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Applicability of Forensic Analysis Techniques on the Improvement of Early Warning Landslides Systems and Components

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Abstract. Intense rainfall and flood are known to be the principal natural cause of onshore landslides. Early warning systems are in place to minimize negative effects of landslides surveying natural hazard events, damages and emergency response actions. The focus of this study is to improve the early warning landslides systems and associated systems and components, including resource management, environmental impact analysis, and environmental planning. This study is part of the main project « Klima 2050 » that aims to the reduction of the societal risks associated with climate changes and enhanced precipitation and flood water exposure within the built environment. This paper infers on the applicability and suitability to some forensic analysis techniques to specific landslides events and to early warning landslides systems, conducting forensic analysis based on detailed damage information collected by the information system after event occurrence.

Keywords. Early warning system, forensic analysis techniques, landslides prevention, climate change risk, fault tree analysis, success event tree.

1. Introduction and scope

Improvement of landslide risk management is often reactive in the meaning that the process of improving the management is driven through major landslide events. Throughout the history, adverse events and mishaps has gradually initiated improvements in legislation and in risk management.

Landslide mitigation and preparedness activities may be informed and driven by the previously occurred events. Review of well-documented, major landslide events influencing transportation infrastructure might provide important input to planning of mitigation and preparedness. Especially useful: causal analysis of what went wrong, but also analysis of what went right.

Early warning systems (EWSs) have been defined [1] as "a set of capacities needed to generate and disseminate timely and meaningful warning information to enable

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individuals, communities and organization, threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce losses". They must comprise four elements: risk knowledge, monitoring and warning services, dissemination and communication, and response capability [2].

2. Background

The mainland of Norway (Scandinavian Peninsula) covers an area of 324 000 km2, with more than 490 000 km of rivers and streams and around 250 000 lakes. The country has large climatic contrasts, from maritime to continental climate, because of rugged topography that causes large local differences. The average annual precipitation is about 1400 mm, of which about one-third is snow. The precipitation distribution is non-uniform. In Western Norway, annual precipitation may exceed 5000mm and daily values of 70 mm are not uncommon. In the east, some valleys annually receive less than 300 mm.

Rainfall- and snowmelt-induced landslides are triggered by water. Intense or long-duration water supply, caused by rain and/or snowmelt, increases the water content in the soil or snow. The cohesiveness of soil or snow particles decreases with higher water content, increasing the risk for mass transportation. Not only steep natural slopes covered by loose Quaternary sediments, but also gentle slopes covered by snow as well as modified slopes and filling along roads and railways are especially exposed to these kinds of hazards.

Climate scenarios for Norway indicate an increased occurrence of extreme weather, and intense precipitation is also expected to increase especially in the coastal areas of Norway [3]. Higher temperatures have led to earlier spring floods, and there is a tendency to increased frequency of rain floods. Future projections show that rain flood magnitude will increase, while snowmelt floods will decrease over time. More frequent and stronger intense rainfall events may in the future create specific challenges in small, steep rivers and in urban areas. Weather conditions are main triggers of certain types of landslides and snow avalanches; therefore, changes in climate may affect their future frequency. The risk of slush-flows will increase and may occur in areas where they have not occurred previously [4].

2.1. Types of warnings in Norway

The daily landslide hazard assessment is performed by a forecaster who uses forecasted thresholds, forecasted hydrometeorological parameters, information from real-time observations, knowledge on historical events and regional susceptibility, and personal experience. The daily landslide assessment routine is summarized in Figure 1 and includes the following phases:

- Weather forecast, also as input for the hydrological model;
- Model run, forecasted hydro-meteorological parameters, forecasted threshold;
- Collection of real-time data;
- Interpretation of model results and use of additional information from simulated hydro-meteorological parameters, i.e. snow and groundwater conditions;
- Analysis of forecasted thresholds also corrected with susceptibility information;

- Preparation of forecast information and warning messages with description of possible events and expected impact;
- Communication and dissemination of messages to warn the public and local authorities;

Type of warnings in Norway:

- General landslide warning issued by NVE: Regional scale warning based on precipitation (threshold-based). Increased awareness regional scale. See Figure 1.
- Slope specific landslide warning systems, such as e.g. for the unstable rock area "Veslemannen"
- Specific warnings after observations; e.g. after train inspections after severe weather. Warning issued after inspection of route; 3 possibilities:
  - o No restrictions
  - o Reduced speed
  - o Damage detected, railway closed

