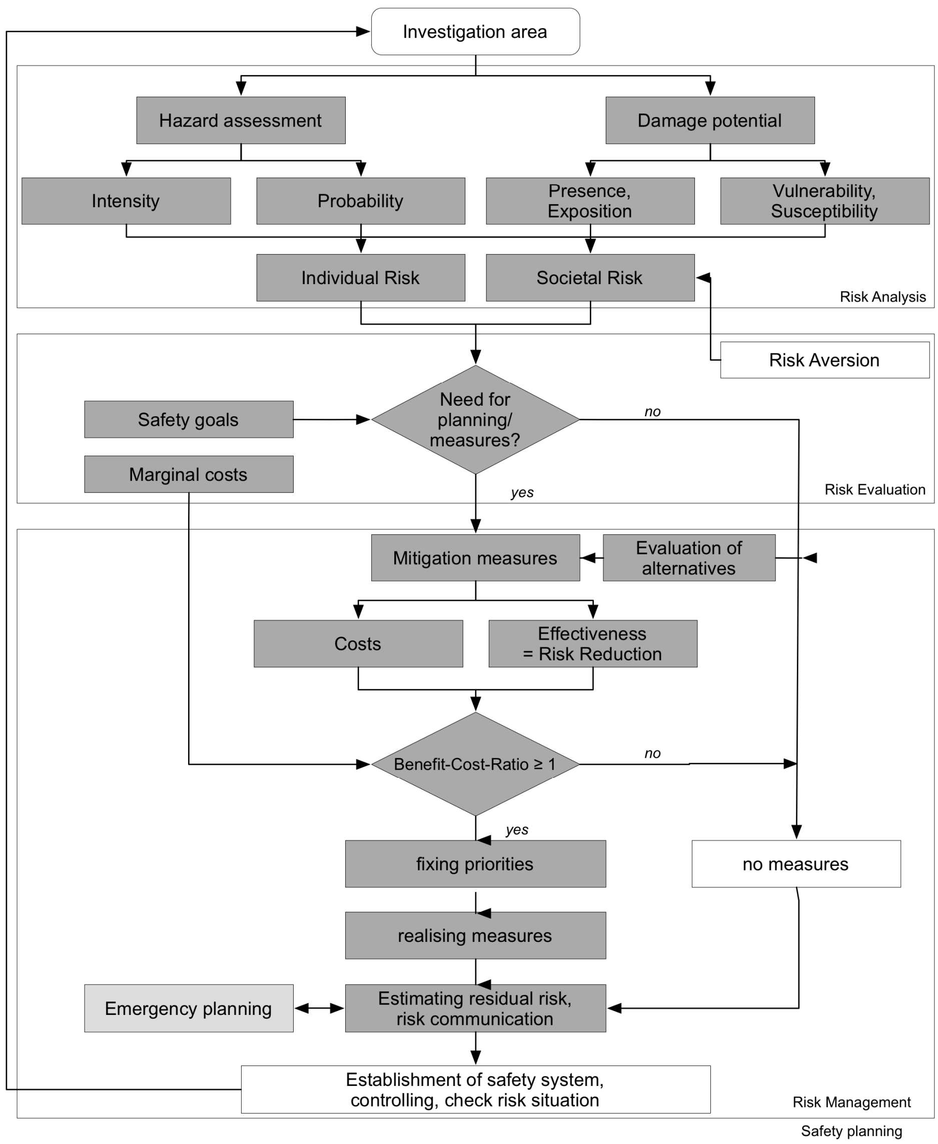


Fig. 1 Schematic illustration of safety planning as it is implemented in “EconoMe-Railway”. This concept follows the risk concept documented in the guideline RIKO (Bründl, 2009).

The risk analysis consists of a hazard analysis and an analysis of the damage potential (Fig. 1). The results of the hazard analysis are intensity maps for various scenarios, which show the physical impact and the spatial extent of processes according to the Swiss guidelines (BFF and SLF, 1984; Loat and Petrascheck, 1997; Lateltin et al., 1997). Their quality is very significant for the results of risk analyses, as sensitivity analyses with "EconoMe" have shown (Schaub and Bründl, 2010). The result of the risk analysis are values of the individual risk and the societal (or collective) risk, i.e. the sum of all risks to persons and material assets but also expected economic loss due to interruption of railway tracks.

In risk evaluation it has to be decided whether mitigation measures have to be taken. One criterion is the individual risk. The individual risk of a person in train is not allowed to exceed 10^{-5}/year due to the protection goal, the authorities responsible for natural hazard management in Switzerland have agreed to (BAFU, 2011a; BAFU and BAV, 2011). If this threshold is exceeded, measures have to be taken. The threshold of 10^{-5} is well in line with comparable values in the literature (e.g. Pate-Cornell, 2002; Jonkman et al., 2008).

