Impacts of Adverse Weather on Arctic Road Transport

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Abstract

Arctic regions are geographically peripheral and characterized by cold climate, constantly changing weather conditions and strong seasonal variations. This article examines variations in road traffic volume due to adverse weather in an arctic region, a topic that has received little attention in the transportation literature. The subject of the case study is northern Norway's Saltfjellet mountain pass, which is part of European Highway 6 (Ev6). A succinct econometric structural equation model was used to test hypotheses regarding the impacts of fluctuations in temperature, precipitation and wind speed on passenger and freight traffic volumes. The findings indicate that there was some reduction in traffic volume during adverse weather, particularly with respect to passenger traffic. However, the day-to-day variations in traffic volumes were relatively low at the studied section of road, although it is known that generalized transport costs increase significantly in adverse weather due to delays related to poor driving conditions and closed roads. The studied region is rural with limited access to alternative routes or transport modes, thus making this portion of the road particularly important for the communities in the region. Hence, the road users have few other options than using this high-cost road in order to maintain their activities. The use of standardized parameters in transport models to predict the effect of adverse weather on traffic volume, would not be appropriate in the studied context. However, it is recommended that the benefits of reducing the extra costs that adverse weather impose on traffic are estimated and included in road-project assessment tools to capture the burden and strain imposed on road users. This to ensure that appropriate decisions are made regarding the development and improvement of transportation facilities, particularly in rural areas.

Keywords: adverse weather, traffic volume, arctic rural context, structural equation modelling

1. Introduction

One of the main objectives of countries with long-term transport plans is to have efficient and reliable transportation systems (see, for instance, the Norwegian National Transport Plan (2013) and National Plan for Sweden's Transport System (2010)). However, extant literature indicates that transport systems are vulnerable to adverse weather[1], as such conditions may reduce the efficiency and reliability of the system (Datla & Sharma, 2008; Keay & Simmonds, 2005; Khattak, Kantor, & Council, 1998; Lam, Shao, & Sumalee, 2008; Thomas H. Maze, Agarwal, & Burchett, 2006). To facilitate decision makers in improving the operations and maintenance of existing infrastructure and in planning new infrastructure and to identify adaptation and mitigation strategies to address weather-related problems of today and those of the future, it is critical to know and understand how weather conditions affect transportation (Jaroszweski, Chapman, & Petts, 2010, 2013). Many road sections in Norway are particularly vulnerable to adverse weather conditions because of the combination of challenging topography, vast mountain areas, deep fjords and adverse climatic conditions. A consensus among climate researchers reveals that the global weather-related problems are not likely to diminish in the near future (Doran & Zimmerman, 2009). Moreover, they project that in Norway, the intensity and duration of precipitation are expected to increase, and while temperatures may increase and result in less snow in lower areas, it is expected that the mountain areas will still receive heavy precipitation in the form of snow during the winter months (NOU 2010: 10, 2010). The probability of an increased number of events with strong winds do also exists.

The aim of this article is to investigate the variability in road traffic volume under varied weather conditions on a rural road section, the Saltfjellet mountain pass, which is part of the main transport corridor of European Highway 6 (Ev6) that connects southern and northern Norway. A better understanding of how adverse weather impacts traffic in the rural context will help policy makers make better decisions regarding the development and improvement of transportation facilities in these areas. Only two alternatives exist to the part of Ev6 studied, and both have significantly higher transport costs. Similar to many other mountain passes, the Saltfjellet mountain pass is often affected by adverse weather that impairs driver ability and causes road closures, both of which increase travel time and thereby reduce arrival time reliability (Bardal & Mathisen, 2015). Assuming that drivers seek to minimize their transport costs, the hypothesis is that adverse weather conditions affect the number of drivers who choose to use this mountain pass. In addition, the literature indicates that various types of road transport respond differently to adverse weather (Button, 2010;

[1] Adverse weather is defined as "atmospheric conditions at a specific time and place that are unfavorable to optimal traffic conditions" (El Faouzi, Billot, Nurmi, & Nowotny, 2010).

De Jong, Schroten, van Essen, Otten, & Bucci, 2010; Graham & Glaister, 2004; Litman, 2013). Accordingly, the two research questions explored in this study are as follows:

1. How does adverse weather affect road traffic volume on the Saltfjellet mountain pass?
2. Do passenger and freight traffic volumes differ in their sensitivity to adverse weather on the Saltfjellet mountain pass?

Though the impact of weather on road transportation has been the subject of much research, the variations in context are limited. The majority of the extant studies have been conducted in densely populated areas where congestion and road capacity are the primary problems, while travel concerns in rural areas have received limited attention (Böcker, Dijst, & Prillwitz, 2013). One important feature of rural areas is that they often lack, or have limited access to, alternative transport modes and routes. Therefore, interruptions in the available transport system may have substantial impacts on transport costs as well as on competition in the product, service and labour markets in these areas (Laird & Mackie, 2009). The climate zones covered in the literature are also limited. For example, all of the mountain passes in Norway have polar climates[2], a climate zone that is virtually ignored in the literature (Böcker et al., 2013). Though roads in mountain areas in some other countries, such as the northern parts of the US, Canada, and some EU countries, experience similar winter problems, the areas are not classified as polar climates. In these cases, local knowledge of the relationship between transportation and weather conditions is essential because this relationship may differ extensively between locations (Böcker et al., 2013; Liu, Susilo, & Karlström, 2014).

This article is structured as follows. In Chapter 2, the theoretical background and hypotheses regarding the relationships between traffic volume and adverse weather are provided. The case study and data are then described in Chapter 3. Chapter 4 presents the model, and Chapter 5 discusses the results. Concluding remarks and possible implications are provided in Chapter 6.

2. Factors Affecting Traffic Volume

2.1 General Theory

In this study, several factors are found to affect traffic volume (Button, 2010; Litman, 2013). Time costs and costs related to discomfort and risk are among the most important factors. These are followed by the high price and limited availability of other transport modes and routes at the section of road studied herein. Additionally, the amount and type of freight transport in the region and the

[2] According to the Köppen-Geiger classification (Böcker et al., 2013)

quality of road maintenance and operations affect traffic volume on the studied mountain pass. It is expected that traffic volume will decrease when general transport costs increase (Button, 2010). Several studies have investigated the impact of adverse weather on generalized transport costs (Asensio & Matas, 2008; Bardal & Mathisen, 2015; Bates, Polak, Jones, & Cook, 2001; Hagen & Engebretsen, 1999; Li, Hensher, & Rose, 2010; Sikka & Hanley, 2013; Tseng & Verhoef, 2008). The findings from these earlier studies form the basis for the relationships illustrated in Figure 1.

