Valuing the risk and social costs of road traffic accidents

- Seasonal variation and the significance of delay costs

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Abstract

By using a conventional risk model, and a time loss model for delay, the risk, severity, and social costs of road traffic accidents have been estimated on a rural transport corridor in an area with large seasonal variations. The novelty of the study lies in the comparison of the estimates between seasons, and the inclusion of delay costs when assessing the total social costs of accidents for private motor vehicles and heavy vehicles. Increasing congestion in urban areas has motivated researchers' interest in studying the cost of delays due to accidents. However, still many countries, such as Norway, do not include delay costs when estimating the social costs of road accidents. In this study, we show that these costs can constitute a significant proportion of the social costs of accidents in rural areas, particularly during winter in regions with strong seasonal variations. The delay costs on the studied road section constituted on average 10 % of total annual social costs of accidents, and were nearly 70 % higher than the accidents' material costs. By including these inconvenience costs, we would achieve better estimates of the social costs of accidents, which would in turn give rise to more accurate assessments of the costs and benefits of accident reduction measures, as well as measures reducing the response time when accidents happen. Many road safety measures have been aimed at reducing accidents involving death and serious injury. This analysis shows that it can also be beneficial to take measures to reduce the number of less severe accidents, particularly in rural areas where delay costs can be high when the roads are closed because of accidents. It is thus, particularly important that such costs are included in project assessment tools to ensure that rural areas do not lose the fight for road investments.

Keywords: Road Accidents; Risk; Severity; Delay costs; Seasonal variation; Rural area

1. Introduction

Steep mountains and long fjords characterize the topography of the region that has been the case for study herein. For this reason, many of the roads in the region are steep, narrow and curved. Combined with cold winters that cover the road surface with snow and ice, this often creates difficult driving conditions, which further increase the risk of accidents (Shankar, Mannering, & Barfield, 1995; Usman, Fu, & Miranda-Moreno, 2010). Drivers may deal with challenging driving conditions in winter in various ways. Some cancel their trips or choose other transport routes or modes. Others take safety precautions such as equipping vehicles with spike tires and chains (Koetse & Rietveld, 2009; Steimetz, 2008; Strandroth, Rizzi, Olai, Lie, & Tingvall, 2012) or meeting the increase in task difficulty by lowering their speed and increasing their level of concentration (Jørgensen & Pedersen, 2002); however, road traffic accidents still occur. Some accidents result in deaths and injuries, while others are restricted to property damage and delays. Regardless, roads must typically close temporarily after an accident in order for the rescue crew to clean up debris.

The aim of this paper is twofold. First, the risk and severity of accidents on a rural road section with cold and snowy winter weather is derived – more specifically, the 632-kilometre European highway 6(Ev6) through Nordland County connecting northern and southern Norway. The results are compared between the summer and winter season and between private motor vehicles and heavy vehicles. Second, the total social costs of these accidents in winter and summer are estimated with particular focus on the delay costs imposed on road users when the road closes and the traffic flow is obstructed by the accidents.

There is limited research on the seasonal variation in risk of accidents, although research has revealed that rain and snowfall cause increased total crash rates mainly due to increase in less severe accidents (see e.g., Andrey, Hambly, Mills, & Afrin, 2013; A. J. Khattak, Kantor, & Council, 1998; Knapp, Kroeger,

& Giese, 2000; Koetse & Rietveld, 2009; Seeherman & Liu, 2015). For areas such as the one studied and similar mountainous areas with cold and snowy weather, the effect of adverse weather on crash rates may last the whole winter season causing a different road accident pattern compared to other locations. By estimating and comparing the risk and severity of accidents for different types of vehicles, the accident patterns of the vehicles groups in each season are revealed. Knowledge of which is scarce in the existing literature.

Cost-benefit analysis is a frequently used governmental decision-making tool for determining the economic consequences of alternative infrastructure projects. In order to evaluate the consequences of various safety measures, the social costs of road accidents are estimated. The problem of vehicle combinations blocking the winter roads is the subject of great attention each winter in Norway and has been further actualized with the increased globalization of transportation, with drivers from the southern parts of Europe entering Norway with limited knowledge of and skills necessary to handle the difficult winter driving conditions (NPRA, 2013; Royal Norwegian Ministry of Transport and Communications, 2014). Attempts to quantify the costs of delays, however, are limited, implying that the benefits of taking measures to reduce the frequency and duration of these accidents are underestimated.

Most countries, including Norway, follow the recommendations of the COST 313 project (Alfaro, Fabre, & Chapuis, 1994) regarding which cost categories to include when studying the social costs of road crashes (NPRA, 2014; SWOV, 2014). These include medical costs, the cost of lost production, material costs, settlement costs and intangible costs (loss of quality of life), but not delay costs. The policy focus in most countries has been on reducing the frequency of severe accidents causing serious injuries or fatalities because the social costs of these are high. With this study, we also want to emphasise the significance of the delay costs of accidents. Not with the intent of undermining the importance of reducing the frequency of severe accidents, but rather to show that in certain circumstances it may be appropriate to prioritize measures to reduce the frequency of less severe accidents as well.

Increasing congestion in urban areas has increased researchers' interest in studying the cost of delays due to accidents (see e.g. Adler, van Ommeren, & Rietveld, 2013). In their study of road accidents in Flanders, Raemdonck et al. (2010) conclude that these types of costs are significant. This has led the Netherlands to include congestion costs as a sixth category of accident costs in their recommendations (SWOV, 2014; Wit & Methorst, 2012).

This study is conducted in a rural area. The existing literature on delay costs of accidents has largely been conducted in urban areas afflicted by recurrent congestion. There are special features of transport in rural areas, however, that make it equally relevant to examine delay costs in this setting. First, there is limited access to alternative transportation routes (Laird & Mackie, 2009). There are only two alternative routes to Ev6 connecting the southern and northern parts of Norway. One goes through Sweden. However, this route has two border crossings and results in a long detour to avoid an obstruction on the Ev6 through Nordland. The other alternative route runs along the coast and is associated with poor road quality and interruption by several ferries. This is also a long detour. A second aspect to consider is the characteristics of the transport on the road section in question. The road section in this study is an important transport corridor for fresh fish, which is particularly dependent on short and reliable travel times (Hanssen & Mathisen, 2011). It is clear that accidents blocking the roads have significant consequences for the transport of perishable goods such as fresh fish. A third factor is that the rescue crews' response and clean up times after traffic accidents may be longer in rural areas than in urban areas because rescue crews may be spaced quite far apart, possibly resulting in longer periods of road closures and obstructions.

Finally, the characteristics of the road are also important for the magnitude of the effect of an accident on traffic flow. Many parts of the studied road section are steep, narrow and winding. This means that it may be difficult for other road users to pass the accident location during post-accident clean up, in which case it will take longer for the traffic flow to normalize after the accident. The road characteristics also cause variation in speed among drivers; e.g., heavy vehicles will often have problems maintaining speed on roads with a high gradient, particularly in combination with winding roads, and some drivers will lower their speed in order to cope with the difficulty of driving on narrow and winding roads (Fuller, 2005). This will hold back all traffic because of the scarcity of opportunities for safe overtaking on winding roads. According to Bogaerts et al. (2004), the robustness of a road is determined by the rest-capacity of the road, the availability of alternative routes, the speed of incident management, information to road users, and the level of road maintenance (Bogaerts et al., 2004). Considering the discussion above in relation to this definition, the robustness of Ev6 Nordland is low.

Each context will have its own combination of characteristics related to climate, topography, demography, and so on. Therefore, it is important to conduct the studies in various context. According to Böcker et al. (2013) concerns related to adverse weather effects on travel behaviour in rural areas with arctic climate have received little attention. Although the results from this study cannot be directly transferred to other contexts, there are rural areas with cold winter weather and/or mountainous topography such as the Alps, the Snow Belt states in US, and areas in Canada, which may benefit from the knowledge produced in this study. Our approach to estimate the often disregarded delay costs due to accidents is particularly useful in this respect.