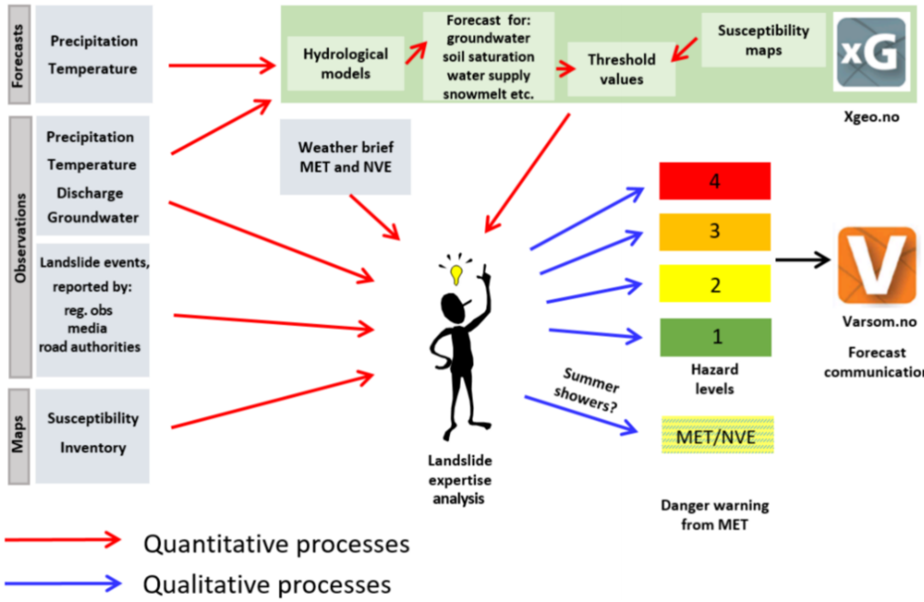

Figure 1. Illustration of the elements involved in the issuing of warnings for soil slides and slush flows in Norway [5].

2.2. Modes of malfunctioning of road or railway lines due to landslides

Every year a number of incidents and accidents related to slope failures impact the roads and railways in Norway. These can be rock falls, landslides in natural or engineered slopes, or failure of road or rail embankments.

Negative impacts of landslides hitting road and railway include accidents, damage to infrastructure or to components of the infrastructure, delays and malfunctioning of the transportation network, resulting in economic consequences. An important step in risk assessment and forensic analyses of landslide events step is to identify undesirable events and to describe how landslides may lead to malfunctioning of road and railways and how it endangers life and health.

- Damage of transportation line: derailment; traffic accidents
- Blocking of transportation line: derailment and traffic accidents
- Direct hit of cars by landslides
- Landslides destroying infrastructure assets:
    - clogging of culvert leading to water accumulation and embankment failure
    - collapse of contact wire due to landslide

Table 1 present the modes of malfunctioning of road or railway lines due to landslides in Norway.

Table 1. Modes of malfunctioning of road or railway lines due to landslides in Norway.

Description of event	Description of direct impact	Indirect impacts
Landslide hit road or railway line	Material destructions of the line	Delays - Derailment (if not detected timely) with potential human injuries and fatalities
	Blocking of the transportation line	Delays - Derailment (if not detected timely) with potential human injuries and fatalities
Landslide hit vehicles on the transportation line	Material damages to vehicles	
	Human injuries and fatalities	
Landslides destroying infrastructure assets	Clogging of culvert	Water accumulation and ultimately embankment failure
	Collapse of contact wire	Loss of power supply
	Deterioration of system	

3. Methodology

3.1. Back analysis of historic events

This technique is applied to single historic events. It has three main steps:

- Thorough description of the event, paying attention to key decisions made before the occurrence and to key pre-events (natural and man-made). If the event produced consequences, the description should include not only the decisions and pre-events related to the hazard, but also to the exposed elements.
- Reconstruct a timeline of pre-events and decisions leading to the hazardous event.
- Translate the timeline of pre-events and decisions into an event tree.
- Identify the "weakest" nodes in the tree which could have led to a reduction of the hazard or of the consequences.