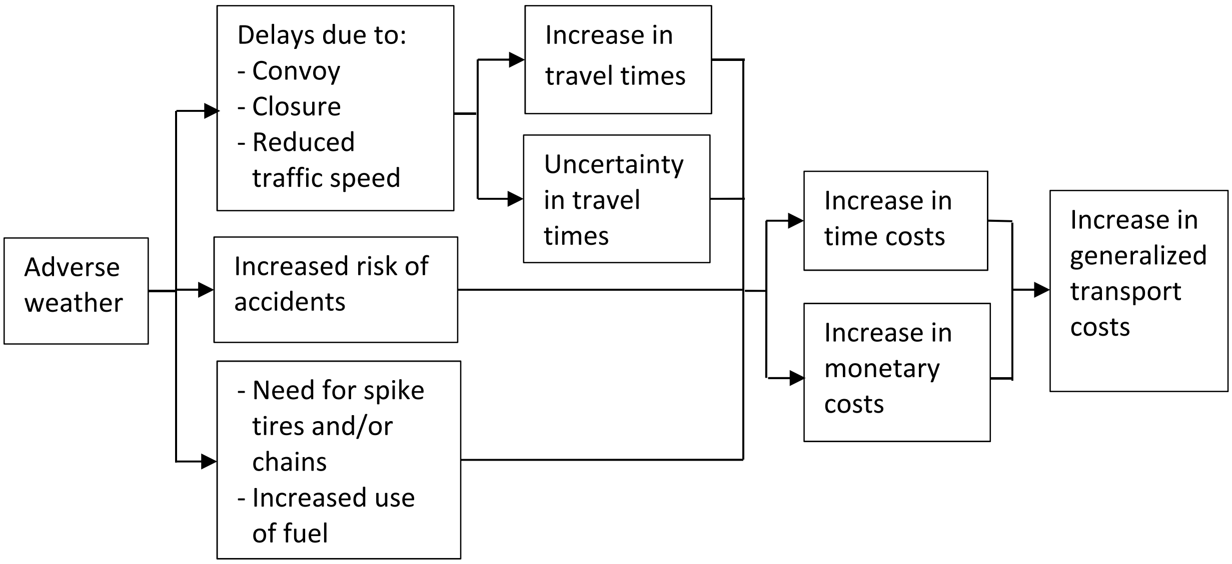

Figure 1: The impact of adverse weather on generalized transport costs.

Assuming that drivers act to minimize their generalized transport costs, we can expect different types of behavioural reactions to adverse weather. Adverse weather may affect trip generation, trip distribution, modal choice, route choice, temporal choice, and speed choice, all of which will cause variation in traffic volume (Koetse & Rietveld, 2009; Ortúzar & Willumsen, 2011). Husdal and Bråthen (2010) investigated how production and transport companies managed uncertainties and disruptions in freight transport due to unforeseen events such as closed roads caused by adverse weather, flooding and avalanches. They found that the commodity owners attempt to reduce their risks by using regular routes and/or by using the same transport companies consistently, and the transport companies include the price of the risk in their cost calculations at the time the transport is ordered. Moreover, the transport companies attempt to reduce their risks by investing in suitable vehicles and equipment and by adding slack time into their schedules.

It is reasonable to expect freight transport is less sensitive to price changes than passenger transport on the mountain pass studied herein (Button, 2010; De Jong et al., 2010; Graham & Glaister, 2004; Litman, 2013). First, cancelling and postponing trips are not likely to be options for freight transporters who are obligated to meet delivery times. Second, it is more difficult for freight transporters to change transport modes or routes on short notice because of limited access to alternatives. Third, a large proportion of the passenger traffic on the Saltfjellet mountain pass is due to leisure activity. Fourth, according to Fuller's (2005) task-capability interface (TCI) model, freight transport drivers will, in general, possess higher capability levels because they are better trained and have more experience driving in adverse weather conditions. Thus, these drivers are better able to contend with challenging driving conditions than are private motor vehicle drivers, although the heavy vehicles may be more difficult to drive on icy roads compared to passenger cars. Finally, freight transport drivers may well have greater motivation than private motor vehicle drivers to complete the trip as quickly as possible due to tight time schedules (Fuller, 2005).

That the measured freight traffic volume is less sensitive to increases in generalized transport costs due to adverse weather is supported by the findings of several studies. For example, Maze et al. (2006; 2005) found in their study of northern Iowa that commercial trips were less likely to be affected by adverse weather conditions than were passenger trips. Cools et al. (2010) explained that the heterogeneity in the effects of weather conditions on traffic between different locations on Belgium highways was due to the underlying differences in travel motives among drivers. For example, work-related traffic was less affected than leisure traffic. Datla and Sharma (2008) studied highways in Alberta, Canada, and found that commuter roads exhibited lower traffic reductions due to cold temperatures than did recreational roads.

2.2 Weather Impact on Traffic Volume

Wind speed, temperature and precipitation (rain and snow) have been identified as important weather indicators affecting road transport (see e.g. Agarwal, Maze, & Souleyrette, 2005; Al Hassan & Barker, 1999; Bardal & Mathisen, 2015; Böcker et al., 2013; Clifton, Chen, & Cutter, 2011; Cools, Moons, & Wets, 2010; Datla & Sharma, 2008; Keay & Simmonds, 2005; Saneinejad, Roorda, & Kennedy, 2012), and the Norwegian Public Road Administration (NPRA) confirms that these are the most important weather variables affecting traffic at the Saltfjellet mountain pass (NPRA, 2012)[3].

An increase in precipitation is expected to cause a decrease in traffic volume (Al Hassan & Barker, 1999; Böcker et al., 2013; Datla & Sharma, 2008; Keay & Simmonds, 2005). As precipitation may reduce visibility and create challenging road surface conditions, some road users are expected to avoid using the mountain pass when precipitation increases, which can be measured as a decrease in

[3] Even though fog and clouds can affect traffic substantially in some geographical areas, fog and sky conditions do not normally cause problems for traffic in the context studied.

traffic volume. Similarly, an increase in wind speed is expected to reduce traffic volume as strong winds may blow vehicles off the road or cause snowdrifts that may block the road and/or reduce visibility (Böcker et al., 2013; Cools, Moons, & Wets, 2010; Knapp, Kroeger, & Giese, 2000; Thomas H. Maze et al., 2006).