In the following risk management step (Fig. 1) mitigation measures are evaluated against their economical, ecological and social compatibility. Economical compatibility is assessed by the benefit-cost-ratio (eq. 4), while the two other are assessed qualitatively.

Along railways there are different damage profiles that have to be considered. Therefore, one crucial step in the development of "EconoMe-Railway" was to structure various damage profiles with an event tree (Fig. 2).

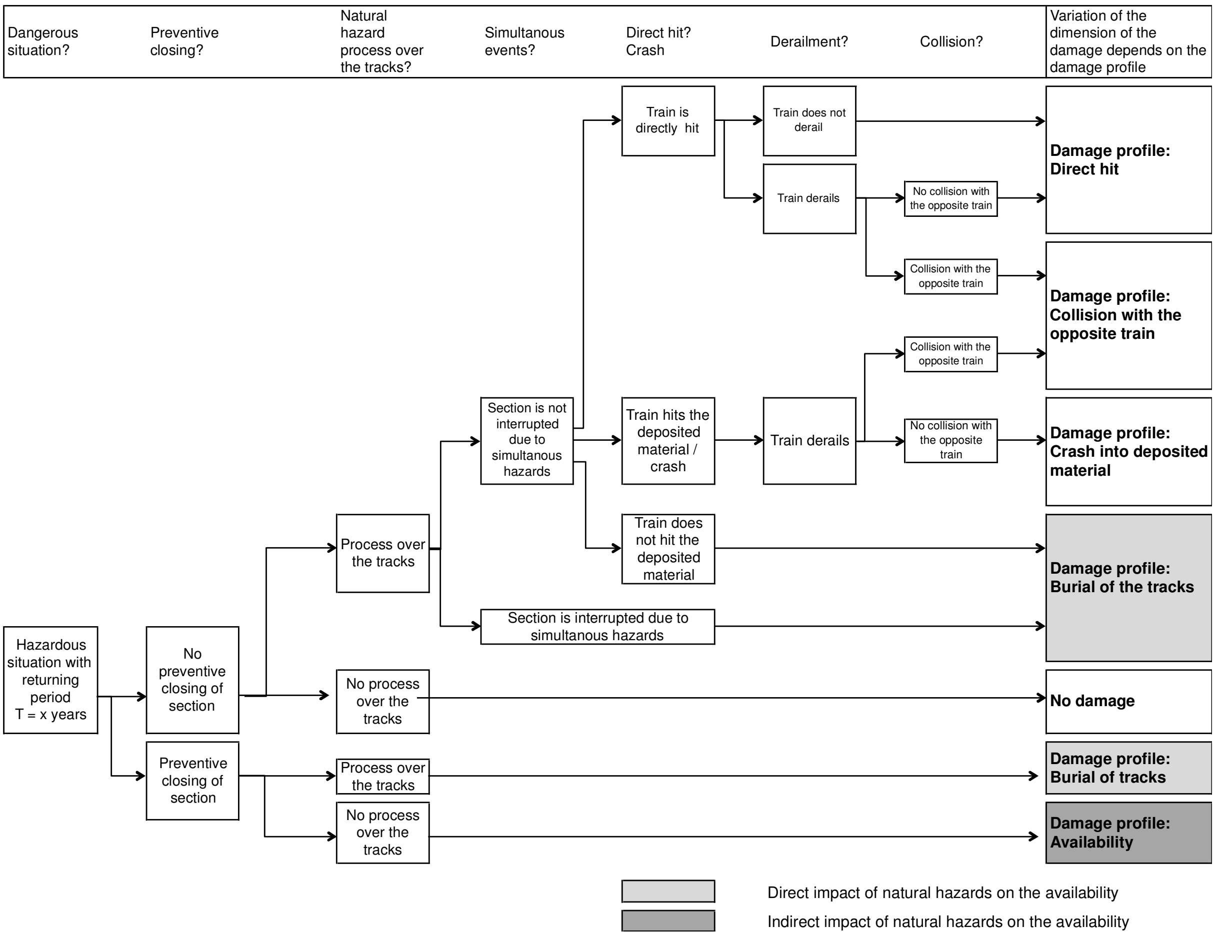


Fig. 2 Event tree "EconoMe-Railway". The event tree illustrates the various damage profiles taken into account for risk analysis.

Starting with the assumption that a train is entering a section endangered by a hazard process with a return period of x years, it is divided into main categories that serve as criteria for branching. These are: preventive closure (yes/no), hazard process over the track (yes/no), simultaneous events in the railway section (yes/no), direct hit (yes/no), collision with deposited material on the track (yes/no), derailment (yes/no), and collision with an oncoming train (yes/no). The event shows various damage profiles at the right side as a consequence of subsequent incidents potentially occurring along a railway. The damage of each of these damage profiles is calculated and contributes to the risk. Equations and assumptions used for the calculation of risk are summarized in the documentary report of "EconoMe-Railway" (Winkler et al., 2011).