The remainder of this article is structured as follows: in chapter 2, the theoretical background of the analysis is presented. In chapter 3, the case and data are described. The results are presented and discussed in chapter 4. Lastly, the main results, some concluding remarks and implications are summarized in chapter 5.

2. The Risk of Accidents and the Associated Social Costs

2.1 The Risk of Accidents

A road traffic accident is a stochastic event with frequency and severity determined by three groups of factors: (1) the characteristics and behaviour of the drivers (age, driving experience, driving speed, level of concentration and attitudes towards risk); (2) factors related to the vehicle (size, type, and vintage); and (3) external physical factors such as weather conditions, lightening, road characteristics and the level of traffic (Høye, Elvik, Sørensen, & Vaa, 2012; Koster & Rietveld, 2011; Maibach et al., 2008). The surface of the road section studied is largely covered by snow and ice during the winter, and wind and snow often create difficult driving conditions. In addition, the lighting is poor due to the dearth of daylight hours and scarce artificial lighting on long stretches of the road. The risk factors are further reinforced by large parts of the road being narrow, winding and of a steep gradient. Summing up, it is reasonable to assume that the risk of accident is higher in winter than in summer.

Freight transport drivers in general are expected to be better trained and have more experience in driving under both normal and adverse weather and are thus generally more capable drivers and more able to handle difficult driving tasks than private motor vehicle drivers (Fuller, 2005). However, two factors indicate that heavy vehicles may have higher risk of accident in winter than private motor vehicles. First, the combination of narrow, winding roads with steep gradient are particularly challenging to handle for large vehicles. Second, a significant amount of the heavy vehicles on the road stretch are foreign (22%), many from southern parts of Europe, with vehicles less well equipped and drivers less trained and experienced with handling difficult driving conditions on Norwegian winter roads.

The risk of accident on a particular stretch of road (R) is here defined as the number of accidents per million vehicle kilometres driven in accordance with e.g. Høye et al. (2012) and the Norwegian Public Road Administration's (NPRAs) guidelines (2008). The registered accident risk for a road section in a specific period is thus calculated as follows:

$$R = A \cdot \frac{10^6}{AADT \cdot T \cdot KM} \quad (1)$$

in which A is the total registered number of accidents on the stretch of road for the period studied, $AADT$ is the average daily traffic volume for the actual period, T is the length of the period measured in number of days and KM denotes average kilometres driven per day, per vehicle on the stretch. Hence, the denominator in (1) is total vehicle kilometres during the period.

An alternative method of calculating the risk is to calculate the risk of one particular vehicle being involved in an accident (Massie, Campbell, & Williams, 1995). Then, we must take into consideration that on average; more than one vehicle is involved in each accident. If we denote the average number of vehicles involved in an accident by δ ($\delta > 1$), the following equation expresses the risk (Q) of one vehicle being involved in an accident:

$$Q = \delta \cdot R = \delta \cdot A \cdot \frac{10^6}{AADT \cdot T \cdot KM} \qquad (2)$$

The value of δ may vary depending on various factors such as the driving conditions and type of accident in question. National statistics indicates that, on average, 1.75 vehicles are involved in each accident in Norway (Høye et al., 2012). We lack data for this figure for different stretches of roads and we find it difficult to speculate on how much it differs from its value nationwide. We therefore assume that $\delta = 1.75$ in our further calculations.

2.2 The Severity of Accidents

Khattak and Knapp (2001) found that accidents that occur during snow events were less severe compared to similar accidents in weather without snow on Interstate highways in Iowa. Most drivers adjust to the increased risk of driving on slippery roads and/or in snowy weather by reducing their speed or increasing their level of concentration (Koetse & Rietveld, 2009). The adjusted driving behaviour counteracts the effect of slippery roads and snowy weather on the frequency and severity of accidents; however, the size of the changes in speed and concentration are usually not high enough to give the drivers the same measure safety as they would have on dry asphalt (Høye et al., 2012). A theoretical discussion on how drivers adapt to changes in exogenous driving circumstances and the subsequent effects on their driving risks is provided in Wilde (1982), Risa (1992, 1994), Jørgensen (1993), and Levy & Miller (2000). In addition to the speed reductions on slippery roads, statistics show that the number of road users is much lower in winter than in summer (see Table 1 in section 3.1). This reduces the risk of oncoming traffic accidents, which are often the most severe accidents (Høye et al., 2012). The discussion above makes it reasonable to assume that the average severity of traffic accidents may be lower in winters than in summers.

2.3 The Social Costs of Accidents

De Wit and Methorst (2012) define the social costs of road traffic accidents as all of the costs arising from them. The costs can be divided into six categories:

- Medical costs (ambulance, hospitalization, rehabilitation, medications, etc.)
- Lost production (because of death or sickness causing permanent or temporary incapacity to work)
- Intangible costs (welfare loss because of pain, grief and suffering)
- Material costs (because of damage to vehicles, cargo, roads, buildings, etc.)
- Handling costs (costs for police, fire brigade, management costs for insurance companies)
- Delay costs (resulting from traffic jams following an accident)

The first five cost components above are commonly considered when estimating the social costs of accidents. As mentioned earlier, however, the delay costs related to road accidents are not currently included in the NPRA's guidance for cost-benefit analysis (NPRA, 2014). One aim of this paper is to calculate these costs on a major road section (Ev6) in Norway.

It is difficult to establish any clear presumption about whether expected accident costs are higher in winter than in summer;[1] however, higher risk of less severe accidents in winter (see section 2.1 and 2.2) is expected to cause the share of delay costs in relation to the total social costs of accidents to be higher in winter than in summer. This because the costs related to severe injuries and fatalities

[1] The expected accident costs (E_i) per million vehicle kilometres on the stretch of a road in season $i\ (i = s\ (summer), w(winter))$ is given by $E_i = R_i \cdot C_i$, where R_i and C_i denote the accident risk and the average costs of an accident, respectively. Because $R_s < R_w$ and $C_s > C_w$ the sign of $(E_w - E_s)$ is ambiguous.

(medical costs, intangible costs and production loss costs) make up a large part of the social costs of an accident. When these costs are lower, the other types of costs will become more prominent such as the delay costs.

Figure 1 visualizes the most important assumptions regarding the magnitudes of different cost components. The left and right vertical axes illustrate the expected shares of the various social costs of an accident in summer and in winter, respectively. The horizontal axis illustrates the a priori assumption that the risk of being in an accident is lower in summer than winter.

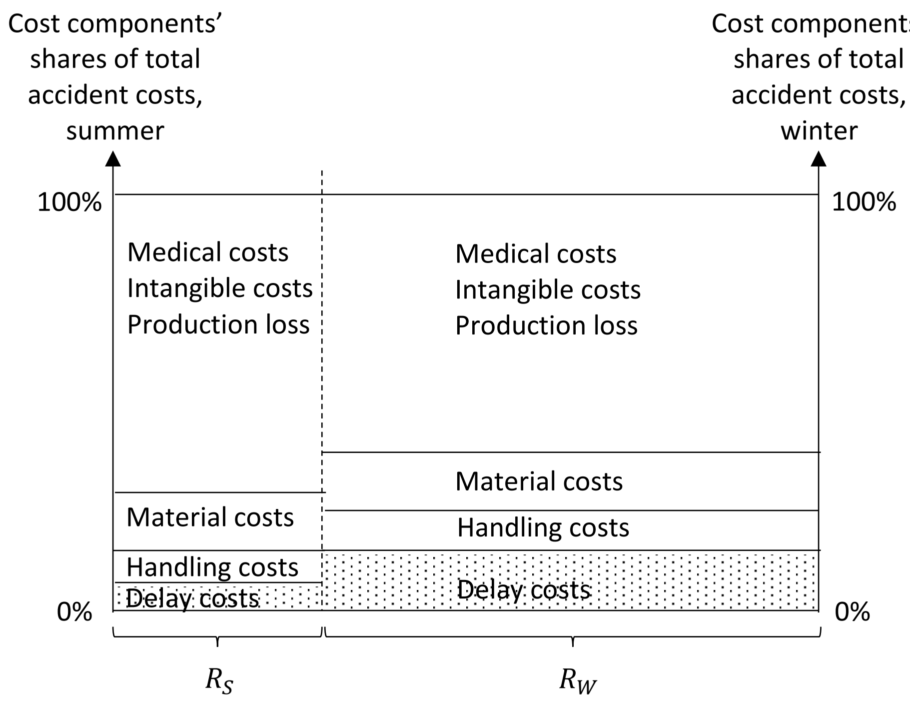

Figure 1: The various types of costs related to accidents and their assumed share of the total social costs along with the assumed difference in risk of being involved in an accident between summer (R_S) and winter (R_W).