Though the relationship between temperature and traffic volume is uncertain, it is postulated that cold temperatures may be associated with lower traffic volumes because some drivers will find it uncomfortable to drive in extremely cold weather (Al Hassan & Barker, 1999; Datla & Sharma, 2008). In addition, low temperatures combined with precipitation/snow may be associated with lower traffic volumes because of poor road conditions, such as ice and snow (Cools, Moons, Creemers, & Wets, 2010).

Convoy on the road or the road result in increased travel time for the road users. The increases in travel time are, in the event of a convoy, the result of the 40 km/h speed limit restriction on convoys, and in the event of a road closure, the result of having to wait for the road to reopen (Bardal & Mathisen, 2015; Hagen & Engebretsen, 1999; Husdal & Bråthen, 2010; NPRA, 2012). In addition, many find it unpleasant to drive in the types of weather conditions that result in road closures and convoys. Because of the road users avoidance behaviour it is expected that the traffic volume will be lower in these situations. According to the Norwegian Public Road Administration's guidelines (NPRA, 2012), weather conditions that call for the regulation of traffic include on, or a combination of the following situations: restricted visibility, narrow or impassable road caused by snowdrift, and possibility that vehicles will be blown off the road by strong winds. As snow is associated with low temperatures, an increase in temperature is expected to reduce the probability of the road being closed or traffic being led in a convoy, while increases in precipitation and wind speed are expected to increase the probability of a closure or a convoy.

3. The Case of Saltfjellet

3.1 The Saltfjellet Mountain Pass

The road section studied herein is part of European Highway 6 (Ev6), which is located at the Arctic Circle and connects the cities Mo i Rana and Fauske in the county of Nordland (see Figure 2 for a map of the area). It is the main transport corridor between northern and southern Norway, and as such, it is important for the transport of perishable goods such as fresh fish from the fisheries along the coast, etc. The highest altitude on the road between Mo i Rana and Fauske is not more than 700 metres above sea level. However, the 20-kilometre stretch between the road barriers on the mountain pass lies above the tree line in the polar climate zone (Norwegian Meteorological Institute, 2014b; Thorsnæs, 2016). Moreover, although the terrain is open and exposed to wind, it is not particularly vulnerable to weather-related landslides.

Figure 2: Map of the studied road section, Ev6 Saltfjellet, with detour opportunities (adapted from Google maps).

The railway runs along Ev6 over the mountain pass. The traffic on the railway is not hindered by adverse weather to the same degree as road transport; however, other parts of the railway further south experience frequent weather-related landslides, which thereby reduces the reliability of this transport mode. There are also several small airports in the region, but they, too, are exposed to adverse weather and must therefore frequently close.

There are two alternative road routes to the 110-kilometre stretch of road between Mo i Rana (south of the mountain) and Storjord (north of the mountain Ev6 Saltfjellet). To the east is the 620-kilometre route through Sweden. As this route, however, also goes through mountainous areas at both border crossings, these road sections are also preventatively closed under adverse weather conditions. To the west is the coastal route. The distance from Mo i Rana to Storjord on this route is 360 kilometres. However, if you are travelling further north on Ev6, the route connects to Ev6, 30 kilometres north of Storjord. Though this route is not hindered by adverse weather to the same degree as Ev6 Saltfjellet, the road is in poor condition and is interrupted by two ferries, which are unpleasant to use in adverse weather. In addition, ferry departures are frequently cancelled when the weather is extremely bad.

Though this study focuses on one section of road, the Ev6 Saltfjellet mountain pass, there are several other similar road sections that would have been equally worthy of study. This mountain pass was partly chosen because of the availability of data, as it is often difficult to obtain good meteorological data for the mountain passes. In addition, this particular section of road is a crucial transport corridor in the region. Moreover, this part of the road shares features that are found on other similar road sections across mountain areas in both northern and southern Norway as well as in other mountainous states, thus allowing for the transferability of the results to other regions. The characteristics common to these sections of roads include the adverse climatic conditions, the open terrain that exposes the sections to particularly adverse weather, and the fact that they are located in rural areas with limited access to alternative transport routes and modes of transportation.

The day-to-day variation in traffic volume on the Ev6 Saltfjellet mountain pass has been studied in the two winter seasons from October 1st, 2011, to May 1st, 2012, and October 1st, 2012, to May 1st, 2013. During these periods, drivers can expect roads to be covered with snow and ice.[4] Table 1 summarizes some of the descriptive statistics of the traffic on the EV6 Saltfjellet mountain pass. The average daily traffic during the studied winter seasons is approximately 560 vehicles. However, there are large seasonal variations in traffic volume. For example, the average number of vehicles per day in July 2013 is 2074, while the average number of vehicles per day in January of the same year is 432 (NPRA, 2015).

Table 1: Descriptive statistics of traffic on the EV6 Saltfjellet mountain pass (NPRA, 2015)

EV6 Saltfjellet:	*2011-2012*	*2012-2013*
Average daily traffic during the period Oct 1st to May 1st	564 vehicles	557 vehicles
Average percentage of heavy vehicles (vehicles > 5.6)	28%	28%
Days affected by closures	16 days	13 days
Days affected by convoys	26 days	6 days

[4] In northern parts of Norway, the car drivers are allowed to use winter tires with spikes from October 16th to May 1st (NPRA, 2013b)

3.2 Data Collection and Description

Data are collected on a daily basis, and the dataset contains 404 out of 427 possible observations. The first 18 days of October 2012 and an additional nine random observations are missing, but this is not expected to influence the results of the analysis.

The Norwegian Public Road Administration (NPRA) has provided data on traffic volume. Traffic volume is defined as the number of vehicles passing, each day, an electronic counter (inductive loops in the asphalt covering (NPRA, 2011)) located at the Sørelva traffic station on the north side of the Saltfjellet mountain pass. The electronic counter is positioned on a straight section of road according to the NPRA's guidelines (NPRA, 2011). In accordance with NPRA's definition, heavy vehicles are defined as being a minimum of 5.6 metres in length (NPRA, 2011). The number of heavy vehicles (Y_h) represents freight traffic volume. The number of vehicles less than 5.6 metres in length represents private motor vehicles, more specifically, passenger traffic volume (Y_p). This grouping of vehicles is reasonable for the mountain pass studied because most of the trips are defined as long-distance trips[5], and in the winter, there are no regular bus routes and few caravan-driving tourists.