The access to "EconoMe-Railway" is restricted to persons authorized by the subsiding organisation. The workflow in "EconoMe-Railway" is strictly organised. The user is guided step-by-step through the risk analysis task, the risk evaluation task and the evaluation of an analysed mitigation project by its benefit-cost-ratio. The mandatory working procedure consisting of ten steps allows a subsequent step only when the preceding step was successfully finished (Fig. 3).

Projektfortschritt

Aktion	Arbeitsschritt	Bearbeiter	Datum/Zeit	Status
	1. Projektleiter benachrichtigen	Winkler, Cornelia	13.04.11, 16:03:02	
	2. Systembeschreibung	Laeubli , Lara	26.04.11, 09:51:20	
	3. Gefahrenanalyse und Szenariendefinition	Laeubli , Lara	16.05.11, 11:14:52	
	4. Schadenpotential im Perimeter	Laeubli , Lara	26.04.11, 09:52:15	
	5. Konsequenzenanalyse	Laeubli , Lara	26.04.11, 09:48:20	
	6. Individuelles Risiko	Laeubli , Lara	19.04.11, 16:25:48	
	7. Definition der Massnahme	Laeubli , Lara	19.04.11, 17:44:29	
	8. Konsequenzenanalyse nach Massnahme			
	9. Individuelles Risiko nach Massnahme			
	10. Übersicht Risiken und Kosten			
	11. Projektabschluss			

Fig. 3 Depiction of the workflow implemented in "EconoMe-Railway". The working procedure demands that every step has to be successfully finished before the next step can be started. Finished working steps are indicated in green (status symbol: hook), working steps in progress in yellow (status symbol: wrench) and remaining working steps in red (status symbol: closed lock).

- Step 1: Message to project leader: the organization responsible for subsidizing a mitigation project is initiating a project and is sending a password to the project leader;
- Step 2: Description of the investigated site: the section under investigation is described by the frequency of trains, the length of trains, the velocity, the number of passengers, the monetary value of trains, the number of tracks, interruption cost per day, etc. Additionally, the prevailing hazard processes are defined;
- Step 3: Analysis and definition of scenarios: the scenarios for each of the considered hazard processes (e.g. ≤ 10-year, 30-year, 100-year, 300-year event for avalanches and debris flows) are defined. For each scenario of each process the percentage of the affected section length, the probability of processes hitting the track, the probability of interruption due to simultaneous events, the duration of interruption, the probability of preventive closure, the duration of interruption due to preventive closure, and the probability that the driver is instructed to drive on-sight is estimated.
- Step 4: Determination of the damage potential: the damage potential like tracks, stations, and other infrastructure along the section is characterized by length, number and type of trains, number of passengers in each train type, velocity of each train type, and the monetary value.
- Step 5: Consequence analysis before mitigation: this is the crucial step of risk analysis. Based on the impact of a hazard indicated as intensity in the intensity maps, the consequences for each of the considered scenarios of each process, i.e. the damages, are calculated. The resulting damages are separately listed for each damage profile. Based on the frequency of the scenarios the annual risk can be calculated (Fig. 4).
- Step 6: Calculation of individual risk before mitigation: the risk to an individual person depending on the frequency of passing the endangered section (normally 2 – 4 times per day) is calculated.

- Step 7: Definition of mitigation measure(s): various mitigation measures and combination of measures are defined and described by initial investment, annual costs for maintenance and operation, and lifetime *n*. The annual costs of mitigation measures are calculated according to eq. 3.
- Step 8: Consequence analysis after mitigation: this step is a repetition of step 5; however, the effectiveness of the mitigation measures is taken into account by using intensity maps including the effect of the considered mitigation measures. The remaining annual risk should be significantly lower compared to the risk before measures (step 5). The difference of the risk obtained in step 3 and step 5 yields the reduced risk, i.e. the benefit of the mitigation measures.
- Step 9: Calculation of individual risk after mitigation: this step is a repetition of step 6 but with regard to the effect of mitigation measures.
- Step 10: Overview on risks and costs: in this step an overview on the calculated risk of each scenario is presented; it allows for a comparison of risk reduction and cost, i.e. the benefit-cost-ratio.
- Step 11: Close of project: the working procedure is finished and reports including the results can be stored or printed.

"EconoMe-Railway" was completed in May 2011. Currently, it is tested by all involved railway companies. First applications indicate slightly different results from "EconoMe" mainly due to additional damage profiles. In the following section the application of "EconoMe-Railway" is presented by an example.

APPLICATION OF ECONOME-RAILWAY IN A CASE STUDY

Due to data protection reasons we will present an anonymous example. The chosen railway section (hereafter named as section A) is a single track railway and part of a larger section endangered by rock fall. For the hazard analysis we chose a 1-year, a 30-year, a 100-year, and a 300-year scenario. The methodology and all equations that are implemented in the calculation tool are documented in the methodology handbook available on the Website of "EconoMe-Railway" (Winkler et al., 2011). For the risk analysis a number of data and factors are necessary, summarised in Tab. 1.