2.4 Deducing the Delay Costs Associated with Road Traffic Accidents

The delay costs related to accidents are in this study estimated by valuing users' time loss when the road is closed due to an accident. The costs resulting from drivers' avoidance behaviour, such as choosing more expensive alternative routes or modes or being forced to cancel trips (Raemdonck et al., 2010; Wit & Methorst, 2012), are not considered.

2.4.1 Users' Time Loss

To deduce road users' time losses associated with road traffic accidents, the model introduced by Koster and Rietveld (2011) is used. The model assumes a single road from *A* to *B* and that the only congestion on this road is due to the accident. The number of vehicles stalled by the accident is a function of the duration of the handling time of the accident and the growth factor of the queue. This is illustrated in Figure 2.

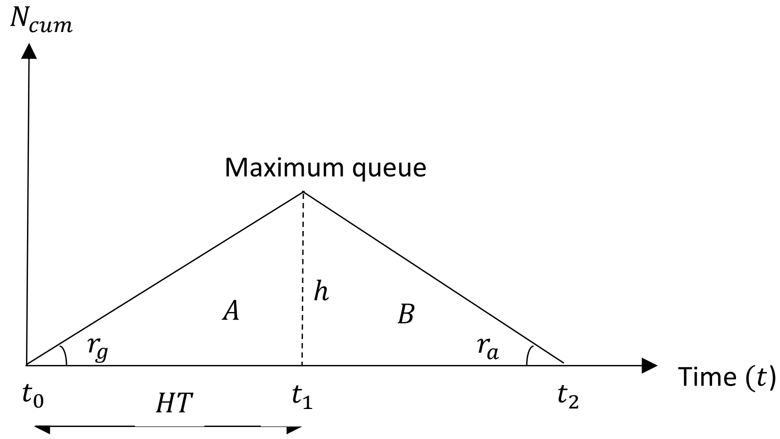

Figure 2: Total time loss associated with a road traffic accident (Koster & Rietveld, 2011) (N_{cum} is the cumulative number of vehicles)

The accident happens at time t_0 and traffic flow is obstructed. At t_1, the rescue crew has cleared the road and the queue starts to dissolve. The number of vehicles stalled by the accident at t_1 is h. The handling time (HT) is then equal to $t_1 - t_0$. At t_2, the queue ends. The flow of vehicles per unit of time (F) is assumed to be constant. Both the normal capacity of the road (CAP) and F are measured in vehicles per minute. The queue grows by the factor r_g , which is equal to the number of vehicles entering the accident location (the flow of vehicles, F) minus the capacity of the road after the accident, CAP_{crash}. When the road is cleared, the queue dissolves at rate r_a. The size of r_a is equal to the normal capacity of the road (CAP) minus F. The total time loss (TTL) experienced by road users because of the accident is equal to the sum of the areas of the two triangles A and B in Figure 2, which gives:[2]

$$TTL = \frac{1}{2} \cdot r_g \cdot (HT)^2 \cdot \left(1 + \frac{r_g}{r_a}\right) \tag{3}$$

Equation (3) shows that there is a quadric relationship between TTL and the handling time (HT) because for each additional minute of handling time, the number of vehicles involved in the queue increases. It is easily deduced from (2) that $EL_{HT}(TTL) = 2$ where $EL_{HT}(TTL)$ denotes the elasticity of TTL with respect to HT. When HT increases by X%, TTL increases by 2X%.

To calculate the average time loss (ATL) per road user, we divide the total time loss (TTL) by the number of road users, which is equal to $(t_2 - t_0) \cdot F$. This gives the following average time loss per road user:

$$ATL = \frac{TTL}{(t_2 - t_0) \cdot F} = \frac{\frac{1}{2} \cdot r_g \cdot (HT)^2 \cdot \left(1 + \frac{r_g}{r_a}\right)}{F \cdot (HT \cdot \frac{r_g}{r_a} + HT)} = \frac{\frac{1}{2} \cdot r_g \cdot (HT)^2 \cdot \left(1 + \frac{r_g}{r_a}\right)}{F \cdot HT \cdot (1 + \frac{r_g}{r_a})} = \frac{1}{2} \cdot HT \cdot \frac{r_g}{F}$$

$$ATL = \frac{1}{2} \cdot HT \cdot \left(1 - \frac{CAP_{\text{crash}}}{F}\right) \tag{4}$$

Equation (4) shows that the average time loss per road user increases proportionally with HT and decreases when the ratio of the flow capacity after the accident (CAP_{crash}) to the flow of vehicles on the road before the accident (F) ($\frac{CAP_{\text{crash}}}{F}$) increases. When traffic is minimally disrupted by the accident ($CAP_{\text{crach}} \approx F$), $ATL \approx 0$. Conversely, when the accident causes a complete standstill in traffic ($CAP_{\text{crach}} = 0$), users' average time loss equals $\frac{1}{2}HT$.

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[2] $r_g = \frac{h}{HT} \;\Rightarrow\; h = r_g \cdot HT$ and $r_a = \frac{h}{(t_2 - t_1)} \;\Rightarrow\; (t_2 - t_1) = \frac{h}{r_a} = \frac{r_g \cdot HT}{r_a}$
$A = \frac{1}{2} \cdot h \cdot HT = \frac{1}{2} \cdot r_g \cdot HT^2$ and $B = \frac{1}{2} \cdot h \cdot (t_2 - t_1) = \frac{1}{2} \cdot r_g^2 \cdot HT^2 \cdot \frac{1}{r_a}$
$TTL = A + B = \frac{1}{2} \cdot r_g \cdot HT^2 + \frac{1}{2} \cdot r_g^2 \cdot HT^2 \cdot \frac{1}{r_a} = \frac{1}{2} \cdot r_g \cdot HT^2 \cdot (1 + \frac{r_g}{r_a})$

2.4.2 Users' Costs

Lateness due to blocked roads is frustrating for both private car drivers and lorry drivers, particularly those transporting perishable goods or with tight time schedules. This suggests a higher value of travel time per hour when traffic is disrupted due to adverse incidents ($ATL > 0$). When the road is completely or partially closed because of an accident, the time costs per unit of time (C) is:

$$C = C_0 \cdot wf(ATL), wf = 1 \text{ when } ATL = 0, wf > 1 \text{ when } ATL > 0 \quad (5)$$

in which C_0 is travellers' value of time when traffic flow is normal and wf is a weight factor to adjust for lateness.

Norwegian studies show that both the values of C_0 and wf vary between private motor vehicles and heavy vehicles (Halse & Killi, 2012; Halse, Samstad, Killi, Flügel, & Ramjerdi, 2010). To our knowledge, no empirical studies have drawn clear conclusions regarding the wf (ATL)-relationship for passenger- and freight transport. The results from a Norwegian study examining users of railway freight (Halse & Killi, 2012), seem to indicate that the wf-value reduces with ATL, meaning lower time costs per unit of time (C) when the delay increases. The authors emphasize, however, that their conclusion in this respect is uncertain. Because we have little basis from available studies for correctly establishing the wf (ATL) relationships for freight and passenger transport, we assume in the following that wf, and thereby C, is independent of ATL ($ATL > 0$) for both categories of vehicles. Consequently, users' delay costs increase proportionally with the magnitude of the delay.
Using equation (4) in combination with (5) gives the average increase in time costs (AC) for each road user when one accident occurs:

$$AC = C \cdot ATL = C_0 \cdot wf \cdot \frac{1}{2} \cdot HT \cdot \left(1 - \frac{CAP_{\text{crash}}}{F}\right) \quad (6)$$

From Figure 2 it follows that the average number of vehicles reaching each accident (N_{cum} at $t_1$in Figure 2) can be written as:

$$N_{\text{cum}(s)} = \sum_{j=1}^{m} x_{js} \cdot HT_s \tag{7}$$

in which x_{js} denotes the average hourly traffic of vehicle type j with m possible vehicles types, in season s (herein $m = 2$ (private cars or heavy vehicles) and s = summer, winter). It is assumed that the flow of vehicles is constant into the accident location and constant in each season.[3] Multiplying N_{cum} with the average increase in time costs for each road user (AC) gives the average increase in time costs per accident in a given season s (ATC_s):

$$ATC_s = \sum_{j=1}^{m} [x_{js} \cdot C_{0j} \cdot wf_j] \cdot \frac{1}{2} \cdot HT_s^2 \cdot \left(1 - \frac{CAP_{\text{crash}(s)}}{F_s}\right) \tag{8}$$

Equation (8) clearly shows that the total increase in users' time costs per accident increase linearly with the level of traffic and convexly with handling time.