Weather data are obtained from the Norwegian Meteorological Institute (2013a) and include measures from the Hjartåsen weather station[6], which is located 20 kilometres south of the road barrier on the Saltfjellet mountain pass. Although weather conditions at the top of the mountain are likely to be slightly more adverse with 2-4 degrees Celsius lower temperatures compared to Hjartåsen due to higher altitude, the weather measures from this station give good indications of the weather conditions in the area.

The choice of which weather variables to include in the analysis is guided by theory (see Section 2.2). Temperature (X_1) is measured in degrees Celsius as daily average temperature of the day of report. Precipitation (X_2) is measured in millimetres per day (mm/day) and relates to the total amount of precipitation from 7:00 am on the day of observation to 7:00 am the next day. Wind speed (X_3) is measured in meters per second (m/s). The strongest wind gust[7] on the day of report is used as an indicator of wind speed. Alternatively, average wind speed could have been used, but as data were aggregated to daily levels and wind speeds can differ significantly throughout the day, this was not considered a good indicator for this analysis.

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[5] Trips greater than 100 kilometres are defined as long-distance trips, according to NPRA (2013a).
[6] The altitude of the weather station is 251 metres above sea level (Norwegian Meteorological Institute, 2013b).
[7] Maximum gust (3 seconds) last hour (Norwegian Meteorological Institute, 2014a).

Descriptive statistics of the traffic and weather data are presented in Table 2. The weather variables and traffic variables are all in metric measurements. However, while the weather variables are continuous, the traffic variables are count data.

Table 2: Descriptive statistics (N=404)

Variable description	*Var. name*	*Mean*	*Std. dev.*	*Min.*	*Max.*	*Median*
Passenger traffic volume	Y_p	378	160	48	1101	344
Freight traffic volume	Y_h	173	62.8	0	360	175
Air temperature (°C)	X_1	-3.43	6.19	-20.50	8.00	-2.60
Precipitation (mm/day)	X_2	3.68	6.81	0.00	48.00	0.80
Wind speed (max wind gust) (m/s)	X_3	10.11	4.48	2.40	31.40	9.50
Convoy (yes=1)	Y_{co}	0.08	0.27	0.00	1.00	0.00
Closure and not convoy the same day (yes=1)	Y_{cl}	0.03	0.18	0.00	1.00	0.00
Weekend (yes=1)	X_4	0.44	0.50	0.00	1.00	0.00
Christmas (yes=1)	X_5	0.04	0.21	0.00	1.00	0.00
Easter (yes=1)	X_6	0.054	0.23	0.00	1.00	0.00
Daylight (minutes)	X_7	480	269	98	1052	469

The variables for convoy (Y_{co}) and closure but not convoy (Y_{cl}) are dummy variables holding the value 1 if true and 0 otherwise. The days with closures also have traffic counts because when the road is closed, it is usually only closed for a period of time during the day rather than the entire 24-hour period. The road is typically closed for a period of time and then, immediately following the closure, the traffic is led in a convoy, or vice versa. The variable Y_{co} represents all the days affected by a convoy alone or in combination with a closure. The variable Y_{cl} represents the days with only a closure.

Weekend (X_4) is a dummy variable holding the value 1 if it is Friday, Saturday or Sunday and 0 otherwise. This variable is included to control for variations in traffic volume throughout the week. An examination of the data reveals that passenger traffic volume was higher on weekends with peaks on Friday and Sunday, while freight traffic volume was higher during the workdays (Monday to Thursday) than on weekends. Two additional dummy variables are included, namely Christmas (X_5) and Easter (X_6), and hold the value 1 if Christmas or Easter and 0 otherwise. Both passenger and freight traffic volumes are typically lower during Christmas. At Easter, however, the pattern is different. While freight traffic volume is lower, passenger traffic volume is higher because people typically travel to their cabins or choose to go skiing in the mountains during this holiday. The variable Daylight (X_7)[8] controlling for variation in day-length, is included because traffic volume is expected to be higher on days with more daylight compared to days with less daylight.

A pair-wise correlation test of the data indicates that some multicollinearity exists between the variables[9], but it is not so high as to cause problems for further analysis (Wooldridge, 2013). The Shapiro-Wilks test for normality indicates that freight traffic volume is normal distributed, while passenger traffic volume is not. The Augmented Dickey-Fuller test rejects the hypothesis of the presence of unit root in passenger traffic volume and freight traffic volume, thus indicating that the data are trend stationary.

4. The Model

With respect to count data, the regression method of choice is the Poisson regression (Bhaskaran, Gasparrini, Hajat, Smeeth, & Armstrong, 2013). However, for counts as large as those in this study (the number of vehicles per day on the Saltfjellet mountain pass), normal distribution can be approximated based on the central limit theorem, which enables the use of other econometric approaches (Wooldridge, 2013). Structural equation modelling (SEM) is selected as the statistical modelling technique because of its ability to handle endogeneity in the variables Y_{co} (convoy) and Y_{cl} (only closure)[10]. The measured variation in traffic volume resulting from adverse weather is expected to be a sum of the direct effect and the indirect effect of the weather variables on traffic volume. The latter via the convoy and closure variables.

Log transformation of endogenous variables[11] is common in applied economics because of certain favourable advantages this approach offers (Wooldridge, 2013). First, when the endogenous variable is greater than 0, as in this study, using a log-transformation often satisfies the classical linear model assumptions more closely than do models using the untransformed variable. Log transformation of endogenous variables can reduce the problem of skewed or heteroscedastic distribution, which is

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[8] Daylight is defined as the number of minutes between sunrise and sunset (Time and Date, 2016).
[9] The three largest between the independent variables were 0.46 between wind gust and lag wind gust, 0.43 between temperature and wind gusts, and 0.41 between precipitation and wind gusts (all three significant at the 5% level).
[10] An alternative technique to handle the endogeneity problem could have been to use two-stage least squares (2SLS) regression (Wooldridge, 2013). However, difficulties with finding good instrumental variables excluded this alternative.
[11] In SEM, the independent and dependent variables are referred to as exogenous and endogenous variables, respectively (Kline, 2011).

often a problem with strictly positive variables. Another benefit of using logs is that it narrows the range of the variable, thus making OLS estimates less sensitive to outliers. In addition, log-transformation may ease the interpretation of the results from the analysis.

