Institute of Transport Economics
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ENGLISH **Summary**

Assessing landslides in cost-benefit analysis

Injury and fatality risk and valuation of landslide frequency and -volume

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More than 53,000 landslides and avalanches hitting public roads have been recorded through the period 2000-2023. Most of these are small, with no recorded damages. A total of 674 cases of damage to vehicles due to landslides have been registered, and of these, 62 cases of bodily injury have been identified. Of these, 13 fatal accidents were registered, with a total of 18 deaths and 2 seriously injured. With the recommended valuation of statical life and health for use in cost-benefit analysis, we find an expected accident cost of NOK 11-21 million. (2020-NOK) per case with bodily injury. Furthermore, we propose that cost-benefit analyses of landslide mitigation measures use simple linear functions to estimate the willingness to pay per person trip for driving on a landslide-prone stretch of road: NOK 3.70 per landslide event that hits the infrastructure per year, and NOK 0.13 per metre landslide width that hits the infrastructure.

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In this report, we have analysed two specific aspects that are relevant for conducting cost-benefit analysis of measures for reducing landslide- and avalanche risk:

1. Expected severity of accidents if a car were to be hit by a landslide or avalanche.
2. Willingness to pay for reduced avalanche frequency and reduced avalanche width (on top of accident risk and disadvantages of road closures).

Expected severity of accidents

To analyse the first aspect, we have used a relatively large data set of landslide- and avalanche events (we will mostly refer to landslide events, but this will cover landslides, avalanches and mudslides) hitting road infrastructure from 2000 to 2023. The data has been retrieved from the National Road Data Bank (NVDB) and has been linked to landslide data from the Norwegian Water Resources and Energy Directorate (NVE) related to deaths related to landslides on roads. To our knowledge, no analyses have been conducted on such a data set in Norway with the aim of estimating the expected socio-economic accident costs of avalanches that hit vehicles on roads. Nor does the literature review in Chapter 2 find many studies that address the expected severity of accidents related to landslides on roads. Our analyses on this topic thus shed light on a field on which there appears to be little research.

More than 53,000 landslides hitting road infrastructure have been recorded through the period 2000-2023. Most of these are relatively small with no recorded no damages. We must assume that there are significant unrecorded figures, but that these dark figures mainly represent small landslides that do not lead to closures or damage.

About 15 % of the recorded landslides are registered with some type of damage. The most common recorded damage is damage to road surfaces and damage to drainage. A total of 674 incidents of damage to vehicles due to landslides have been registered, which account for approximately 1.2 % of the registered landslides. Of the cases of damage to vehicles, 62 cases of bodily injury have been identified. This constitutes approximately 0.11 % of all registered landslides on roads and 9% of landslides with registered damage to vehicles.

In other words, the probability of bodily injury incidents due to avalanches on roads is relatively low, with less than 3 cases per year on average. Of the 62 cases of bodily injury, 13 incidents of death were registered, i.e. over 20 % of the accidents with bodily injury. These 13 cases accounted for a total of 18 deaths and 2 seriously injured.

Given that we do not know the degree of bodily injury in accidents that do not result in fatalities, it is difficult to estimate the expected severity. However, we can estimate reasonable bounds, with either a high proportion of accidents involving minor injuries or a high proportion of severely injured persons. **With the recommended valuation of life and health for use in cost-benefit analysis, we find an expected accident cost of NOK 11-21 million (2020-NOK) per bodily injury case**. Even with such a wide uncertainty interval, the findings point to relatively high average costs per case.

The relatively high death rate per bodily injury incident translates to the expected accident cost, given that a vehicle is hit by a landslide, to be relatively high. The data indicate an expected accident cost per landslide that damages vehicles of between NOK 1 and 2 million before any differentiation is made on landslide volume. The lower accident cost estimate for a landslide narrower than 10 metres that hits a vehicle on a road is approximately NOK 0.6 million, while the upper estimate for a landslide wider than 100 meters is approx. NOK 5 million. This underlines the importance of having a well-founded idea of how large landslides can be expected on a given stretch of road when doing transport appraisal. This matters a lot to the valuation.

To illustrate the importance of the assumptions for landslide width, we have carried out two example calculations using the tool EFFEKT (which is used for cost-benefit analysis – CBA) on a landslide-prone stretch. Given the rough categories in NVDB's landslide data, we estimate that an average recorded landslide on the road has a width of between 6 and 18 meters. We use these estimates as a basis for our example calculations. If the average landslide width is 6 metres, with the lowest estimate of the damage cost in the width category, EFFEKT calculates a present value of accident costs of approx. NOK 8 million. If the width is 18 metres, with the highest estimate of the damage cost, EFFEKT calculates a present value of the accident costs of approx. NOK 54 million. Some of the gap in estimates is due to uncertainty in the estimates, but the calculations also take into account the important principles that wider avalanches give a substantially higher probability of actually hitting a car, and this will increase the expected severity of the hit.