3. Case and data description

3.1 Ev6 Nordland

The studied road section is the 632 kilometre long European highway 6 (Ev6), which crosses the county of Nordland starting at Majavatn in the south and cuts through largely rural areas to the north end of the county, a little north of Bjerkvik (see Figure 3 for a map of the area). This stretch of road is chosen as case for the analysis because of its importance as transport corridor both within the cities in the region and for transport between northern and southern Norway. Among others, it is crucial for the transport of perishable goods such as fresh fish from the fisheries along the coast.

[3]The traffic between 06:00 and 24:00 on the road studied is close to zero, so the average daily traffic has been divided by 18 to obtain the average hourly traffic between 06:00 and 24:00 for use in the analysis.

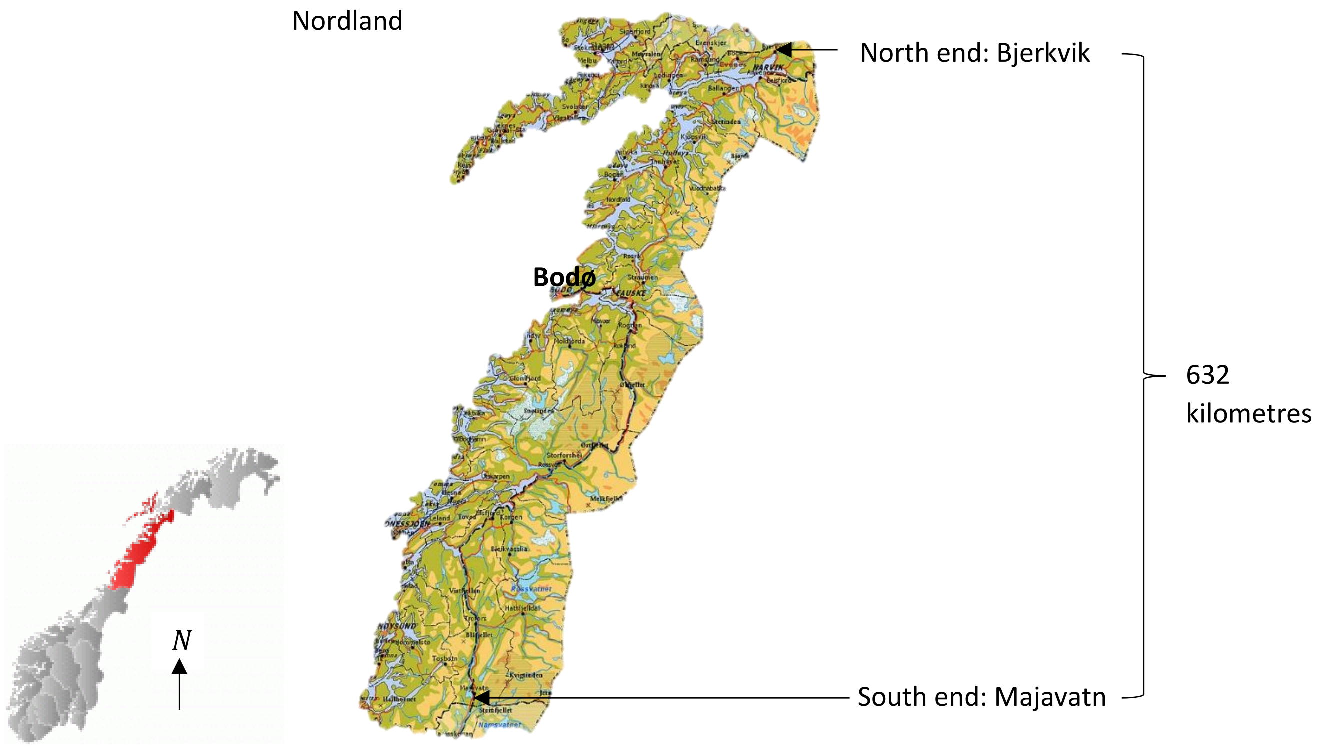

Figure 3: European Highway 6 (Ev6) through Nordland, Norway

The AADT varies significantly throughout the year. For some sections of the road, e.g., the mountain pass Saltfjellet, the AADT is as much as four times higher in July versus January. This can be partly explained by the peak in tourist traffic in summer and partly by the harsh winter weather in the region, which often results in difficult driving conditions (Bardal & Mathisen, 2015). It has been shown in literature that adverse weather causes variation in traffic volume (see e.g., Al Hassan & Barker, 1999; Cools, Moons, & Wets, 2010; Datla & Sharma, 2008; Keay & Simmonds, 2005; Knapp et al., 2000). In some areas, this can be seen as a day-to-day or hour-by-hour variation in traffic volume, while in other areas often affected by adverse weather such as the one studied, the effect in traffic can also be seen between seasons.

The timeframe for the study is the years 2010-2014. The NPRA has provided traffic data and data related to the accidents. Traffic is counted continuously as the number of vehicles passing electronic counters in the asphalt at 17 locations along the road. The average AADT for the years 2010-2014 in the summer and winter seasons for private cars and heavy vehicles is listed in Table 1. Winter season is here defined as the months October, November, December, January, February, March and April, while summer season is defined as the months May, June, July, August and September. The division in two seasons (not considering spring and fall) has been chosen because of the marked difference in driving conditions between the two on the studied road section. From October to April, quite a few stretches of the road can be expected to be covered with snow and ice creating difficult driving conditions. In the northern parts of Norway, vehicles are, therefore, allowed to be equipped with winter tires with spikes during our definition of winter season (Lovdata, 2014). The AADT is on average 61% and 64% higher in summer than in winter for private motor vehicles and heavy vehicles, respectively[4]. Heavy vehicles make up approximately 18% of total traffic.

Table 1: Average AADT in the period 2010-2014 along Ev6 Nordland.

Season	*Total*	*Private cars*	*Heavy vehicles*	*% Heavy*
Winter	1 554	1 280	277	17.8
Summer	2 515	2 059	456	18.1
Average	2 034	1 670	366	18.0

3.2 Accident Reports

The NPRA has provided the data on accidents on Ev6 Nordland for the period from 2010 to 2014. The dataset contains 1193 observations of accidents, of which 249 are accidents with fatalities and/or injuries.

[4]By comparison, statistics from the NPRA show that on Ev6 in the southern part of Norway such as in Østfold County, AADT is approximately 18 % higher in summer than in winter (NPRA, 2017). This signals that harsh winter climate particularly suppresses traffic in arctic regions.

The problem of accident underreporting, particularly with regard to less severe accidents, is well known (Elvik & Mysen, 1999; Fridstrøm, 1999), but its magnitude is difficult to estimate. In line with official accident statistics from Norway, we have chosen not to adjust the dataset for underreporting.

Accident statistics are presented in Table 2 and show that 75% of the total number of different accidents reported occurred during the winter months. For heavy vehicles, as much as 85% of accidents took place in winter. Private motor vehicles were annually involved in 47% more accidents than heavy vehicles; however, in the summer, private motor vehicles were involved in 80% of accidents compared to 26% for heavy vehicles.[5]

Table 2: Accident statistics for Ev6 Nordland, Norway, in the 5 year period from 2010 to 2014 (Source NPRA).