3.2. Fault trees and Success trees Analyses

A fault tree is a top-down logical diagram that shows the relationships between a critical event and its causal events. Success tree analysis (STA), which is the counterpart of FTA, is a logical diagram that shows the relationships and combination of the causal events to attain a positive event (wanted successful condition).

3.2.1. Fault tree analysis (FTA)

The main elements of a fault tree are:

- The top event, which describes the critical system event (unwanted fault condition).
- Basic events, which are the lowest level of identified causal events.
- Logic gates. The gates are OR or AND logic operators, which provide the relations between the top event and the basic events.

A fault tree analysis is the qualitative and quantitative analyses which can be performed on a fault tree.

This analysis consists of five steps:

1. Definition of the problem, the system and boundary conditions for the analysis.
2. Building of the fault tree.
3. Identifying minimal cut sets.
4. Qualitative analysis of the fault tree.
5. Quantitative analysis of the fault tree.

3.2.2. Application examples of fault trees to landslides in the literature

Several examples can be found in the literature of fault trees applied to landslides. Figure 2 present the fault tree diagram to categorize human errors in slope construction [5]

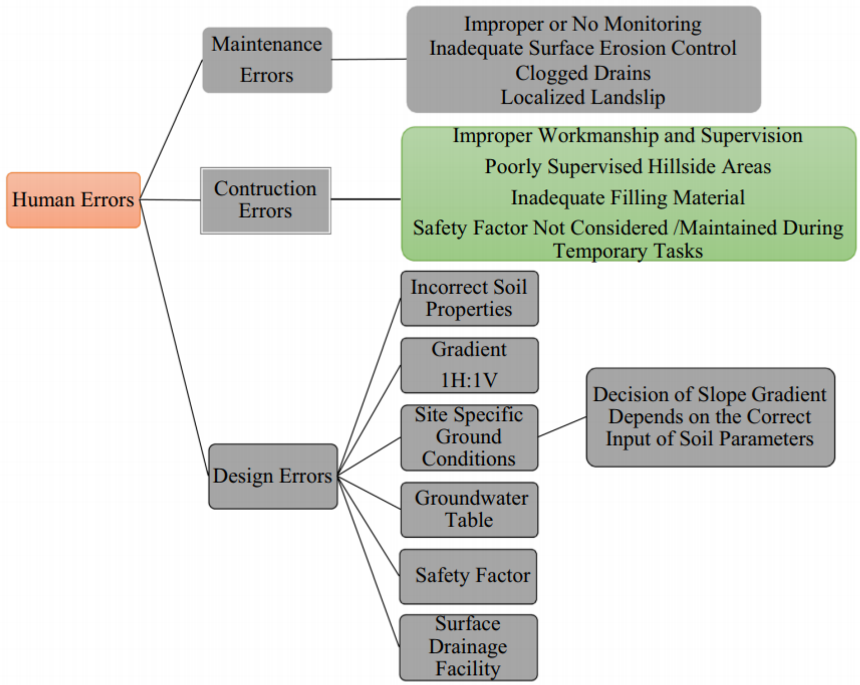

Figure 2. Theoretical framework to categorize human errors in slope construction [5].

3.2.3. Success tree analysis (STA)

Success tree analysis analyses what combined events brings to a positive output. What went right to prevent human casualties?

Success tree analysis has not been found in the available literature. Two case study are presented in this paper to illustrate STA application to landslides.

4. Case study

Two case study are presented and analyzed with STA in this paper. Both case study occurred in Norway.

4.1. Closure of railway line

This first case study describes a series of events that combined stopped a train just in time to prevent a life treating catastrophe.

4.1.1. Description of case – What happened?

A heavy rain event combined with snow melting, had produced the complete erosion of a railroad embankment, leaving the rails without support. Table 2 present the time line analysis backwards in time.

Table 2. Time line analysis of the specific event; backwards in time.

