Evaluation Outcome Report

Norway

NordicWay

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1. Summary

This evaluation seeks to answer the following research question: *Can an RSI (Road status information) decision support system based on friction values be used for the purpose of maintenance of winter roads?* This evaluation focuses specifically on how RSI data can be used to *provide input* to an RSI decision support system for winter maintenance in Norway. However, we will also discuss how the raw RSI data can help *provide information on winter maintenance*. The evaluation relies on two main approaches in answering the research question: i) a technical evaluation and ii) an evaluation of the user acceptance related to such a decision support system. The technical evaluation focues on the quality of the raw RSI data, while the evaluation of the user acceptance primarily focuses on what the potential users identify as critical for the acceptance of an RSI decision support system.

The RSI system is suggested to provide the winter maintenance personell with information on road friction, which could be an additional source of information or replace other existing data sources. In today's system, the contractors could have the following information available for monitoring the conditions on the road: observations from their own employees, observations from other road users, information from the road traffic centals (Vegtrafikksentralene, VTS), weather stations, web applications on weather and climate, internet of things (IOT) sensors provided by the NPRA, and their own friction measurements such as trailing sensors and break retardation tests. A subset of these observations act as decision-making support for the contractors. The NPRA on the other hand follow up on the contracts by performing random tests to check whether or not the road conditions are on a satisfactory level. These tests are mostly performed by RoAR, a vehicle that uses one wheel slip to calculate friction values.

Due to low data quality, this evaluation finds it unlikely that one can use RSI data and an RSI decision support system for exactly same purposes as RoAR data are used today, such as verification of contractual obligations. It is also questionable whether the RSI system can be used for a real-time decision support system for connected vehicles. Based on our results, we find that the most promising avenue is to use historical data from RSI for the purpose of monitoring the transport system. The major advantages from RSI data are, however, likely to be realized when they are combined with other data sources, such as temperature and images of the road.

Even though it is unlikely that RSI can be used for the same purposes as RoAR is used today, this does not imply that one should not continue investigating new data sources. Only by exploring the possibilities that new technology and data sources provide, the authorities and other stakeholders will be equipped to use the innovations that are continuously becoming available.

2. Description of the problem

This evaluation starts with describing how the winter maintenance system in Norway is organized today, the RSI system, and the research question of this evaluation: *Can RSI (Road status information) friction values be used for maintenances of winter roads?* Then we move on to describe the technology readiness level (TRL) and the main stakeholders involved in use of an RSI-based decision support system. Next, we present the program theory of this evaluation and the corresponding hypotheses. Then we present the evaluation design and the evaluation results, before a discussion of the impact of the service follows, that is, the RSI decision support service. Here, we focus on discussing the hypotheses. Last, we present a discussion of the transferability of the results.

2.1. Background for winter maintenance in Norway

The Norwegian Public Roads Administration (NPRA) uses contractors for maintenance and operation of the road network. The current regime for hiring contractors is based on the contractors bidding on specific projects. Contracts of operation define how contractors are expected to conduct their operations, and winter maintenance is specified in several documents and handbooks provided by the NPRA. The requirements for level of winter maintenance of state highways is described in Handbook R610, chapter 9 (NPRA, 2014). This evaluation will first and foremost relate to the requirements concerning friction as defined in Handbook R610, chapter 9.

Handbook R610 defines the maintenance period according to weather events: before a weather event, during a weather event or after a weather event. The requirements for road conditions and measures that should be taken are based on a holistic assessment of how the road conditions are influenced by the weather event. These are described in Table 1. The winter maintenance class determines what is the approved conditions on roads. Friction level is a key indicator for measuring the road conditions and whether these are in accordance with the requirements in contracts of operations. All roads in Norway have a required friction level, depending on their winter maintenance class. The rest of this evaluation will focus on friction levels as the main indicator measuring approved road conditions.