The true nature of the relationships between the weather variables and traffic volume is unknown. However, the assumption of non-linear relationships is supported by Böcker et al. (2013) who argue that studies often wrongfully assume linear relationships between weather and travel behaviour that are underlying the variation in traffic volume measured in this study. Based on a consideration of the favourable advantages of log transforming the endogenous variables, an exploration of the data, and the literature review, log-linear specifications were selected for both traffic volume variables (McCarthy, 2001).[12] Log transforming the endogenous variables convoy (Y_{co}) and closure (Y_{cl}) was not possible because they are dummy variables holding the value 1 or 0. The weather variables could not be log-transformed either because they also have a value of 0. An explorative modelling-approach excluded other transformations of the variables as suitable. One lag in the traffic volume variables was included to control for autocorrelation in the data.[13] Based on conceptual reasoning and an explorative approach to the data, lags in the weather variables were also included. The section of road studied herein is a two-lane low traffic road. Although both vehicle groups share the same lanes, it is assumed that their volumes are not interdependent as there is no congestion and limited access to alternative road routes. A pair-wise correlation test of the traffic volume data confirms this assumption by showing that the correlation between the freight and passenger traffic volumes is 0.045 and non-significant.

The four equations estimated in the model are (t = day of observation):

(1) $$lnY_{pt} = \beta_0 + \beta_1 Y_{pt-1} + \beta_2 X_{1t} + \beta_3 X_{1t-1} + \beta_4 X_{2t} + \beta_5 X_{2t-1} + \beta_6 X_{3t} + \beta_7 X_{3t-1} + \beta_8 X_{4t} + \beta_9 X_{5t} + \beta_{10} X_{6t} + \beta_{11} Y_{cot} + \beta_{12} Y_{clt} + \beta_{13} X_{7t} + \varepsilon_1$$

(2) $$lnY_{ht} = \delta_0 + \delta_1 Y_{ht-1} + \delta_2 X_{1t} + \delta_3 X_{1t-1} + \delta_4 X_{2t} + \delta_5 X_{2t-1} + \delta_6 X_{3t} + \delta_7 X_{3t-1} + \delta_8 X_{4t} + \delta_9 X_{5t} + \delta_{10} X_{6t} + \delta_{11} Y_{cot} + \delta_{12} Y_{clt} + \delta_{13} X_{7t} + +\varepsilon_2$$

(3) $$Y_{cot} = \alpha_0 + \alpha_1 X_{1t} + \alpha_2 X_{1t-1} + \alpha_3 X_{2t} + \alpha_4 X_{2t-1} + \alpha_5 X_{3t} + \alpha_6 X_{3t-1} + \alpha_7 X_{5t} + \varepsilon_3$$

(4) $$Y_{clt} = \gamma_0 + \gamma_1 X_{1t} + \gamma_2 X_{1t-1} + \gamma_3 X_{2t} + \gamma_4 X_{2t-1} + \gamma_5 X_{3t} + \gamma_6 X_{3t-1} + \gamma_7 X_{5t} + \varepsilon_4$$

[12] In the log-linear model, the endogenous variable (traffic volume) is in logarithms and the exogenous variables are in linear form (McCarthy, 2001).
[13] Since most of the traffic on the studied section of road is long-distance traffic, it was assumed no repetition of behaviours among the observed sample on a given day.

The a priori assumptions regarding the signs of the coefficients are discussed in sections 2.2 and 3.2[14]. The coefficients $\beta_4, \beta_6, \beta_9, \beta_{11}, \beta_{12}, \delta_4, \delta_6, \delta_8, \delta_9, \delta_{10}, \delta_{12}, \alpha_1, \alpha_2, \gamma_1$ and γ_2 are expected to be negative, while $\beta_2, \beta_8, \beta_{10}, \beta_{13}, \delta_2, \delta_{13}, \alpha_3, \alpha_4, \alpha_5, \alpha_6, \alpha_7, \gamma_3, \gamma_4, \gamma_5, \gamma_6$ and γ_7 are expected to be positive. The expected signs of the remaining coefficients are uncertain because the effect of adverse weather and one day's traffic volume on the next day's traffic volume is ambivalent. Periods with bad weather often last several days, thereby creating difficult driving conditions for several days in a row, a factor that may cause traffic volume to be lower the next day. On the other hand, traffic volume the day after adverse weather may increase if people postponed their trips when the weather was bad and then made the trip the next day.

Because the observed values of precipitation and wind speed are non-negative and the coefficients $\beta_4, \beta_6, \delta_4$ and δ_6 are expected to be negative, which yields negative first-order derivatives ($\frac{\partial Y_{pt}}{\partial X_{2t}}, \frac{\partial Y_{pt}}{\partial X_{3t}}, \frac{\partial Y_{ht}}{\partial X_{2t}}, \frac{\partial Y_{ht}}{\partial X_{3t}} < 0$), the effect of precipitation and wind speed on traffic volume are represented by falling curves. As the second-order derivatives of the precipitation and wind speed variables are positive, the model specification assumes that the marginal effect of a change in wind speed and precipitation on traffic volume is decreasing. This is reasonable given that drivers who are sensitive to driving in adverse weather will likely consider other alternatives when it starts to snow and/or when the wind begins to increase. With respect to the temperature variable, the coefficients (β_2 and δ_2) are expected to be positive, and both the first- and second-order derivatives will be positive. This is reasonable as the temperature in the studied region never becomes uncomfortably high (maximum value measured in the period studied was 8°C).

The log-linear specification in equation (1) and (2) allows the model to handle interactions between the weather variables. Considering that $lnY = X$ is equivalent to $Y = exp^X$, it is evident that $\frac{\partial Y_{pt}}{\partial X_{2t}} = \beta_4 Y_{pt} < 0$. Hence, the effect of a change in precipitation on passenger traffic volume is dependent on the level of the other weather indicators. For example, as both precipitation and wind speed are assumed to negatively influence passenger traffic volume, their cross-derivatives are positive.[15] This implies that the negative effect of precipitation on traffic volume is moderated for higher values of wind speed and, conversely, that the negative effect of wind speed on traffic volume is moderated

[14] According to McCarthy (2001), the coefficients in equation (1) (and similar for equation (2)) can be interpreted as follows: An increase in one of the exogenous variables in equation (1) by one unit, will change passenger traffic volume by 100·β_j, $j = 1,2, \dots, 13$.