	Total	*Winter*	*Summer*
Number of accidents with at least one private motor vehicle involved	775	537	238
Number of accidents with at least one heavy vehicle involved	528	450	78
Total number of accidents	1193	894	299

3.3 Valuing the Social Costs of Accidents

The average costs related to injuries and fatalities per accident on Ev6 Nordland are estimated in accordance with the NPRA's valuations (NPRA, 2014). These values include medical, intangible and production loss costs. The material damage costs and handling costs are estimated based on the total claims and number of material damages reported in the county of Nordland in the studied period (Finance Norway, 2015).

Only 288 of the 1193 accident observations were complete in reporting both the closure and re-opening of the road. These were used in the analysis in order to calculate the extra time costs imposed

[5] The numbers do not add up to 100% because some accidents involved both vehicle types.

on road users due to the accidents, i.e., the delay costs. Inspection of the dataset revealed no clear pattern in the reporting of accidents. The dataset contains data with various lengths of closure or handling time (HT). On average, the road was completely closed for 68 minutes and partially closed for 46 minutes in winter, while in summer, the numbers were 62 and 69 minutes, respectively.

4. Results and discussion

4.1 The Risk and Severity of Traffic Accidents on Ev6 Nordland

The risk figures in Table 3 were estimated using equation (1). The number of vehicle kilometres driven was estimated from the traffic on 17 count points along the road and the distances between them. Because the first and the last counter were located only at the endpoints of the road, an approximate estimate of the number of vehicle kilometres driven(VKM) is:

$$VKM = \sum_{i=1}^{M-1} D_i \cdot \frac{X_i + X_{i+1}}{2} \quad (9)$$

where M is the number of counters on the stretch of road, X_i is the number of vehicles passing counter i, and D_i is the distance in kilometres between counter i and counter $(i+1)$. The average annual number of vehicle kilometres driven on Ev6 during the period from 2010 to 2014 was 432 million vehicle kilometres or approximately 1.1% of the national number of vehicle kilometres driven on Norwegian roads.

The results in Table 3 support the a priori assumption that the total accident risk is higher in winter for both private motor vehicles and heavy vehicles. For private motor vehicles, the risk was 2.8 times higher in winter, while for heavy vehicles, the risk was as much as 7 times higher. Next, in line with our assumption, heavy vehicles had a 3.8 times greater risk of being involved in an accident in winter compared to private motor vehicles.

The difference in risk between winter and summer was highest for accidents with only material damage (4 and 10 times higher for private motor vehicles and heavy vehicles, respectively). The risk of accident with injuries was only slightly higher in winter than summer. Consequently, the share of accidents with injuries and/or fatalities was 2.5 and 3.3 times as high during summer than in winter for private motor vehicles and heavy vehicles, respectively. This is in accordance with our a priori assumption that the average severity of accidents in summer is higher than in winter.

Table 3: The risk of accidents per million vehicle kilometres (R) of various severity on Ev6 Nordland, 2010-2014.

		Risk of accidents (R)		
		Average	*Winter*	*Summer*
Private motor vehicles	*Risk of accident with injury and/or fatality*	0.12	0.13	0.12
	Risk of accident with only material damage	0.32	0.57	0.13
	Total risk of accident	0.44	0.70	0.25
	Share of accidents with injury and/or fatality (%)	27.7	18.8	48.0
Heavy vehicles	*Risk of accident with injury and/or fatality*	0.20	0.29	0.14
	Risk of accident with only material damage	1.16	2.38	0.24
	Total risk of accident	1.36	2.67	0.38
	Share of accidents with injury and/or fatality (%)	14.5	10.9	36.1

4.2 The Social Costs of Accidents on Ev6 Nordland

4.2.1 The Conventional Approach to Estimating the Social Costs of Accidents

The conventional method to calculate the social costs of accidents in Norway is to include medical costs, intangible costs, production loss, material damage costs and handling costs. In Table 4, the average conventional social cost per accident on Ev6 Nordland is presented. The numbers were estimated as follows: first, the total cost of injuries and fatalities (including medical, intangible and production loss costs) were derived by multiplying the number of fatalities and various injuries with the NPRA's valuations of a fatality, a serious injury, a less serious injury, and so forth, and finding the sum (NPRA, 2014). Second, the total costs of fatalities/injuries were divided by the total number of accidents reported (1193) in order to find the average medical, intangible and production loss costs per accident. These costs were assigned to private motor and heavy vehicles according to the frequency of their involvement in accidents with fatalities/injuries.[6] The material damage cost was estimated as an average damage cost per accident based on the average damage cost per vehicle reported multiplied by 1.75, which is found in literature to be the average number of vehicles involved in each accident in Norway (Finance Norway, 2015; Høye et al., 2012). The handling costs were estimated based on the total handling costs in Norway in the studied period. It was assumed that the ratio of handling costs to material damage costs on Ev6 Nordland is the same as the ratio of these costs at the country level.

Table 4: The average social costs[7] per accident on Ev6 Nordland in the period 2010 -2014 estimated by the conventional approach.

	Average costs per accident (EUR)			
	Private motor vehicles		*Heavy vehicles*	
	Winter	*Summer*	*Winter*	*Summer*
Medical, intangible and production loss costs	96 772	212 467	42 951	241 819
Material damage costs	5 078	4 590	11 626	14 793
Handling costs	907	820	2 078	2 643
Total	**102 757**	**217 877**	**56 655**	**259 255**

Table 4 suggests some patterns of interaction between season, vehicle and cost types. Among others, and as expected, the average costs per accident is higher in summer than in winter for both vehicle groups because of higher frequency of severe accidents in summer.

[6] Private motor vehicles were involved in 277 of the accidents with injuries while heavy vehicles were only involved in 77.
[7] All costs are Consumer Price Index adjusted to July 2015 prices (Statistics Norway (SSB), 2015). 1 Euro = 9.403 NOK, August 27, 2015 (Norwegian Central Bank, 2015).

Official figures of the costs components in Table 4 are not available for Norway, but rough estimates of the total social cost per accident can be made. According to unpublished information from the Norwegian Institute of Transport Economics, the annual total social cost of accidents in Norway is approximately 2.7 billion Euro, while the total number of accidents per year is approximately 150 000 (Høye et al., 2012). This gives a total average cost per accident of 17 000 Euro. This is far less than the figures for our studied road stretch in Table 4 suggest, which indicates a significantly higher proportion of accidents with serious injuries and/or fatalities on Ev6 than at the national level.

4.2.2 Delay Costs of the Accidents

Increased Travel Time

Equation (4) was used to estimate the average time loss experienced by each road user (ATL) in each accident due to accidents on Ev6 Nordland in the studied period. It was assumed that when one lane was closed, the capacity of the road was half of the flow into the accident location; that is, $CAP_{crash} = \frac{1}{2}F$. Consequently, from equation (4) it follows that the average delay is $\frac{1}{4}HT$ when one lane was open and $\frac{1}{2}HT$ when the road was completely blocked. The average time loss each road user experienced due to each accident is summarized in Table 5.

Table 5: Average time loss experienced by each road user due to an accident on Ev6 Nordland.

	HT *closed (min)*	*HT* *one lane closed (min)*	*ATL* *closed (min)*	*ATL* *one lane closed (min)*	***ATL*** ***total (min)***
Winter	68	46	34.0	11.5	**45.5**
Summer	62	69	31.0	17.2	**48.3**

Increased Time Costs

A time value of 48.2 Euro per hour for private motor vehicles and an average time dependent operation cost of 68.4 Euro per hour for heavy vehicles were used as the traveller's time cost when traffic flow was normal (C_0) in accordance with the NPRA's recommendations (2014). Moreover, the value of time for passenger transport in severely congested traffic is estimated to be 3.0 times higher than the value of time in uncongested traffic for trips longer than 70 kilometres (Østli, Halse, & Killi, 2015). In a study of Norwegian freight transport, the Norwegian Institute of Transport Economics found that shippers with hired transport, shippers with their own freight accounts and carriers valued time 5.6 times higher on average during delays than when traffic runs smoothly (Halse et al., 2010). The above implies that the weight factors wf in formula (5) are set to 3.0 for private motor vehicles and 5.6 for heavy vehicles, resulting in time values of delays (C) of 144.6 Euro and 383.0 Euro, respectively.