Table 1: (NPRA, 2014). The maintenance period, as defined in Handbook R610.

	Before weather event	During weather event	After weather event
Required road conditions	Approved conditions	Deviations from approved conditions are accepted	Return to approved conditions within given time requirement
Measures	Monitoring	Monitoring	Monitoring
	Winter maintenance to maintain approved conditions	Winter maintenance to maintain approved conditions and to make sure the deviations are as small as possible	Winter maintenance to return to approved conditions within given time requirement

Mapping the road conditions through various forms of monitoring is a necessary and important task for the contractors during the winter season. Contractors must continuously oversee that they take the right measures to meet the given requirements before, during and after weather events. Only through careful monitoring will this be successful in a country as Norway, where weather and road conditions change rapidly.

In today's system, the contractors could have the following information available for monitoring the conditions on the road: observations from their own employees, observations from other road users, information from the road traffic centals (Vegtrafikksentralene, VTS), weather stations, web applications on weather and climate, internet of things (IOT) sensors provided by the NPRA, and their own friction measurements such as trailing sensors and break retardation tests. Chapter C on contracts (as specified in Handbook R610) for winter maintenance states that all contractors conducting winter maintenance shall have procedures for measuring friction, and that these should be used as decision support for winter maintenance. The road surface friction shall fulfil the required levels of friction, as stated in chapter D1, process 95. These should be reported to road owner (for instance the NRPA) every 14^{th} day.

All equipment which measures friction shall be calibrated according to the OSCAR vehicle, which is defined as the reference measure system for friction. The calibration should be done at least one time every winter season. In addition, RoAR vehicles are calibrated directly with measurements from OSCAR, while other equipment might be calibrated with respect to RoAR. RoAR and OSCAR have specific requirements concerning how they measure friction. OSCAR measures friction using data from all four wheels, while RoAR uses one trailing wheel. For RoAR, the trailing wheel could either be fixed to a given slip value (typically 20 % on winter conditions) or the slip could be continuously reduced from free rolling to full break in approximately 2 seconds. In the latter case, a complete friction curve is measured, see Figure 1 from the NPRA, for a few examples.