[15] The impact of wind speed on the relationship between precipitation and passenger transport demand is given by $\frac{\partial^2 Y_{pt}}{\partial X_{2t} \partial X_{3t}} = \beta_4 \beta_6 Y_{pt} > 0$. Hence, increased wind would reduce the negative influence of precipitation on transport demand. This build-in assumption in the model fit the empirical data well.

for higher values of precipitation. Hence, the marginal effect of precipitation on traffic volume is larger in weather with no wind compared to when traffic volume is already low due to strong wind.

The model is a recursive path model because all variables are observed and all causal effects in the model are assumed to be unidirectional (Kline, 2011). The disturbances, ε_i (i = 1, 2, 3, 4), are assumed to be uncorrelated, and the model is over-identified with 26 degrees of freedom. The model was estimated by minimizing the difference between the sample covariance and the model implied covariance matrices (De Oña, De Oña, Eboli, & Mazzulla, 2013). The parameters were estimated using the maximum likelihood method (ML), which is the most frequently used estimation method (De Oña et al., 2013; Golob, 2003). Although the linear SEM with ML estimation assumes normal distributed variables, the method has proven to be robust to non-normality in the variables if the sample size is sufficiently large (Golob, 2003). Thus, according to the literature, a sample size of 404 observations should be adequate (Golob, 2003; Kline, 2011).

5. Results and discussion

When estimating the theoretical model, several of the paths were found to be insignificant.[16] Therefore, most of the insignificant paths were removed in the final model. Goodness-of-fit statistics, summarized in Table 3 (Kline, 2011), all indicate that the model is appropriate with the exception of the Chi-square statistic (Hooper, Coughlan, & Mullen, 2008). However, the Chi-square statistics are derived under the assumption that the observed variables are normal distributed, which is not the case for all variables in the analysis. In addition, the Chi-square statistic is sensitive to sample size and nearly almost always rejects the model when large samples are used (Hooper et al., 2008).

[16] The model was estimated using STATA version 13.1.

Table 3: Goodness-of-fit statistics of the estimated model.

Goodness of fit statistics	***Value***	***Description***
Likelihood ratio		
Chi-square	56.2	Model vs. saturated model
p > chi-square	0.0005	
Degrees of freedom	26	
Population error		
RMSEA	0.05	Root mean squared error of approximation
90% conf.int.,		
lower bound	0.03	
upper bound	0.07	
Prob. $\mathrm{RMSEA} \leq 0.05$	0.35	
Baseline comparison		
CFI	0.96	Comparative fit index
TLI	0.92	Tucker-Lewis index
Size of residuals		
SRMR	0.02	Standardized root mean squared residuals

In Figure 3, the results from the final model without insignificant paths are summarized. All estimated coefficients have the expected signs according to the hypotheses. Table 4 summarizes the direct, indirect and total effects of the weather variables on traffic volume (Sobel, 1987).

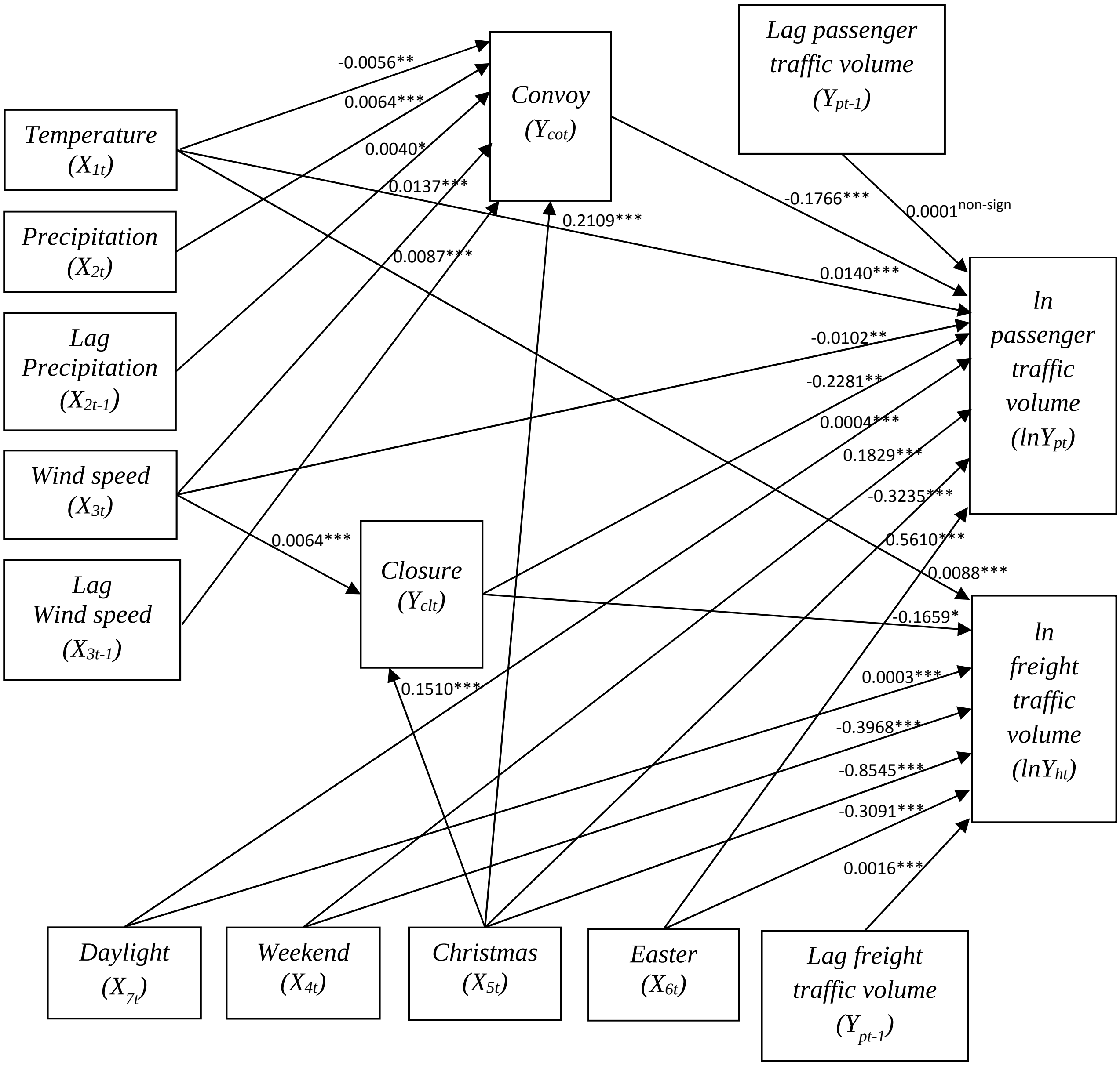

Figure 3: Model results (unstandardized estimates). *, **, and *** indicate significance at the 0.1, 0.05 and 0.01 levels, respectively.