Time	Event
Saturday 21 April, 17.00	The railway line "Nordlandsbanen" was closed for traffic between Mosjøen and Drevvatn.
Saturday 21 April, 16.45	The loss of the railway substructure was detected by the driver of a passenger train from NSB (Norwegian state railways), who managed to stop on time and notified the management of NSB.
Saturday 21 April, before 16.45	The material comprising the railway substructure slipped out. The landslide occurred at the stretch Mosjøen-Drevvatn, 30 km north of Mosjøen. Bane NOR (the state-owned company responsible for the Norwegian national railway infrastructure) stated the following cause: A slush slide has carried trees and branches, sealed a larger concrete slab. A lot of water accumulated after a period with rapid snow melting. The accumulated water washed out the substructure over a stretch of 40 meters, and up to 10 m high.
Saturday 21 April, morning.	The entire stretch from Steinkjer to Fauske was inspected due to the landslide warning at the highest warning level. During inspection, accumulated water was discovered at a location at the stretch Mosjøen-Drevvatn, 30 km north of Mosjøen. Bane NOR lowered the allowed train speed of the stretch to 40km/h.
Friday 20 April	Emergency group in the municipality arranged a meeting. The preparedness was increased.
Thursday 19 April	Local emergency management and the main rescue center were gathered and went through the plans and conducted a risk assessment. Implementation of emergency preparedness measures at the road and rail authorities.
Thursday 19 April	NVE issues snow avalanche (and landslide) warning at the highest warning level (5) at Helgeland and Svartisen

Table 2. (*continued*) Time line analysis of the specific event; backwards in time.

Time	Event
Thursday 19 April	Weather forecast: heavy precipitation (up to 80 mm), mild weather and wind
Background situation:	Large amount of snow accumulated in the mountains through cold and dry periods in February and March.

4.1.2. Success tree description of the case

The success event tree diagram for this case is presented in Figure 2.

The most important (positive) events that have helped to finally stop the train in time:

- Earlier, a special inspection has been done because the NVE had issues snow avalanche (and landslide) warning at the highest warning level (5) for the region.
- During this special inspection, inspectors have observed important volumes of water ponding nearby structures supporting the railway.
- Inspectors decided to reduce the velocity on the rails.
- The driver was alert and with a low velocity. This have allowed the driver to see the affected area and to stop the train in time to prevent a life treating situation.

4.2. False warning and evacuation, Veslemannen, Møre og Romsdal County, Norway.

A second case study describing a repetitive situation of false warning from the early warning system for rock avalanche in a valley coming from the "Mannen" mountain.

4.2.1. Description of case.

"Mannen" is a mountain at 1294m in the Romsdal Valley, characterized by a distinctive mountain-needle. The mountain is unstable, and experts fear a major landslide, up to 100 million m^3. A part of the landslide of 2-3 million m^3 might cross the valley floor and hit buildings, railroads and the European road, E136. The river Rauma can also be dammed with danger of flooding. The mountain has since 2009 been monitored. The Norwegian national contingency plan for rock avalanches defines four hazard levels classified by the rate of movement in the rock slope:

- low / green,
- moderate / yellow,
- high / orange, and
- extreme / red constituting the avalanche alert, see Figure 4.

Figure 4 presents an schematic representation of the expected development of a rock avalanche, from the Norwegian national contingency plan for rock avalanches.

The hazard levels express increasing likelihood of a rock avalanche. The monitoring center determines at any time the hazard level for the monitored mountain parties and report changes in hazard levels to all emergency operators, with four preparedness levels corresponding to the hazard levels.