Tab. 1 Data and factors used for risk analysis of sector A.

Data, Factor	Value
Length of railway section	2,265 m
Length intensity class in scenario 1-year (low/medium/high)	795/610/0 m
Length intensity class in scenario 30-, 100-year (low/medium/high)	0/795/610 m
Length intensity class in scenario 300-year (low/medium/high)	0/0/1405 m
Frequency trains / day	53
Velocity trains	80 km/h
Length of trains	83 m
Average number of passengers per train	44
Monetary value of train	5 million CHF
Interruption costs for duration of 1 – 3 days	100,000 CHF / day
Interruption costs for duration of 4 – 7 days	200,000 CHF /day
Interruption costs for duration > 7 days	100,000 CHF / day
Value of statistical life (VSL) for averting a fatality	5 million CHF / averted fatality

The intensity maps of the 100-year and the 300-year section A are shown in Fig. 4 (sections of equal intensity are the same for the 30-, and the 100-year scenario). The three intensity classes were selected according to the Swiss guidelines for hazard mapping for rock movements (Lateltin et al., 1997) considering the kinetic energy of rocks. Low intensity (marked with “l” in Fig. 4) holds for kinetic energy below 30 kJ, medium intensity (marked with “m” in Fig. 4) for a kinetic energy between 30 and 300 kJ and high intensity (marked with “h” in Fig. 4) for a kinetic energy of larger than 300 kJ.