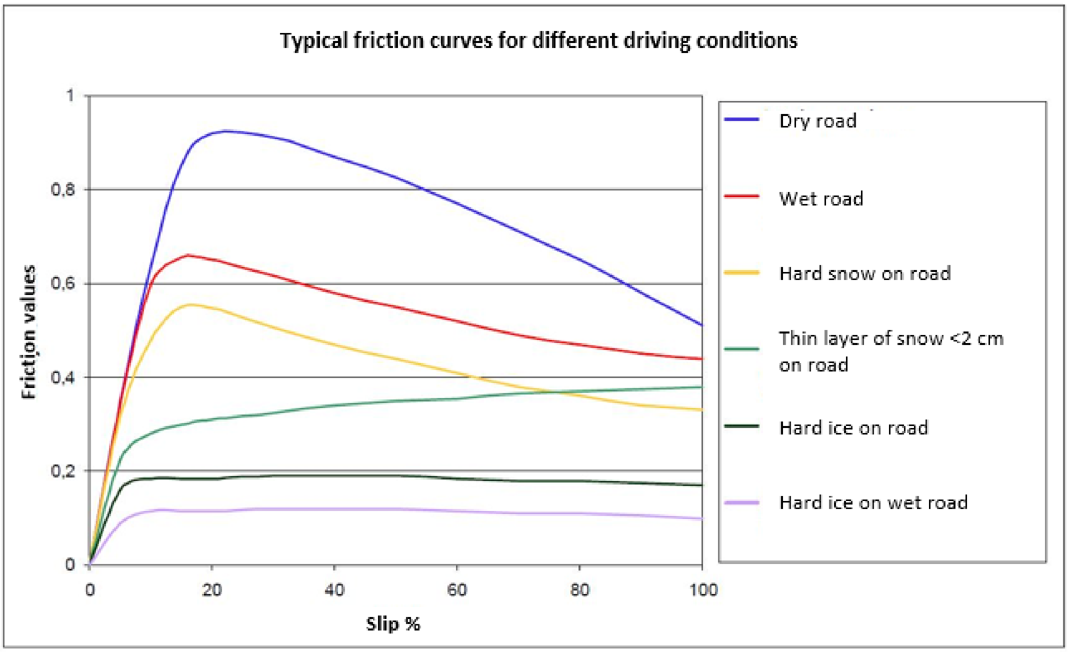

Figure 1: Typical friction curves for different road conditions. (Statens vegvesen & Norsemeter, januar. 1995)

Lastly, the maximal friction value of this curve is collected as the final friction value. For RoAR measurements, the drivers continuously try to drive at the most slippery point on the cross section of the road in order to obtain the "worst-case" friction value.

As already mentioned, in addition to measure friction on the road, the RoAR vehicles are used to calibrate simpler friction measure equipment like vehicles with retardation measure systems. A retardation measurement consists of driving a vehicle on a straight road in 50 km/t and break hard for 1 – 2 seconds. This measurement type is less preferable since it requires collecting data on roads with zero horizontal and vetical curvature and it is not safe to execute with other traffic around. However, it is a cheap type of measurement.

As stated above, all roads in Norway have a required friction level, and the NPRA uses the RoAR measurements to control whether the contractor fulfills the given requirements for the friction level. This control system is based on random checks.

2.2. The car as a sensor: RSI

In line with the paradigm shift from traditional data collection methods to big data, the car as a sensor and data source has emerged as a well-known term within the transport sector.

Road status information (RSI) is one particular data source potentially useful for winter maintenance. The RSI system in Volvo cars measures friction approximately every 10th millisecond. Each of these measurements is given a quality parameter ranging from 1 to 7, where 1 represents low quality and 7 represents high quality. High quality is usually obtained in acceleration situations (increase/ decrease of speed, turns etc.). Typically, the majority of the observations are collected with a low quality parameter.

Using big data methodology one can imagine collecting RSI data from a fleet of vehicles and use data to map the road surface conditions into a decision support system. In this evaluation we imagine that a road map interface could have been operated by the NPRA, based on data from a fleet of vehicles.

2.3. Research question

Our research question in this evaluation is:

Can an RSI (Road status information) decision support system based on friction values be used for the purpose of maintenance on winter roads?

This evaluation focuses on how RSI data can be used to provide input to decision support system for winter maintenance in Norway. However, we will also discuss how the raw RSI data can help provide information on winter maintenance.

3. Description of the C-ITS implementation

The following chapter describes how the RSI decision support system is suggested to be implemented. First, a brief description of the technology readiness level is presented. Second, we briefly describe the main stakeholders for implementing the C-ITS service (RSI decision support system).

3.1. Technology Readiness Levels

With respect to the technology readiness level, the version shown in Figure 2, this evaluation consider the technology for the TRL 4 and TRL 5.

TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9
Basic principles observed	Technology concept formulated	Experimental proof of concept	Technology validated in lab	Technology validated in relevant environment	Technology demonstrated in relevant environment	System prototype demonstrated in operational environment	System complete and qualified	Actual system proven in operational environment
Concept development			Proof of principle			Proof of performance		

Figure 2: The technology readiness level (TRL) scale

In the early stages of this project the technology was evaluated with a field test from the 17th to 19th of February on a Swedish test site at Jokkmokk. This test was documented in the report "Road friction estimations on winter conditions" written by NTNU for NPRA, which corresponds to testing the technology on a TRL 4 level. Although it is questionable that RSI is proven to be on TRL 4 based on the findings in the aboventioned report, the results presented here evaluate the technology for the TRL 5 level. It is important to note that we refer to this scale only for the technical aspect of this report. Many of the questions and discussions in the interviews was done under hypothetical expressions like "given that this technology can provide this application with thrustworthy results", and so forth. Hence, the results from the interviews do not refer to a specific TRL level, but are rather subjective opinions of the interviewees concerning the concept of an RSI decision support system. The technical evaluation does not evaluate the decision support system, as this has not been developed.