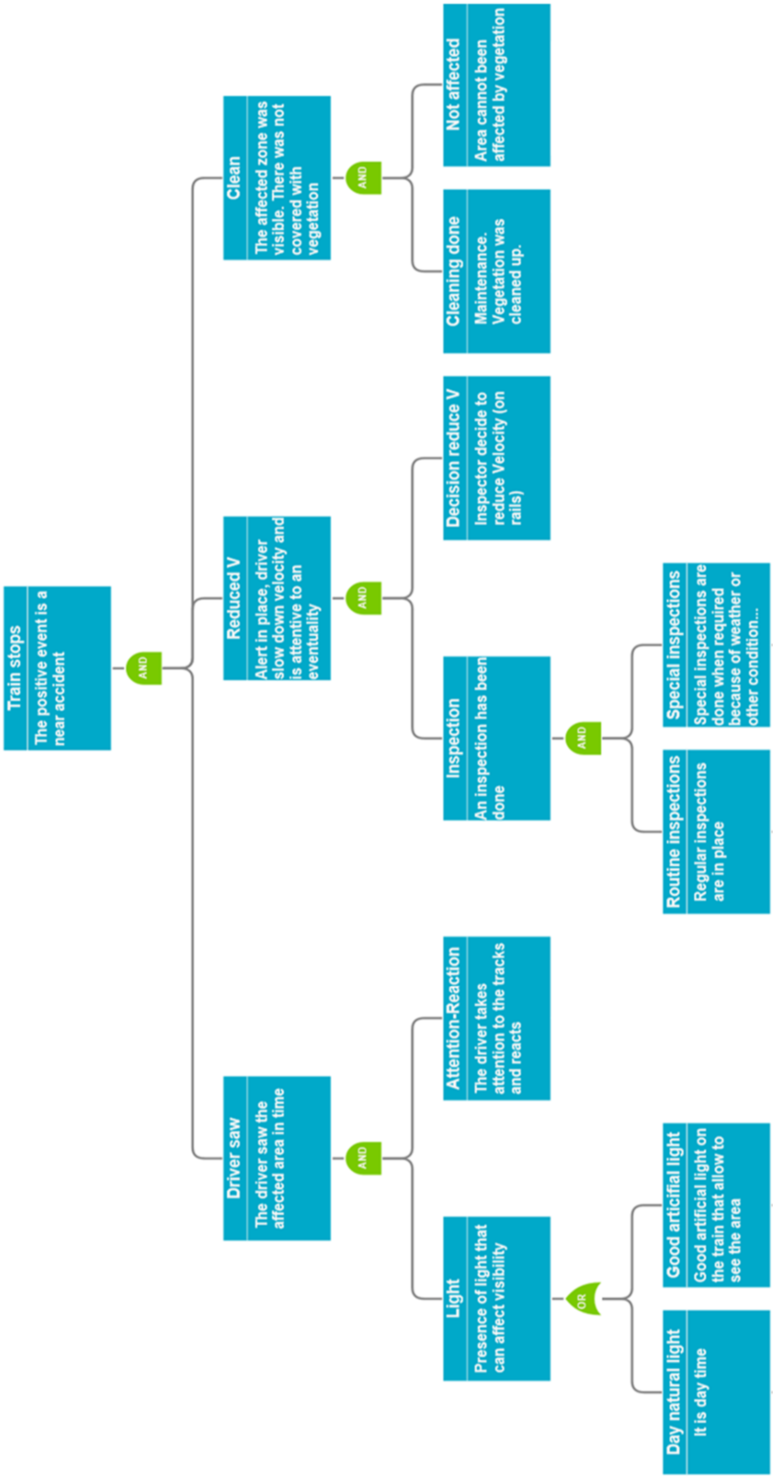

Figure 3. Success event tree diagram for the stopped train case.

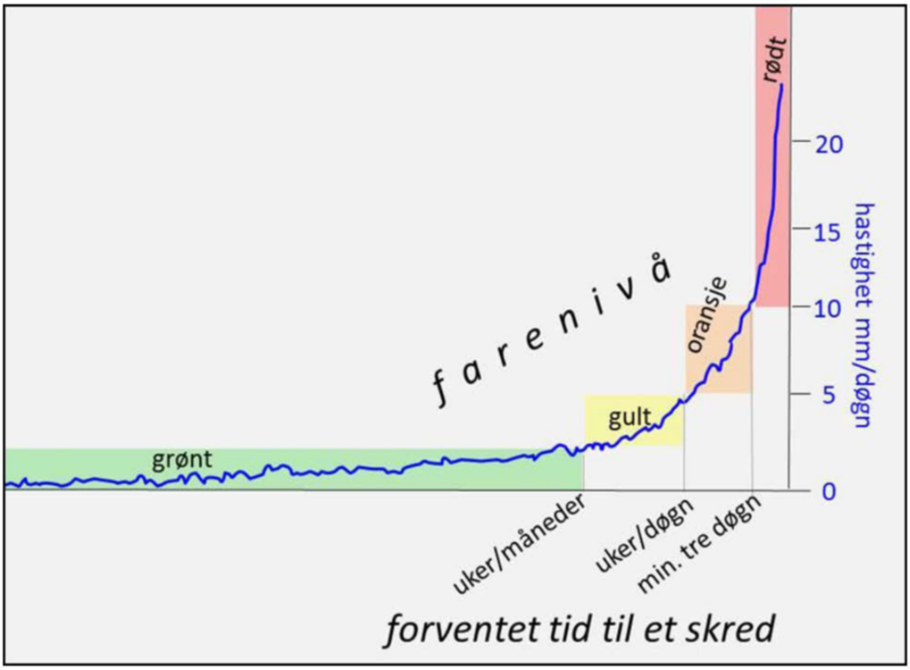

Figure 4. Schematic representation of the expected development of a rock avalanche, from the Norwegian national contingency plan for rock avalanches [7].