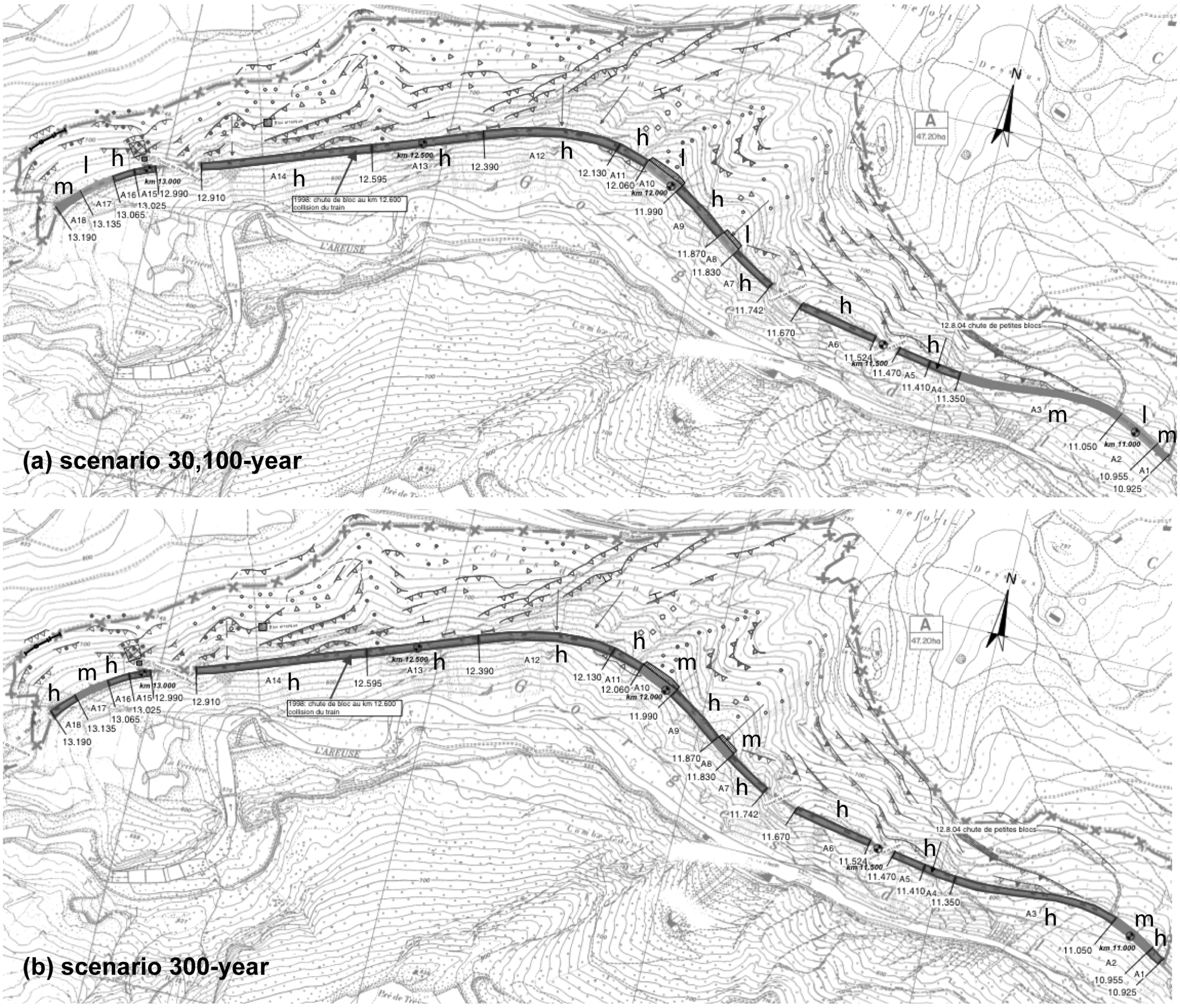


Fig. 4 Intensity maps of the railway section A. Low intensity is marked with “l”, medium intensity with “m”, high intensity with “h” according to the Swiss guidelines for hazard mapping of rock fall (Lateltin et al., 1997). In the 1-year scenario the length of low intensity corresponds to the length of medium intensity in the 30-, 100-year scenario; the length of medium intensity (1-year scenario) corresponds to high intensity in the 30-, 100-year scenario.

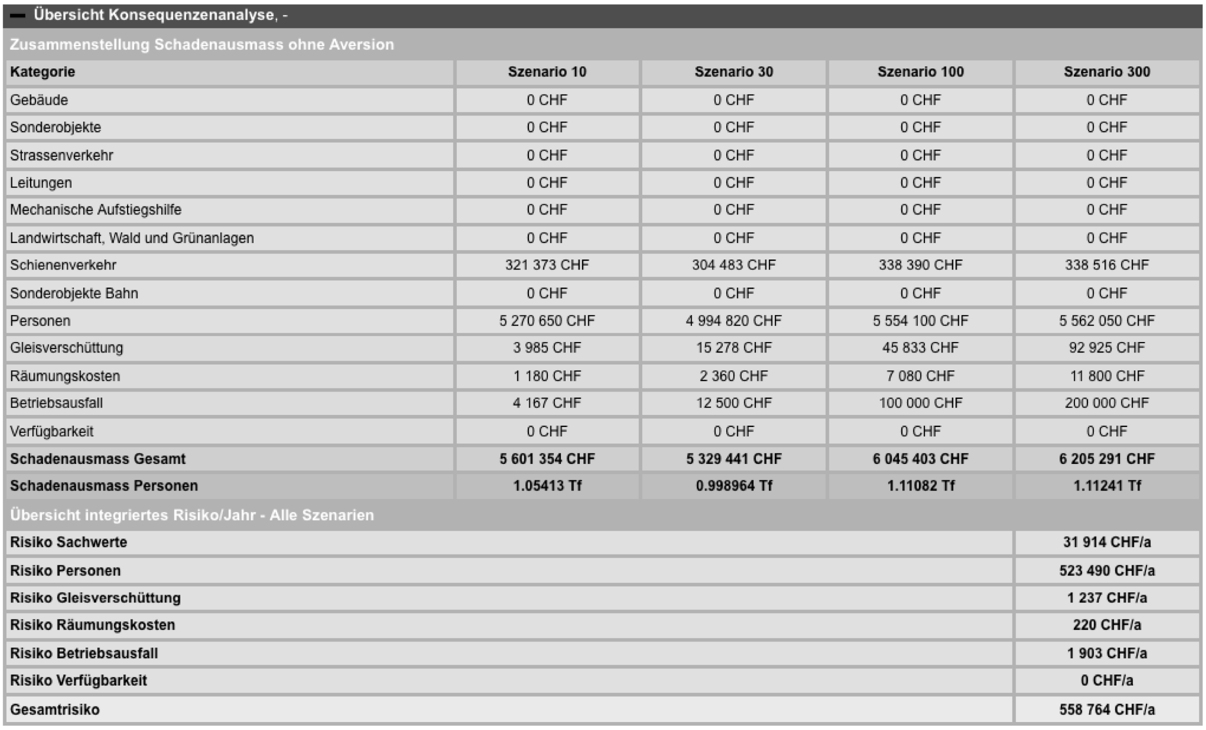
Based on these assumptions the risk to persons, railway infrastructure and risk due to spillage of tracks, clearing and interruption was calculated. The results show that without measures risk to railway infrastructure and risk to persons contribute to 99% of the risks, while risk due to spillage of tracks, clearing and interruption contributes to only 1% (Tab. 2). For mitigating the risks rock fall net fences were considered at annual cost of 280,000 CHF (invest sum: 5.6 million CHF; annual maintenance costs: 112,000 CHF, lifetime: 50 years; discounting rate: 2%, according to eq. 3).

This mitigation measure would completely reduce the risk in the 1-, 30-, and 100-year scenarios, whereas the risk in the 300-year scenario would not be reduced. Risk reduction ranges between 90 and 100% for the different categories.

Tab. 2 Damage and risk in all scenarios before and after measures.