Table 4: Unstandardized total effects.

Endogenous Variable	*Weather Variable*		*Coefficients*		
			Direct effect	*Indirect effect*	*Total effect*
lnY_{pt} *(ln passenger traffic volume)*	X_{1t}	*(air temperature)*	0.0140***	0.0010*	0.0150***
	X_{2t}	*(precipitation)*	0	-0.0011**	-0.0011**
	X_{2t-1}	*(lag precipitation)*	0	-0.0007	-0.0007
	X_{3t}	*(wind speed)*	-0.0102**	-0.0039***	0.0140***
	X_{3t-1}	*(lag wind speed)*	0	-0.0015**	-0.0015**
lnY_{ht} *(ln freight traffic volume)*	X_{1t}	*(air temperature)*	0.0088***	0	0.0088***
	X_{3t}	*(wind speed)*	0	-0.0011	-0.0011

***indicates significance at the 1% level
**indicates significance at the 5% level
*indicates significance at the 10% level

5.1 Weather Impact on Passenger Traffic Volume

Table 4 indicates that the direct effect of temperature on the log-transformed passenger traffic volume variable was 0.0140 and that the indirect effect was 0.0010 (the product of the effect of temperature on the convoy variable (-0.0056) and the effect of the convoy variable on the log-transformed passenger traffic volume variable (-0.1766)). By adding the direct and indirect effects, we obtain the total effect of temperature on passenger traffic volume. A 1°C increase in temperature caused a 1.5% increase in the number of private motor vehicles. By adding the direct and indirect effects of wind speed, we find that an increase in wind speed of 1 m/s caused a 1.4% decrease in passenger traffic volume. Precipitation did not directly affect passenger traffic volume. However, all of the weather variables affected passenger traffic volume indirectly by affecting the chance of a convoy and a road closure. Passenger traffic volume was 18% lower on days affected by a convoy (alone or in combination with a closure) and 23% lower on days with only a closure.

The results indicate that an increase in precipitation and wind speed one day increased the probability of traffic being led in a convoy the next day. In addition, passenger traffic volume was, on average, 18% higher on weekends and 56% higher over the Easter holiday, while it was 32% lower during the Christmas holidays, as expected.

A direct comparison of the estimates with findings of earlier studies is not straightforward because the studies vary in how they operationalize the weather variables. In this study, a continuous temperature variable was used, while, e.g., Al Hassan and Barker (1999) studied traffic volume on days with a lower than expected maximum temperature and found that on these days traffic volume was 2.8% lower than normal. Their study was conducted in the relatively densely populated Lothian region in Scotland, which has a temperate climate and a mix in topography from hills (up to 600 metres) to coastal plains. It is not clear from the article the months for which Al Hassan and Barker (1999) reported observations; however, they collected data from days with a range of weather conditions. Datla and Sharma (2008) categorized temperature into six classes and found that on days with extreme cold (temperatures below-25°C), the average daily traffic volume decreased by 30% compared to days with temperatures above 0°C. They collected traffic data from four categories of highways in Alberta, Canada, specifically commuter, regional commuter, rural long-distance and recreational roads. Their analysis was limited to the winter season from the beginning of November to the end of March. Another factor complicating a direct comparison between the results of this study and those of earlier studies is that Al Hassan and Barker (1999) and Datla and Sharma (2008) did not analyse passenger and freight traffic volumes separately. As the results indicate that adverse weather affects the variation in freight traffic volume less than passenger traffic, we would expect the impacts of the weather variables on passenger traffic volume to be greater than the impacts revealed in the comparison studies. Conversely, Al Hassan and Barker (1999) found that traffic volume decreased almost twice as much on weekend days with temperatures lower than expected compared to weekdays, indicating that adverse weather impact leisure traffic volumes less than commuting and commercial traffic volumes. This is in accordance with the results of our study.

The operationalization of the wind speed variable also differs between studies, which makes comparisons difficult. However, the direction of effect in this study is similar to that found in earlier studies (Knapp et al., 2000; Thomas H. Maze et al., 2006).

A more surprising result is the low impact of precipitation on traffic volume revealed in this study. Keay and Simmonds (2005), Al Hassan and Barker (1999), Datla and Sharma (2008), Maze et al. (2006; 2005) and Knapp et al. (2000) all found that traffic volume was significantly decreased by precipitation, even though the results varied in size of effect. For example, Maze et al. (2006; 2005) found in their study of snowy days in rural northern Iowa that on days with snow but good visibility and low wind speed, there was a 20% reduction in traffic volume compared to the volume on a clear day during the same year, month, and day of the week. On snowy days with poor visibility and high wind speed, the reduction in traffic volume was as high as 80%. Knapp et al. (2000) also studied winter days and found that the decrease in traffic volume on seven interstate roadways in Iowa during winter storms varied between 16% and 47% with an average of 29%. Compared to these results, we would have expected traffic volume on the Saltfjellet mountain pass to also be affected by precipitation. The contrast in findings emphasizes the importance of conducting research in different geographical areas as results from a study in one context may not be transferable to a different context.

5.2 Weather Impact on Freight Traffic Volume

In accordance with the hypothesis and the findings in the literature, the weather variables did not seem to have effect on freight traffic volume to the same extent as they did passenger traffic volume. Only temperature had a direct effect on freight traffic volume. An increase in temperature by 1°C increased the volume of heavy vehicles by 0.9%. Wind speed had an indirect effect on freight traffic volume by leading to the closure of the road. When the road was closed, the number of heavy vehicles was 17% lower than average. However, the effect of a closure on freight traffic volume was only statistically significant at the 10% level, and as Table 4 indicates, the indirect effect of wind speed based on the closure variable was not statistically significant. Furthermore, the convoy variable did not statistically significantly influence freight traffic volume.