In autumn 2014 some major movements in a demarcated area of 4000 m2 at 1100 to 1200 metres altitude were detected. Some information attains the media and the incident escalated due to internal competition between media companies, which envisioned the possibility of a direct transfer of the avalanche incident. The mayor expressed that the media coverage was exaggerated, and that there was no risk to life and health after the evacuation was conducted. A few months later, the evacuated residents were allowed to move back home, after movements in the mountains had stabilized.

Although the rock avalanche did not happen, the incident had negative consequences for the evacuees. Economic impact and others, non-quantifiable impacts such as impacts associated with the feeling of insecurity in everyday life and uncertainty about long-term perspective on the future.

The events also had major impacts on the railway, especially on the freight transport. The events have also created uncertainty about new closures of the railway and long-term effects for freight transport.

Establishing thresholds for parameters to define hazard levels is very demanding and associated with large uncertainties. The thresholds are set for parameters describing the speed of movement in the mountainside, based on the experience from other, monitored rock avalanches. Although the avalanche development follows the same overall pattern, local conditions will be crucial for the timing and values of threshold for the different hazard levels. In addition, there are uncertainties related to the development of the weather situation. The thresholds must be balanced between a conservative treatment of uncertainties to ensure the security of the population and the disadvantages associated with unnecessary evacuations. In the long term, repeated unnecessary evacuations may lead to a loss of confidence in the warning system for the population. This confidence is a critical element in the system, in order to be able to complete future evacuation(s). Repeated incidents with unnecessary evacuation may also lead to loss of reputation for the involved geologists.

There is a need for improved predictions of timing of the rock avalanches, through:

- Improved models for prediction of timing of rock avalanches. The available models (i.e. the inverse velocity model) predicted that a rock avalanche was short ahead in time; obviously, these models were insufficient for the analysis of the timing of the avalanche.
- A calibration of the threshold for early warning is needed. Establishing and calibration of thresholds is an important part of the warning system.

After the first evacuation in 2014, a new system of monitoring was established. The surveillance system consisted of radar, quake measurements and powerful tension legs, which in total gives a good overview and control of the situation.

Final Note: by the end of September 2018, the hazard level was red and families living in the areas exposed to the potential landslide have been evacuated for the 4th time in 2018.

4.2.2. Success tree description.

The success event tree diagram for this case is presented in Figure 5.

The most important (positive) events that have helped to evacuate the valley to prevent a life treating situation:

- Early warning system in place with adequate surveillance
- Professionals and adequate Thresholds increase the hazard level
- Increase in the hazard level (to red)
- Population evacuation and ban across the area
- No life is exposed to a possible avalanche

The success tree diagram (Figure 5) put in evidence an event that can change from positive to negative if the population is finally affected by the repeated evacuations.

5. Concluding remarks

Gaps and needs identified in research projects are listed below. They include the need for:

- Improvement of guidelines, as well as implementation of codes and guidelines
- Need for more data and systems for collection of data:
    - Systematic collection in databases, e.g. public database for rock falls and landslides at SGI (Swedish Geotechnical Society),
    - Access to more accurate and timely information,
    - Improved resolution
- More extensive landslide hazard evaluation and mapping, which are actively taken into account in area and urban planning
- Improvement of organizational aspects, co-operation and co-operation procedures and communication systems, e.g.
    - Clarification of responsibility for inspections and maintenance
    - Conduction of design and construction of slopes in an effective and sustainable manner.