Category	Damage before measures [CHF]				Damage after measures [CHF]			
	Sc 1	Sc 30	Sc 100	Sc 300	Sc 1	Sc 30	Sc 100	Sc 300
Railway infrastructure	321,103	305,241	343,558	354,908	0	0	0	354,908
Persons	2,827,825	2,713,235	3,139,860	3,517,045	0	0	0	3,517,045
Spillage of track	17,120	63,473	190,418	442,575	0	0	0	442,575
Clearing costs	5,620	11,240	33,720	56,200	0	0	0	56,200
Interruption costs	4,167	12,500	100,000	200,000	0	0	0	0
Availability	0	0	0	0				0
Risk assets	331,699 CHF/yr				1,183 CHF/yr			
Risk persons	2,923,790 CHF/yr				11,723 CHF/yr			
Risk spillage of tracks	21,346 CHF/yr				1,475 CHF/yr			
Risk clearing costs	6,294 CHF/yr				187 CHF/yr			
Risk interruption costs	5,792 CHF/yr				0 CHF/yr			
Risk availability	0 CHF/yr				0 CHF/yr			
Total risk	3,288,920 CHF/yr				14,569 CHF/yr			

A closer look to the results of the consequence analysis considering mitigation measures (step 8) for the 300-year scenario is shown in Fig. 5. It indicates that damage due to collision with deposited material on the tracks ("Anprall" in Fig. 5) contributes mainly to the damage to persons compared to the risk due to a direct hit of the train ("Direkttreffer" in Fig. 5). Spillage of the track ("Gleisverschüttung" in Fig. 5) also significantly contributes to the damage in the 300-year scenario. However, the main damage is composed of damage to persons, which is monetised with 5 million CHF per fatality (VSL).



Übersicht Konsequenzenanalyse, -				
Zusammenstellung Schadenausmass ohne Aversion				
Kategorie	Szenario 10	Szenario 30	Szenario 100	Szenario 300
Gebäude	0 CHF	0 CHF	0 CHF	0 CHF
Sonderobjekte	0 CHF	0 CHF	0 CHF	0 CHF
Strassenverkehr	0 CHF	0 CHF	0 CHF	0 CHF
Leitungen	0 CHF	0 CHF	0 CHF	0 CHF
Mechanische Aufstiegshilfe	0 CHF	0 CHF	0 CHF	0 CHF
Landwirtschaft, Wald und Grünanlagen	0 CHF	0 CHF	0 CHF	0 CHF
Schienenverkehr	321 373 CHF	304 483 CHF	338 390 CHF	338 516 CHF
Sonderobjekte Bahn	0 CHF	0 CHF	0 CHF	0 CHF
Personen	5 270 650 CHF	4 994 820 CHF	5 554 100 CHF	5 562 050 CHF
Gleisverschüttung	3 985 CHF	15 278 CHF	45 833 CHF	92 925 CHF
Räumungskosten	1 180 CHF	2 360 CHF	7 080 CHF	11 800 CHF
Betriebsausfall	4 167 CHF	12 500 CHF	100 000 CHF	200 000 CHF
Verfügbarkeit	0 CHF	0 CHF	0 CHF	0 CHF
Schadenausmass Gesamt	**5 601 354 CHF**	**5 329 441 CHF**	**6 045 403 CHF**	**6 205 291 CHF**
Schadenausmass Personen	**1.05413 Tf**	**0.998964 Tf**	**1.11082 Tf**	**1.11241 Tf**
Übersicht integriertes Risiko/Jahr - Alle Szenarien				
Risiko Sachwerte				**31 914 CHF/a**
Risiko Personen				**523 490 CHF/a**
Risiko Gleisverschüttung				**1 237 CHF/a**
Risiko Räumungskosten				**220 CHF/a**
Risiko Betriebsausfall				**1 903 CHF/a**
Risiko Verfügbarkeit				**0 CHF/a**
Gesamtrisiko				**558 764 CHF/a**

Fig. 5 Results of step 8 in "EconoMe-Railway" presenting the results for the 300-year scenario. The table gives an overview on damages for all considered damage profiles (see Fig. 2). Fatalities are monetised with 5 million CHF (VSL). The total risk considering mitigation measures amounts to 14,600 CHF/year. Translation of terms: Schadenausmass = damage; Risiko = risk; Jahr = year; Personen = persons; Sachwerte = assets; Gesamt = total; Ereignis = event; Todesfälle = fatalities; Fahren auf Sicht = driving on sight; vorsorgliche Sperrung = precautionary closure; Personenzug = passenger train; Güterzug = cargo train; Direkttreffer = direct hit; Anprall = collision with rocks on tracks; Kollision = collision with oncoming train; Gleisverschüttung = spillage of tracks; Räumungskosten = clearing costs; Betriebsunterbruch = interruption costs; Verfügbarkeit = availability.