The wf-values suggested by Østli et al. (2015) and Halse et al. (2010) were estimated using questionnaires that included choice experiments. The transport users could choose between different hypothetical transport alternatives with varying pecuniary costs, time and delay probabilities. It is reasonable to believe that most of the costs caused by delays such as missed appointments and lost goodwill are internalized in the wf-values above. Hence, they can be regarded as good proxies for users' true inconveniences related to delays. For thorough discussions of the estimation procedures, we refer readers to the works mentioned above.

It is worth noting that the weight factors for delay, 3.0 and 5.6, are not adjusted for seasonal effects and the above study does not allow us to do that either. We do not think this is a serious problem for heavy vehicle transport because we see no reasons to believe that the inconvenience costs per hour of late deliveries will differ between seasons. For private motor vehicles, however, the assumption is more debatable. It could be argued of lower weight factor in summer due to higher proportion of tourist traffic with probably less tight time schedules than local or regional traffic. This indicates somewhat lower delay costs in summer than our estimates suggest.

The road users' total increase in time costs (TC) per year associated with the road being partly or completely closed due to accidents were estimated by combining equation (8) and the figures in Table 5 and multiplying them by the average number of accidents per season per year. The results are summarized in Table 6 and show that road users on the road section studied experienced a total delay cost of 3.45 million Euro each year due to road accidents. The delay costs were higher for private motor vehicles than for heavy vehicles in both summer and winter because the number of light vehicles affected by the closures was much higher. Moreover, due to the significantly higher risks of accidents in winter than in summer, delay costs were approximately 50% higher in winter than in summer for both groups of vehicles.

Table 6: Road user's total increase in time cost (TC) per season/year associated with accidents on Ev6 Nordland

	Per winter season	*Per summer season*	*Per year*
TC Private motor vehicles per year (EUR)	1 324 900	868 400	2 193 300
TC Heavy vehicles per year (EUR)	754 100	505 500	1 259 500
TC Total per year (EUR)	2 079 000	1 373 900	3 452 800

4.2.3 The Total Social Costs of Accidents Including Delay Costs

The magnitudes and shares of the different types of annual accident costs are summarized in Table 7 and Table 8, respectively. According to Table 7, the total annual social costs of accidents on Ev6 were approximately 34 million Euro for the period from 2010 to 2014. Heavy vehicles account for 10.4 million Euro (31 %) of these costs. Not surprisingly, costs related to fatalities and injuries were the most prominent costs associated with the accidents. The share of these costs in the total social cost were higher for private motor vehicles than for heavy vehicles and higher in summer than in winter for both categories of vehicles. The delay costs constitute between 7.7% and 10.7% of the total social costs for private motor vehicles and between 11.1% and 12.9% for heavy vehicles. In line with our a priori assumption, delay costs' percentage share of total social costs of accidents is higher in winter than in summer – 3 percentage points higher for private motor vehicles and 1.8 percentage points higher for heavy vehicles. The tables show that except for heavy vehicles in winter, the delay costs are higher than material costs for all other cases. In total, annual delay costs are approximately 70 % higher than material costs. This illustrates the seriousness of disregarding delay costs in cost benefit analyses of road project in rural, artic areas; it can lead to beneficial projects not being implemented.

Table 7: Annual total social costs (EUR) including delay costs of accidents on Ev6 Nordland for the period from 2010 to 2014.

		Per winter season	*Per summer season*	*Per year*
Medical, intangible and production loss costs (EUR)	Private motor vehicles	10 401 500	10 095 500	20 496 900
	Heavy vehicles	3 869 100	3 755 300	7 624 500
	Total	14 270 600	13 850 800	28 121 400
Material costs (EUR)	Private motor vehicles	545 800	218 100	763 900
	Heavy vehicles	1 047 300	229 700	1 277 000
	Total	1 593 100	447 800	2 040 900
Handling costs (EUR)	Private motor vehicles	97 500	39 000	136 500
	Heavy vehicles	187 200	41 000	228 200
	Total	284 700	80 000	364 700
Delay costs (EUR)	Private motor vehicles	1 324 900	868 400	2 193 300
	Heavy vehicles	754 100	505 500	1 259 500
	Total	2 079 000	1 373 900	3 452 800
Total social costs (EUR)	Private motor vehicles	12 369 700	11 221 000	23 590 600
	Heavy vehicles	5 857 700	4 531 500	10 389 200
	Total	18 227 400	15 752 500	33 979 800

Table 8: Percentage distribution of social costs of accidents

Social costs	*Private motor vehicles*		*Heavy vehicles*	
	Winter	Summer	Winter	Summer
Medical, intangible and production loss costs	84.1%	90.0%	66.0%	82.9%
Material costs	4.4%	1.9%	17.9%	5.1%
Handling costs	0.8%	0.4%	3.2%	0.9%
Delay costs	10.7%	7.7%	12.9%	11.1%
Total social costs	100%	100%	100%	100%

Because traffic differs significantly between the winter and summer season, [8] the different cost components per 1000 kilometres driven are presented in Table 9. It shows significant increases in all types of costs per kilometre driven in winter, in particular for handling costs and material costs. The delay costs per vehicle kilometres driven were 77% higher in winter than in summer for both heavy and private motor vehicles. In addition, these costs were 163% higher for heavy vehicles compared to private motor vehicles. The total social costs per kilometres driven were 28% and 54% higher in winter than in summer for private motor vehicles and heavy vehicles, respectively. In addition, the total social costs per vehicle kilometres were 119% and 82% higher for heavy vehicles compared to private motor vehicles in winter and summer, respectively.

[8] See Table 1 for AADT. There are five and seven months in the defined summer and winter season, respectively.

Table 9: Social costs (EUR) of accidents per 1000 vehicle kilometres driven.

		Winter	*Summer*	*Percent higher costs in winter*
Medical, intangible and production loss costs (EUR)	Private motor vehicles	60.7	50.7	20%
	Heavy vehicles	104.3	85.2	22%
Material costs (EUR)	Private motor vehicles	3.2	1.1	191%
	Heavy vehicles	28.2	5.2	442%
Handling costs (EUR)	Private motor vehicles	0.6	0.2	191%
	Heavy vehicles	5.0	0.9	442%
Delay costs (EUR)	Private motor vehicles	7.7	4.4	77%
	Heavy vehicles	20.3	11.5	77%
Total social costs (EUR)	Private motor vehicles	72.1	56.4	28%
	Heavy vehicles	157.8	102.8	54%

It is important to keep in mind that most of the inconveniences caused by unreliable travel times are internalized in our estimates of delay costs (see section 4.2.2); however, the costs resulting from drivers' avoidance behaviour are not included. Hence, the total delay costs on the road section studied are higher than what is revealed in the results. In addition, because the problem of accident underreporting is larger for less severe accidents, the shares of material, handling and delay costs revealed in our study are conservative estimates.

To our knowledge, only researchers in the Netherlands and Australia have attempted to estimate delay costs related to traffic accidents. De Wit and Methorst (2012) found the delay costs to be only 2.4% of the social costs of accidents in the Netherlands, which is less than half of our result for private motor vehicles and one fourth of the results for heavy vehicles. Travel delay and additional vehicle operating costs amounted to 4.7% of the social cost of road crashes in Australia in 2006 (Bureau of Infrastructure Transport and Regional Economics (BITRE), 2009). The above two results compared to ours indicate that it may be just as or even more beneficial to reduce the frequency of accidents and incident duration on low traffic roads in rural areas as in congested urban locations.