Willingness to pay for reducing frequency and volume of landslides

We have based our assessment on the valuation of changed (expected) frequency and (expected average) width of landslides hitting infrastructure from Navrud et al. (2020), in NOK per person-trip, proposed by Magnussen et al. (2022). The estimates are based on a valuation study with a choice experiment. Since the choice experiment for valuing landslide frequency and landslide width also included severe injury/fatality and infrastructure closure (for all possible causes, for both attributes), we assume that the willingness to pay for reduced landslide frequency and avalanche width primarily includes effects other than serious accident risk and road closure risk, since this is controlled for in the analysis. The choice experiment reported by Navrud et al. (2020) enables the valuation of reduced landslide frequency and volume *in addition to the valuation of expected accidents and road closures*, <u>with a low probability of double counting</u>.

What Navrud et al. (2020) estimated are economic valuations of changed landslide frequency and landslide width/ volume affecting infrastructure, for given levels of infrastructure closure, travel time and serious injuries/deaths. The valuation of reduced landslide frequency/size may include several possible (non-specified) effects of landslide risk, in addition to road closure risk, time loss and risk of severe injury/death. **We argue that the valuation of reduced landslide frequency/size may reflect an option value, a valuation of reduced transport availability uncertainty.** In other words, respondents have appreciated reducing a source of uncertainty about travel opportunities at a given future date. Respondents are likely to have separated this transportation availability option from the number of expected annual road closures. There could also be other possible motives/causes, as we do not have the basis to exclude them.

We propose an expansion from the fixed values per stretch of landslide-prone road, as Magnussen et al. (2022) showed in their example calculations. **We recommend simple linear functions**: NOK 3.70 per landslide hitting the infrastructure per year, and NOK 0.13 per metre avalanche width hitting the infrastructure on average (2019-NOK). Both parameters are calculated to have a 95 % confidence interval of +/- 25 %. We therefore propose to include the magnitude of the changes that the landslide protection measure is expected to entail, so that the valuations can differentiate the value of these measures. Measures that provide a greater reduction will be calculated to have a higher social benefit than measures that provide a smaller reduction. The following features will provide benefit estimates per year for avalanche measures that are expected to reduce the expected number of annual landslide events (reaching the road) by *x* and reduce the expected average landslide width (reaching the road) by *y* meters:

- NOK for change (*x*) in landslide frequency: <u>NOK 3.70 * *x* landslides/year * occupancy * AADT * 365</u>
- NOK for change (*y*) in landslide size: <u>NOK 0.13 * *y* meters * occupancy * AADT * 365</u>

where *y* meter = $\Delta(L_A+L_B)$, where L_A is primary landslide width and L_B is secondary landslide width (neighbouring landslide), as described in documentation of calculation modules in EFFEKT.

We show in a concrete example (CBA of avalanche protection measures along Sandvinvatnet on riksvei 13, where there are three points of avalanche risk), which benefit estimates this would give for reduced avalanche frequency (between 0.1 and 1) plus reduced avalanche width (6 m or 18 m). The benefit estimates vary between approx. 15 and 80 million NOK per point of avalanche risk in a 75-year project perspective. This is on par with or somewhat higher than the estimated benefit of landslide-associated accident/bodily injury risk reduction (but the landslide-associated personal injury risk is relatively very low compared to the personal injury risk in road transport associated with other causes).

When infrastructure closures, travel time and serious accidents have already been included in the CBA, **valuation of reduced landslide frequency/size may be considered a "residual willingness to pay for reduced landslide risk"**, which may include option values and non-specified effects of avalanche risk. More research is needed to reveal whether there is a transport availability option or whether there are other unspecified consequences that are the strongest drivers behind the valuation of reduced avalanche frequency/avalanche size.

Conclusions and recommendations

We believe that our findings have **implications for how cost-benefit analysis of landslide measures in the transport sector should be undertaken**. In principle, the standard system for valuation of landslide measures in EFFEKT includes the most important benefit components of reducing landslide risk. The following is usually calculated:

- Accident probability and accident costs
- Inconvenience costs of road closures - both because of landslides and preventive road closures
- Restoration costs
- In recent years, it has also been possible, as a test-option, to calculate the residual willingness to pay to reduce landslide frequency and width (previously imprecisely referred to as "discomfort due to landslide risk")

We consider it appropriate to include all these components in the calculation, and that willingness to pay to reduce landslide frequency and landslide width (beyond accident risk and road closure inconvenience) should be a standard component in the CBA of landslide measures.

The main weakness associated with the standard CBA system of landslide protection measures is that the value of securing areas with relatively large and frequent landslides are not sufficiently differentiated to areas where rare and small landslides are expected. This applies to both estimates of the severity associated with accident costs and willingness to pay to reduce landslide frequency and width.

We recommend updating the practice for CBA of landslide measures by using our results (parameter values and functions). By implementing our recommended parameter values in calculating accident costs and "residual willingness to pay for reduced landslide risk", as a function of expected landslide frequency and width, we believe that the CBAs will achieve more realistic calculations on the benefit side. This will in turn provide a better basis for decision-making when evaluating different project alternatives against each other, and different projects against each other in a portfolio.

However, we must emphasize that the aim of this report is to find more realistic values and functions for the actual valuation of various aspects of landslides. It is important that thorough climate, geological and engineering assessments are used as a basis for making realistic estimates of the expected landslide frequency and width for actual transport appraisal on a given stretch of road.