Given a risk reduction of 3.3 million CHF per year and annual costs of mitigation measures of 280,000 CHF per year the benefit-cost-ratio is calculated as 11.8, meaning that 1 CHF invested in mitigation prevents 12 CHF of damage (considering the factors and the assumptions of the risk analysis).

DISCUSSION AND CONCLUSION

In mountainous regions safe and reliable traffic routes are indispensible for economic welfare. Therefore, it is the goal of authorities in charge for safety to achieve the maximum level of safety at reasonable cost. Risk-based decision making and evaluation of economic efficiency of mitigation measures for buildings and traffic routes has become state-of-the-art (e.g. Gamper et al., 2006; Budetta, 2004; Agliardi et al., 2009; Rheinberger et al., 2009). In Switzerland, the national strategy for dealing with natural hazards is based on the risk concept (PLANAT, 2005), which has been implemented during the last years by several calculation tools for risk assessment and benefit-cost-analysis of mitigation measures (Bründl et al., 2009; BAFU, 2011a, 2011b; ASTRA, 2011). One of these calculation tools is "EconoMe-Railway" (BAFU and BAV, 2011), which is based on "EconoMe", a decision support tool for cantons and for the Federal Office for the Environment for prioritising mitigation measures (BAFU, 2011a). "EconoMe-Railway" was developed for addressing the specific needs of the Swiss railway companies to risk assessment and to the evaluation of mitigation measures. "EconoMe-Railway" allows for considering various damage profiles typical for railway traffic like e.g. direct hit, collision with deposited material on tracks, collision with oncoming trains; additionally, the economic consequences of business interruptions caused by deposited material on tracks or the economic consequences precautionary closures can be calculated. As started by representatives of railway companies, these economic consequences often cause significantly larger financial loss than direct damages to railway infrastructure. This statement is confirmed by a case study along the Lecco-Colico railway, where an 8-day long traffic interruption caused by a rock fall of 4000 – 5000 m^3 caused significant economic losses for the railway company, estimated to be about 1,600,000 Euro (Agliardi et al., 2009).

"EconoMe-Railway" was developed as an online tool, which can only be accessed by authorised users, who are in charge of assessing risk on railways and planning of mitigation measures. The mandatory working steps are in close agreement with the general risk concept and to comparable analyses of natural risks along transportation lines (Jaiswal et al., 2010). The application of "EconoMe-Railway" is illustrated by a case study of a railway section in the Swiss Alps endangered by rock fall. The results of this case study showed that risks to persons and to assets contributed to over 90% of the total risk. Risk to persons caused by collision of the train with deposited material on the track is the main reason for fatalities in this study. This might be due to the fact that the probability of fatalities is modelled as probably too high in the damage profile "collision with material on the track". In "EconoMe-Railway" the fatality rate depends on the velocity of the train and the terrain type in the area of an accident. In the regarded case the lethality is assumed to be 0.015 (hilly terrain, velocity 80 km/h). Since the data base for comparable accidents is thin, risk assessment along railways have to base on rough assumptions. Consequent recording of such accidents is necessary in order to improve the data basis and the results of risk assessments along railways.

Despite these uncertainties, "EconoMe-Railway" makes risk assessments and benefit-cost-analyses along railways comparable and supports authorities and planning engineers in their decision-making regarding the efficient use of resources. Experiences gained with the tools of the "EconoMe-family" (BAFU, 2011a,b; BAFU, BAV, 2011) so far are indicating that user-friendly risk assessment tool are supporting risk-based decision making.

ACKNOWLEDGEMENTS

The development of "EconoMe-Railway" was supported by the Swiss Railway Company SBB, the Bern-Lötschberg-Simplon Railway Company BLS, the Bernese Oberland Railway Company BOB, the Matterhorn-Gotthard Railway Company MGB, the Rhatian Railway Company RhB, the Zentralbahn, the Federal Office for Traffic, and the Federal Office for the Environment. We thank for fruitful discussions and financial support. We especially thank Peter Gutwein, GRSoft for his patience and his support during the development phase of "EconoMe-Railway". Parts of this study were elaborated within the Interreg Project PARAmount ("imProved Accessibility: Reliability and security of Alpine transport infrastructure related to mountainous hazards in a changing climate"). The first author thanks the Center for Interdisciplinary Research (ZiF) in Bielefeld for the excellent support during his fellowship in the research group “Communicating Disaster”. We also thank an anonymous reviewer for valuable comments.

REFERENCES

Agliardi F., Crosta G. B., Frattini P. (2009). Integrating rockfall risk assessment and countermeasure design by 3D modelling techniques. Natural Hazards and Earth System Sciences, 9: 1059-1073.

ASTRA (2011). RoadRisk 1.0. Beurteilung von Naturgefahren auf Nationalstrassen. http://www.roadrisk.admin.ch. Federal Roads Office, Bern. (Access 4 October 2011).