5. Conclusions and Implications

By using a conventional risk model (NPRA, 2008) and a time loss model due to accidents by Koster and Rietveld (2011), the risk, severity and social costs of accidents on a stretch of road on the main transport corridor European Highway 6 connecting the northern and southern parts of Norway have been estimated. This study's novelty lies in the comparison of the risk and severity of accidents between the summer and winter seasons and the inclusion of delay costs in the total social costs of accidents. This is done for both private motor vehicles and heavy vehicles. Despite the attention the media has given the inconveniences related to delays caused by road accidents, no attempts have been made to calculate this type of delay cost in Norway. Only a few countries have started to include such costs as a separate category of the total social cost of accidents. Although this study focuses on one section of road in an arctic area, its findings and methodological approach should be applicable to other rural roads with similar geographic and/or climatic challenges, such as the Snow Belt states in US, parts of Canada, and other rural regions in in Europe characterized by cold and snowy winters.

The results confirm our a priori assumptions that the risk of accident is higher in winter than summer but that winter accidents are on average less severe on the studied road section. Heavy vehicles in particular had an increased risk of accidents in winter. The annual social cost of accidents was 34 million Euro and the medical, intangible and production loss costs constituted the major share; however, the share of the new cost component not typically included in cost-benefit analyses, the delay cost, here measured as increase in travel costs, was also significant. For private motor vehicles and heavy vehicles collectively, the delay costs were approximately 3.4 million Euro or 10% of the annual social cost of accidents. In comparison, material accident costs accounted for only 6% of total social accident costs in this transport corridor. The proportion of delay costs in total accident costs estimated here is twice and four times as high as in Australia and the Netherlands, respectively, which may be partly explained by the importance of the studied road section and the lack of alternative transport routes in this rural area. This signals that to include delay costs in assessment tools such as cost-benefit analyses may be particularly important when assessing the profitability of road projects in peripheral regions. By excluding the delay costs, there is a risk of underinvesting in infrastructure in these areas.

In summary, the analysis confirms the results from earlier studies that the social costs of accidents are high and that it can be beneficial for society to take measures to reduce the risk of accidents (for examples of measures see, e.g. Høye et al., 2012). Analysing winter and summer accidents separately and including the delay costs make it easier for decision makers to choose the most efficient measures. Although the social costs of accidents with fatalities and injuries are high and clearly worth preventing, the analysis shows that it can also be beneficial for society to take measures to reduce the number of less severe accidents, which are particularly frequent during the winter months. Improving the driver's skills on winter roads is one example of measure that could reduce the number of accidents in winter. This could imply higher requirements in educational programs for practice in driving on slippery roads – also for foreign drivers not used to the snowy and icy driving conditions. More strict requirements for vehicle equipment (e.g. use of winter tires and chains), and better control by the authorities that vehicles follow the requirements, are other examples of measures that could reduce the frequency of accidents.

A higher level of emergency response in order to reduce handling time is also an important measure that can reduce delay costs caused by accidents. Our modelling shows that a decrease in handling time (HT) by X% reduces these costs by $2X$%. If, for example, handling time is reduced by 10% (approximately 5 minutes), annual delay costs on Ev6 will be reduced by 0.7 million Euro. Assuming the same relative importance of delays on the entire Norwegian road network as on Ev6, reducing handling time by 10% would result in a total reduction in national delay costs of approximately 27 million Euro. Finally, improvement of the road structure and better winter maintenance may reduce the frequency of accidents and ease clearing-up after an accident. The authors recommend that the delay costs are included in road-project assessment tools ensure that appropriate decisions are made regarding the development and improvement of transportation facilities.

Admittedly, there is uncertainty related to some of the numbers used in the analysis that could affect the results. First, there is uncertainty related to the number of vehicle kilometres driven (VKM) used in the analysis since average traffic counts from 17 locations have been used. Higher (lower) numbers of VKM would give lower (higher) risk numbers. Second, the model estimates of transport users' increased travel time due to accidents are based on rather strict assumptions, and the users' delay costs per unit time must be considered crude estimates in spite of being based on extensive study of Norwegian car drivers and the Norwegian transport industry (see section 4.2.2). Due to lack of good seasonal estimates, the weights of delay costs are, for example, equal in summer and winter for both types of vehicles. Third, our figures on medical, intangible and production loss costs are based on recommended national values (NPRA, 2014), which are of course open to debate. All the above factors give rise to some uncertainty in the cost estimates, particularly for private car vehicles.

Fourth, since locals know about the difficult driving conditions and that there is a risk of being delayed because of accidents, the level of traffic is probably supressed in winter because trips are cancelled or costly detours/other transport modes are chosen. The magnitude of decrease in traffic and the welfare loss stemming from this is hard to estimate because there are other explanations for the seasonal difference in AADT such as e.g., the summer tourist traffic and peak freight transport in August and September (see section 3.1). The welfare loss will, generally speaking, be higher the more inelastic traffic on the road is with respect to generalised travel costs; i.e. the fewer realistic other transportation options and the more necessary the trips are for the users. The above points in the direction that we have underestimated the accident-related welfare loss.

Finally, the known problem of the underreporting of accidents, particularly underreporting of less severe accidents further enhances that we have made conservative estimates of accident risks, material costs and delay costs.

Nevertheless, these uncertainties should not interfere with the main conclusions. Ultimately, this analysis provides better estimates of the social costs of accidents with special focus on the delay costs they cause, which again gives rise to the more accurate use of policy instruments in order to reduce different types of accident costs.

Acknowledgements

This work has partly been funded by the County Administration of Nordland and the Norwegian Public Roads Administration. The data on traffic and regularity was kindly provided by the Norwegian Public Roads Administration.

References:

Adler, M. W., van Ommeren, J., & Rietveld, P. (2013). Road congestion and incident duration. *Economics of transportation, 2*(4), 109-118.

Al Hassan, Y., & Barker, D. J. (1999). The impact of unseasonable or extreme weather on traffic activity within Lothian region, Scotland. *Journal of Transport Geography, 7*(3), 209-213.

Alfaro, J.-L., Fabre, F., & Chapuis, M. (1994). *COST 313: socioeconomic cost of road accidents. Final report of the action*: Commision of the European Commuinities, Brussels/Luxembourg.

Andrey, J., Hambly, D., Mills, B., & Afrin, S. (2013). Insights into driver adaptation to inclement weather in Canada. *Journal of Transport Geography, 28*, 192-203.

Bardal, K. G., & Mathisen, T. A. (2015). Winter problems on mountain passes–Implications for cost-benefit analysis. *Transportation Research Part A: Policy and Practice, 74*, 59-72.

Bogaerts, M. P., Van Ginneken, P. C. H. J., Kramer, J. H. T., Molenkamp, L., Van Beek, F. A., & Penning, A. (2004). Ontwikkelingen Verkeer en Vervoer 1990-2020. Probleemverkenning voor de Nota Mobiliteit. Amsterdam: Ministerie van Verkeer en Waterstaat, Rijkswaterstaat, Adviesdienst Verkeer en Vervoer.

Bureau of Infrastructure Transport and Regional Economics (BITRE). (2009). *Road crash costs in Australia 2006*. (Report 118). Canberra, November.

Böcker, L., Dijst, M., & Prillwitz, J. (2013). Impact of Everyday Weather on Individual Daily Travel Behaviours in Perspective: A Literature Review. *Transport Reviews, 33*(1), 71-91.

Cools, M., Moons, E., & Wets, G. (2010). Assessing the Impact of Weather on Traffic Intensity. *Weather, Climate, and Society, 2*(1), 60-68. doi: 10.1175/2009WCAS1014.1

Datla, S., & Sharma, S. (2008). Impact of cold and snow on temporal and spatial variations of highway traffic volumes. *Journal of Transport Geography, 16*(5), 358-372.

Elvik, R., & Mysen, A. (1999). Incomplete accident reporting: meta-analysis of studies made in 13 countries. *Transportation Research Record: Journal of the Transportation Research Board*(1665), 133-140.

Finance Norway. (2015). Claims statistics. Retrieved 12.10.2015, 2015, from https://www.fno.no/statistikk/skadeforsikring/

Fridstrøm, L. (1999). *Econometric models of road use, accidents, and road investment decisions.* Institute of Transport Economics Oslo.