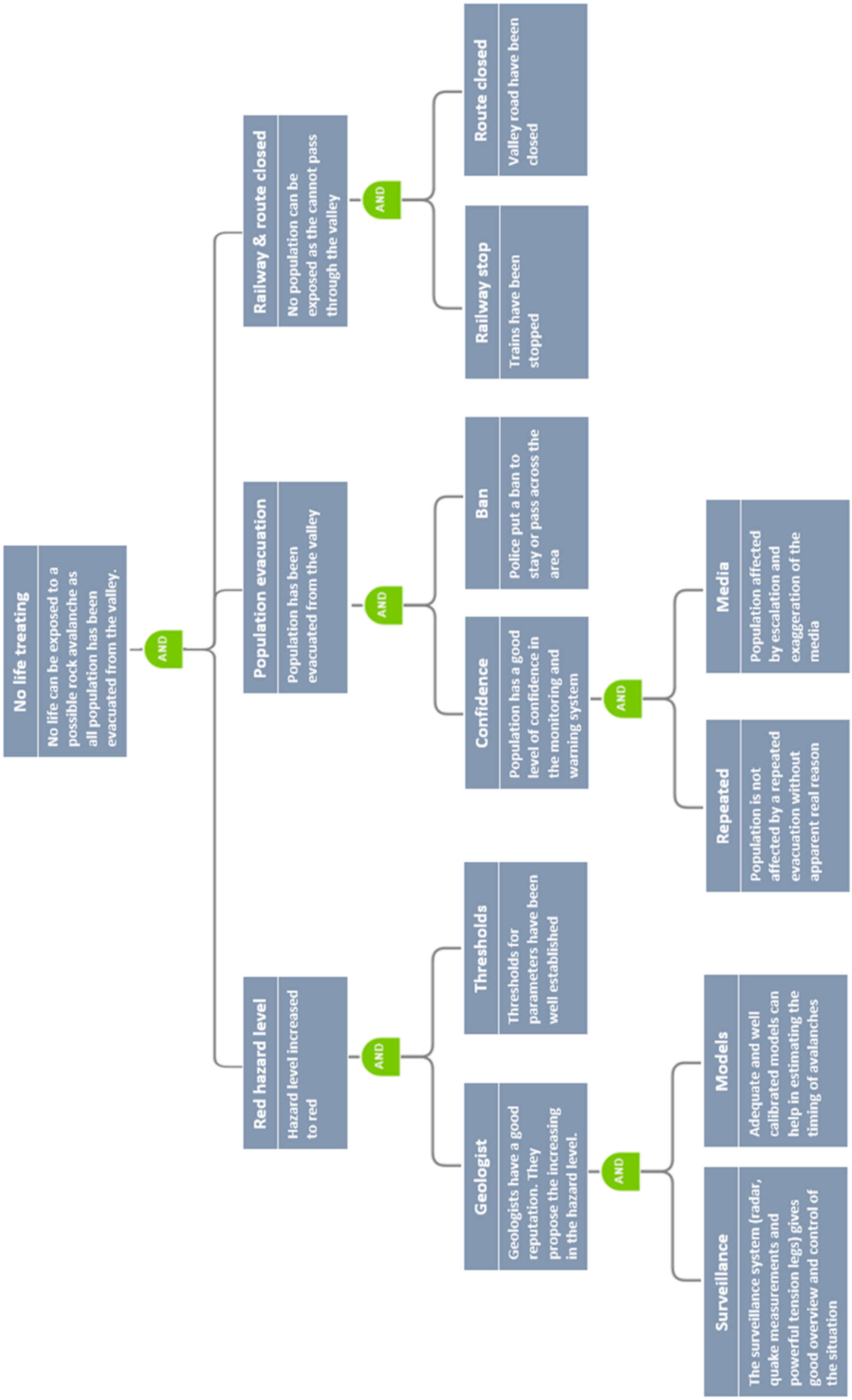

Figure 5. Success event tree diagram for false warning and evacuation..

- Training and education, e.g. concerning laws and regulations, technical risks in spatial planning and effect of climate change.

Figure 6 presents The ISO 31000 risk management framework.