The results indicate that the variables with the greatest influence on freight traffic volume are those that control for weekends and holidays. The number of heavy vehicles was 40%, 85% and 31% lower on weekends, during the Christmas holidays and during Easter holidays, respectively.

5.3 Discussion of Results

Adverse weather seems to have relatively low effect on both passenger and freight traffic volumes on this specific mountain pass when compared to the results of other studies. This is surprising knowing that adverse weather may cause a considerable increase in transport costs, as seen in Figure 1. Traffic speeds are, on average, lower, the risk of accidents is higher, and there is a need for extra equipment such as spike tires, chains and extra fuel when driving in adverse weather. In addition, the costs associated with the uncertainty of not knowing when the road will close and reopen are also high (Thomas H Maze et al., 2005). Since it is assumed that when the generalized transport costs increase, some road users will no longer be willing to pay to drive the mountain pass and will look for other alternatives, it is surprising that this is not reflected in lower traffic volumes at the mountain pass. There are several possible explanations for this. First, it can be explained by the importance of this particular mountain pass as a transport corridor that connects the southern and northern parts of Norway, especially when considering that there is limited access to good alternative transport routes and modes. As a result, many of the trips across the mountain pass that might otherwise be diverted must be made despite the increase in transport costs caused by adverse weather.

Second, both passenger and freight transport drivers may have longer-term adaptation strategies in place to cope with the adverse weather-related problems on the mountain pass. People living in this region are familiar with the challenging winter driving conditions and know that road closures are not uncommon. In total, convoys and/or closures affected 45 days out of 427 days (10.5%) during the two winter seasons studied. Consequently, many people probably avoid using the road during this time of year, planning either to travel by other transport modes or routes or to not travel at all, or they have other strategies in place to deal with the effects of adverse weather, such as those discussed in the study by Husdal and Bråthen (2010) and described in Section 2.1.

Third, both the NPRA and the drivers in this region are accustomed to snow days during the winter. Accordingly, the NPRA has the necessary equipment to maintain acceptable driving conditions, and the drivers are capable of driving even though the driving conditions are not optimal. This may be why precipitation has less impact on traffic volume in this study compared to the results of earlier studies conducted in other geographical areas.

Finally, we know that one important export article produced in the region is fresh fish (Mathisen, Nerland, Solvoll, Jørgensen, & Hanssen, 2009). This means that some of the freight transported over the Saltfjellet mountain pass is fresh fish, a commodity type known to have low price elasticity. Thus, as transport of this commodity must be fast and reliable, cancelling or postponing transport is extremely expensive (Graham & Glaister, 2004), which suggests that increased and unreliable transport times are particularly costly with respect to transport.

6. Conclusions and Implications

The results reveal that the effects of adverse weather conditions on traffic volume on the studied road section are limited compared to the results from other studies and that freight traffic volume is less affected than passenger traffic volume. Earlier studies have demonstrated that it would be appropriate to include the effects of adverse weather in transport models in order to predict traffic volume more precisely. However, the results from this study imply that standardized parameters from such a transport model would not be suitable on the type of road studied herein. In this rural and arctic case, applying the relatively inelastic parameters outlined in Table 4 would give better predictions of traffic volume. This illustrates the necessity to be context specific regarding the effects of weather conditions on traffic volume.

Earlier studies have shown that adverse weather may cause large increase in time and monetary costs for the road users (see Figure 1). Previous work by Bardal and Mathisen (2015), e.g., shows that the drivers' time costs associated with driving the studied mountain pass (Saltfjellet) increased by 23% in adverse weather purely because of lower traffic speed due to unfavourable driving conditions. In addition, adverse weather caused closed roads and need for spike tires and chains. Despite the fact that generalized transport costs increase significantly in adverse weather for the road users, this study shows that the decrease in traffic is low. This low sensitivity to transport cost for the travellers, can be explained by the rural context of this study and the importance of this transport corridor. The less traffic is affected by the increase in generalized transport costs the higher the welfare loss for the users. This suggests that the welfare loss for the road users of adverse weather can be high even if traffic is little affected. Consequently, traffic changes due to bad weather give alone insufficient signals of the welfare loss the travellers.

It is thus particularly important to include this welfare loss in road-project assessment tools for rural roads to ensure that appropriate decisions are made regarding the development and improvement of transportation facilities. One way of including this welfare loss is to extend models to estimate the increase in travel times and uncertainty in travel times, and thereby increase in time costs, that adverse weather generate by causing road closures and reduced traffic speed (see Figure 1). Another suggestion, which follows from Figure 1, is to include the extra pecuniary costs associated with the need for spike tires and chains and extra fuel consumption when driving in adverse weather. By including the benefits of removing the extra costs adverse weather imposes on road users, the net present value of a cost- benefit analysis of a road project aimed at reducing these costs would increase. Examples of such projects include the development of tunnels to avoid mountain areas, the construction of snow and wind shelters, the improvement of road structures in affected areas, the improvement of operations and maintenance of exposed road sections, as well as improving the implementation of road closures and the way in which road closure information is communicated to the public. As most countries conduct cost-benefit analyses (CBAs) to assess the impacts of new infrastructure projects, and there are many advocates for using the results of CBAs when deciding whether to implement road projects, it is a shortcoming that the societal benefits of reducing weather-related problems for road users are not captured in today's analyses. The result may be that projects, like the ones mentioned above, will not appear as beneficial for society and therefore not be implemented.

Summing up, this study shows that it is more appropriate to include the burden adverse weather impose on travellers indirectly in road-project assessment tools, instead of including standardized weather parameters directly in traffic volume analysis. This can be done by calculating road user's benefits of reduced travel times, increased reliability in travel times and reduced monetary costs from reducing the impact of adverse weather on traffic in each case. A suggestion for further research is to build models that quantifies these benefits in order to be able to include them in road-project assessment tools such as CBA.

A limitation with this study is that it only considers one segment of roadway. Still, several other important transport corridors in Europe and in northern parts of the American continent have topography characterized by mountain areas and adverse winter weather to which the results may be transferable. Therefore, further research should conduct analyses on similar road segments to contrast the results of this study. Another limitation of the study is that only day-to-day variation in traffic volume have been examined. It is reasonable to believe that drivers in rural and arctic areas have developed long-term adaptation strategies regarding the problems created by adverse weather conditions. Accordingly, a suggestion for further research is to investigate these long-term adaptation strategies. Moreover, the relationship between weather forecasts and traffic volume has not been analysed in this study, but it is a factor that could be included in future studies.

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