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention, 37*(3), 461-472.

Halse, A. H., & Killi, M. (2010). The value of reliability in economic analysis - theoretical foundation, PUSAM *TØI report 1103/2010,* . Oslo, Norway: Institute of Transport Economics, Norwegian Centre for Transport Research.

Halse, A. H., & Killi, M. (2012). Values of transport time and reliability for railway freight *TØI report 1189/2012*. Oslo, Norway: Institute of Transport Economics, Norwegian Centre for Transport Research.

Halse, A. H., Samstad, H., Killi, M., Flügel, S., & Ramjerdi, F. (2010). Value of freight transport time and reliability *TØI report 1083/2010*. Oslo, Norway: Institute of Transport Economics, Norwegian Centre for Transport Research.

Hanssen, T.-E. S., & Mathisen, T. A. (2011). Factors facilitating intermodal transport of perishable goods–Transport purchasers viewpoint. *European Transport\Trasporti Europei, n. 49 (2011): 75-89*.

Høye, A., Elvik, R., Sørensen, M. W. J., & Vaa, T. (2012). Trafikksikkerhetshåndboken (4 ed.). Oslo: Institute of Transport Economics, Norwegian Centre for Transport Research

Jørgensen, F. (1993). Measuring car drivers' skills—an economist's view. *Accident Analysis & Prevention, 25*(5), 555-559.

Jørgensen, F., & Pedersen, P. A. (2002). Drivers’ response to the installation of road lighting. An economic interpretation. *Accident Analysis & Prevention, 34*(5), 601-608.

Keay, K., & Simmonds, I. (2005). The association of rainfall and other weather variables with road traffic volume in Melbourne, Australia. *Accident Analysis & Prevention, 37*(1), 109-124. doi: http://dx.doi.org/10.1016/j.aap.2004.07.005

Khattak, A., & Knapp, K. (2001). Interstate highway crash injuries during winter snow and nonsnow events. *Transportation Research Record: Journal of the Transportation Research Board*(1746), 30-36.

Khattak, A. J., Kantor, P., & Council, F. M. (1998). Role of adverse weather in key crash types on limited-access roadways: implications for advanced weather systems. *Transportation Research Record: Journal of the Transportation Research Board, 1621*(1), 10-19.

Knapp, K. K., Kroeger, D., & Giese, K. (2000). *Mobility and safety impacts of winter storm events in a freeway environment.* Paper presented at the Mid-Continent Transportation Symposium 2000.

Koetse, M. J., & Rietveld, P. (2009). The impact of climate change and weather on transport: An overview of empirical findings. *Transportation Research Part D: Transport and Environment, 14*(3), 205-221. doi: http://dx.doi.org/10.1016/j.trd.2008.12.004

Koster, P., & Rietveld, P. (2011). Optimising incident management on the road. *Journal of Transport Economics and Policy, 45*(1), 63-81.

Laird, J., & Mackie, P. (2009). *Review of Economic Assessment in Rural Transport Appraisal - Research Findings*. Retrieved from http://www.scotland.gov.uk/Publications/2009/10/29110904/0.

Levy, D. T., & Miller, T. (2000). Review: Risk Compensation Literature—The Theory and Evidence. *Journal of Crash Prevention and Injury Control, 2*(1), 75-86.

Lovdata. (2014). Bruk av piggdekk. Retrieved 18.08.2014, from http://lovdata.no/artikkel/bruk_av_piggdekk/57

Maibach, M., Schreyer, C., Sutter, D., Van Essen, H. P., Boon, B. H., Smokers, A., . . . Bak, M. (2008). Handbook on estimation of external costs in the transport sector. Produced within the study Internalisation Measures and Policies for All external Cost of Transport (IMPACT). Version 1.1. Delft, CE.

Massie, D. L., Campbell, K. L., & Williams, A. F. (1995). Traffic accident involvement rates by driver age and gender. *Accident Analysis & Prevention, 27*(1), 73-87.

Norwegian Central Bank. (2015). Daily exchange rates. Retrieved 27.08.2015, from http://www.norges-bank.no/Statistikk/Valutakurser/

NPRA. (2008). *Dokumentasjon av beregningsmoduler i EFFEKT 6*. Oslo: Statens vegvesen, Vegdirektoratet.

NPRA. (2013). Vogntog på nordnorske vinterveger. Retrieved 03.09.2015, from http://www.vegvesen.no/Om+Statens+vegvesen/Presse/Nyheter/Lokalt/Region+Nord/vogntog-p%C3%A5-nordnorske-vinterveger

NPRA. (2014). *Konsekvensanlalyser: Håndbok V712*. Norwegian Public Road Administration.

NPRA. (2017). Traffic records. Retrieved 16.02.2017, from http://www.vegvesen.no/_attachment/62346/binary/1159628?fast_title=%C3%98stfold%2C+%C3%A5rs-+og+m%C3%A5nedsd%C3%B8gntrafikk.pdf

Raemdonck, K. V., Macharis, C., & Malderen, F. V. (2010). *The cost of congestion due to road accidents: Peanuts compared to the value of life?* Paper presented at the 12th WCTR, July 11-15, 2010, Lisbon, Portogal.

Risa, A. E. (1992). Public regulation of private accident risk: The moral hazard of technological improvements. *Journal of Regulatory Economics, 4*(4), 335-346.

Risa, A. E. (1994). Adverse incentives from improved technology: traffic safety regulation in Norway. *Southern Economic Journal*, 844-857.

Royal Norwegian Ministry of Transport and Communications. (2014). Competence to drive under winter conditions - Letter to the Europen Commision - DG Mobility and Transport. Retrieved 03.09.2015, from https://www.regjeringen.no/globalassets/upload/sd/vedlegg/veg20og20vegtrafikk/kompetansekrav_yrkessjaafoerer_glattkjoring_eu.pdf

Seeherman, J., & Liu, Y. (2015). Effects of extraordinary snowfall on traffic safety. *Accident Analysis & Prevention, 81*, 194-203. doi: http://dx.doi.org/10.1016/j.aap.2015.04.029

Shankar, V., Mannering, F., & Barfield, W. (1995). Effect of roadway geometrics and environmental factors on rural freeway accident frequencies. *Accident Analysis & Prevention, 27*(3), 371-389. doi: http://dx.doi.org/10.1016/0001-4575(94)00078-Z

Statistics Norway (SSB). (2015). Consumer Price Index (CPI) July 2015. Retrieved 31.08.2015, from http://www.ssb.no/en/priser-og-prisindekser/statistikker/kpi

Steimetz, S. S. (2008). Defensive driving and the external costs of accidents and travel delays. *Transportation Research Part B: Methodological, 42*(9), 703-724.

Strandroth, J., Rizzi, M., Olai, M., Lie, A., & Tingvall, C. (2012). The effects of studded tires on fatal crashes with passenger cars and the benefits of electronic stability control (ESC) in Swedish winter driving. *Accident Analysis & Prevention, 45*, 50-60. doi: http://dx.doi.org/10.1016/j.aap.2011.11.005

SWOV. (2014). Fact sheet - Road crash costs. Institute for road safety research, Leidschendam, the Netherlands.

Usman, T., Fu, L., & Miranda-Moreno, L. F. (2010). Quantifying safety benefit of winter road maintenance: Accident frequency modeling. *Accident Analysis & Prevention, 42*(6), 1878-1887. doi: http://dx.doi.org/10.1016/j.aap.2010.05.008

Wilde, G. J. (1982). The theory of risk homeostasis: implications for safety and health. *Risk analysis, 2*(4), 209-225.

Wit, M. d., & Methorst, R. (2012). Kosten verkeersongevallen in Nederland: Ministerie van Infrastructuur en Milieu Directoraat-generall Rijkswaterstaat Dienst Verkeer en Scheepvart, Delft.

Østli, V., Halse, A. H., & Killi, M. (2015). Value of time, safety and environment in passenger transport - adjusted to NTM6 *TØI report 1389/2015*. Oslo, Norway: Institute of Transport Economics, Norwegian Centre for Transport Research.