BAFU (2011a). EconoMe 2.1. Wirtschaftlichkeit von Schutzmassnahmen gegen Naturgefahren. www.econome.admin.ch. Federal Office for the Environment, Bern. (Access 4 October 2011).

BAFU (2011b). EconoMe-Develop 1.0. Wirtschaftlichkeit von Schutzmassnahmen gegen Naturgefahren. www.econome-develop.admin.ch. Federal Office for the Environment, Bern. (Access 4 October 2011).

BAFU, BAV (2011). EconoMe-Railway 1.0. http://www.econome.ch/eco_rail. Federal Office for the Environment and Federal Office for Transport, Bern. (Access 4 October 2011).

BFF, SLF (1984). Richtlinien zur Berücksichtigung der Lawinengefahr bei raumwirksamen Tätigkeiten. EDMZ, Bern.

Bründl M. (Editor) (2009). Risikokonzept für Naturgefahren. Einzelprojekt A1.1: Leitfaden. Nationale Plattform Naturgefahren PLANAT, Bern, 420 pp. http://www.planat.ch. (Access 1 September 2011).

Bründl M., Romang H., Bischof N., Rheinberger Ch. (2009). The Risk Concept and Its Application in Natural Hazard Risk Management in Switzerland. Natural Hazards and Earth System Sciences, 9(3): 801-813.

Budetta P. (2004). Assessment of rockfall risk along roads. Nat. Hazards Earth Syst. Sci., 4(1): 71-81.

Burkard A., Winkler C. (2005). Pflichtenheft Risikoanalysen Naturgefahren SBB. Mit Excel-Anwendungs-Tool. Brig.

Gamper C.D., Thöni M., Weck-Hannemann H. (2006). A conceptual approach to the use of Cost Benefit and Multi Criteria Analysis in natural hazard management. Nat. Hazards Earth Syst. Sci., 6(2): 293-302.

Hammitt J.K., Robinson L.A. (2011). The Income Elasticity of the Value per Statistical Life: Transferring Estimates between High and Low Income Populations. Journal of Benefit-Cost Analysis 2(1): Article 1. DOI: 10.2202/2152-2812.1009.

Jaiswal P., Westen C.J.v., Jetten V. (2010). Quantitative assessment of direct and indirect landslide risk along transportation lines in southern India. Nat. Hazards Earth Syst. Sci., 10(6): 1253-1267.

Jonkman S., Kok M., Vrijling J. (2008). Flood Risk Assessment in the Netherlands: A Case Study for Dike Ring South Holland. Risk Analysis, 28(5): 1357–1374.

Krummenacher B., Romang H., Odermatt L. and Kühne R. (2006). Überprüfung des BAFU Excel Tools "Wirtschaftlichkeitsindex". Bericht No. G0509.1, ARGE GEOTEST und tur GmbH, Davos.

Lateltin O., Tripet J.-P., Bollinger D. (1997). Berücksichtigung der Massenbewegungsgefahren bei raumwirksamen Tätigkeiten. Empfehlungen, BUWAL, BWW, BRP.

Loat R., Petrascheck A. (1997). Berücksichtigung der Hochwassergefahren bei raumwirksamen Tätigkeiten. Empfehlungen, BWW, BRP, BUWAL.

Pate-Cornell M.E. (2002). Risk and uncertainty analysis in government safety decisions. Risk Analysis, 22(3): 633-646.

PLANAT (2005). Strategie Naturgefahren Schweiz. Synthesebericht in Erfüllung des Auftrages des Bundesrats vom 20. August 2003. www.planat.ch (Access 4 October 2011).

Rheinberger C.M. (2011). A Mixed Logit Approach to Study Preferences for Safety on Alpine Roads. Environmental Resource Economics, 49(1): 121-146.

Rheinberger C.M., Bründl M., Rhyner J. (2009). Dealing with the White Death: Avalanche Risk Management for Traffic Routes. Risk Analysis, 29(1): 76-94.

Schaub Y., Bründl M. (2010). Zur Sensitivität der Risikoberechnung und Massnahmenbewertung von Naturgefahren. Schweizerische Zeitschrift für das Forstwesen, 161(2): 27-35.

Wilhelm C. (1999). Kosten-Wirksamkeit von Lawinenschutz-Massnahmen an Verkehrsachsen 1999 Vorgehen, Beispiele und Grundlagen der Projektevaluation. Vollzug Umwelt. Praxishilfe. Buwal, Bern, 110 pp.

Winkler C., Lambrigger A., Bründl M. (2011). EconoMe-Railway Methodik. Risikoanalysen Naturgefahren entlang von Bahnstrecken. Version 1.0 vom 19. Mai 2011, unpublished, Brig, 51pp.
Winkler C. (2011). Study of indirect consequences as a result of closed railway lines caused by natural hazards. Working report Interreg IV-B Alpine Space PARAmount. Brig-Glis, 62pp. http://www.paramount-project.eu (Access 4 October 2011).