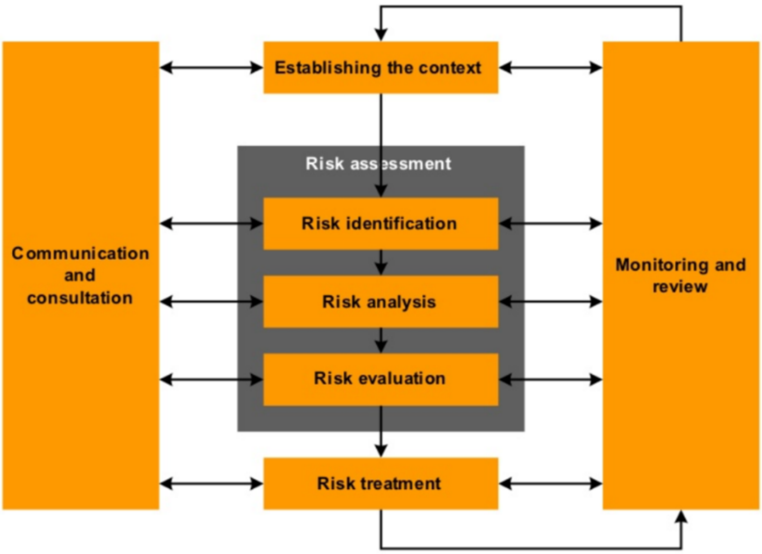

Figure 6. The ISO 31000 risk management framework

The findings organized per step in the risk management process (Figure 6).

5.1. Establishing the Context: Legal and regulatory requirements, organizational aspects

Risk management starts with defining objectives, and external and internal factors that may influence success in achieving those objectives. Risk management practices are influenced by legal and regulatory requirements as well as by policies, standards and guidelines.

- Improvement in legislation (technical requirement with regard to design/codes, requirement to procedures/work flows, requirement to risk analysis, clearer distribution of responsibilities, avoid formulations that allow subjective interpretation)
- Need for improved systems for control and management/organizational aspects, clarification of roles and responsibility for inspections and maintenance, improved guidelines co-operation procedures and communication systems
- Improved risk awareness (knowledge and further education, training and educational interventions)
- Improved systems for data collection and better access to data e.g. as input to improved risk assessment, monitoring and warning and more accurate and timely information for the affected areas. Need for improved coordination of data on many levels, for example: improved measurements, improved records related to events, enhanced list of measures, enhanced cooperation on mapping

of risk, standardization of format and presentation of data, improved information sharing.

5.2. Risk identification

Risk identification requires the application of systematic processes to understand what could happen, how, when and why. It involves the identification of risk sources, events, their causes and potential consequences. Risk identification may involve historical data, theoretical analysis, expert opinions, and stakeholder's objectives.

- Better access to data from previous events

5.3. Risk Assessment

Risk analysis is concerned with developing an understanding of each risk, its consequences, and the likelihood of those consequences. Disaster loss- and damage data are essential when exploring landslide risk.

- Further need for mapping (hazard and vulnerability).
- Assessment of change in risk pattern including effect of climate changes
- Identification and assessment of uncertainties within models for risk identification and risk assessment, including effect of resolution. Neglecting uncertainties may lead to underestimation of the landslide risk.

5.4. Risk evaluation

The purpose of risk evaluation is to assist in making decisions, based on the outcomes of risk analysis, about which risks need treatment and the priority for treatment implementation. Damage data may be applied as the basis for establishing explicit risk acceptance criteria, or as a basis for assessing whether estimated risk is acceptable or if there are needs for risk treatment. Damage data will also be input to cost-benefit calculations. The need for better access to data from previous events is thus also reflected within this stage of the risk management process.

5.5. Risk Treatment

Risk treatment is the process to modify risk. It can involve measures to avoid activities that give rise to risk, removing the risk source, changing the likelihood, changing the consequences, or accepting the possibility of loss, with or without transferring the risk to an insurance company.

Need for:

- Improved land use planning, actively taking hazard evaluations and mapping into account
- Improved methods for monitoring and warning
- Procedures for selection of mitigation measures: structural and non-structural

5.6. Communication and consultation and Monitoring and review

Considerable iterations are required between the previously described steps and between the continuously applied elements of communication and consultation and monitoring and review.

There is continual communication with external and internal stakeholders, where practicable, to gain their input to the process and their ownership of the outputs. It is also important to understand stakeholders' objectives, so that their involvement can be planned and their views can be taken into account in setting risk criteria.

Monitoring and review involve environmental scanning by risk owners, control assurance, taking on board new information that becomes available, and learning lessons about risks and controls from the analysis of successes and failures.

- Challenges related to organizational aspects including inter-institutional organization, co-operation and co-operation procedures and communication systems.
- Focus on communication, across disciplines, with policymakers, with stakeholders and with general public
- Cooperation between the Nordic countries on common problems.

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