3.2. Stakeholders

Below follows a brief introduction to the three most important actors for an RSI decision support system: The NPRA, maintenance contractors, and Volvo. Other actors might also be important for such a decision support system, such as software providers and telecom companies, but these are not included in the Norwegian evaluation. In this evaluation the focus is rather how the NPRA can collaborate with a car producer to develop a service to help winter maintenance personnel.

The NPRA is responsible for the implementation of the RSI decision support system. This includes receiving the data from Volvo, providing the contractors with a decision support system interface, and managing the system. The NPRA is also responsible for controlling and verifying the winter maintenance levels among the contractors.

The contractors are responsible for using the RSI decision support system, as well as executing the winter maintenance based on the available information.

Volvo is responsible for the RSI data collection and for adjusting and improving the algorithm used for estimating friction.

4. Program theory: How will an RSI decision support system influence winter maintenance?

This part of the evaluation describes how RSI is expected to influence winter maintenance. In particular, we present three hypotheses, evaluated using both an technical evaluation and an evaluation of user acceptance.

4.1. Increased efficiency in the execution of winter maintenance

Shifting the focus from measurents made by dedicated equipment to using the car as a sensor will increase the spatial and temporal scope of the data. Today contractors are dependent on road friction values from only a few different sources, which all are characterized by limited spatial and temporal scope. The RSI decision support system would enable information to be collected from a fleet of cars, which would dramatically increase the spatial and temporal scope of data.

In terms of *spatial* scope, a fleet of cars would imply that data on road friction would be collected on a larger spatial scale than what is the current situation. With limited resources, it is difficult for contractors to collect road friction data for all roads in their contract area. This means that contractors are dependent on other sources of information than road friction data for mapping the situation on the road. These data sources, such as real-time observations from their own employees, are also characterized by a limited spatial scope.

A fleet of cars would also imply *more frequent* observations, at least on the busiest roads. On the less busy roads, a fleet of cars would imply that there are some available observations on road friction. In today's system, the less busy roads are naturally less prioritized in terms of collecting data.

Friction measured with RoAR is based on standards dependent on the road condition. It measures friction as a quality of the road, but friction also depends on the vehicles driving on the road. The RSI decision support system will increase the understanding of how individual drivers experience the road surface, knowledge that can and should be used to increase the quality of the winter maintenance. Different road segments, and fleet of vehicles driving on it, have different needs in terms of road surface friction A more detailed data collection of individual vehicle friction values would help identify and understand segments where the necessary road surface friction is often critically low for the majorities of the travelling vehicles.

The RSI decision support system would allow the contractors to have available information from a larger spatial and temporal sample than they have in today's system. The RSI data could also mean that contractors could be able to execute winter maintenance more cost-efficiently. One argument in favour of this hypothesis is that the contractors then might reduce their personnel because they are less dependent on observations from their own employees as a source of information.

The RSI decision support system would also allow the contractors to improve the quality of the winter maintenance. Increased spatial and temporal scope of friction data could be a useful tool for ensuring that winter maintenance is kept at the required level. Furthermore, an RSI system could mean that it becomes easier for the contractors to stay one step ahead of weather events, which is critical for maintaining the required winter maintenance level.

4.1.1. HYPOTHESIS

Based on the discussion above, the following hypothesis is suggested:

Hypothesis$_1$: An RSI decision support system improves the efficiency and the quality of winter maintenance for the contractors.

4.2. Control and verification

AN RSI decision support system based on information from a fleet of cars could provide the NPRA with a useful tool for control and verification of winter maintenance levels among the contractors. Today the NPRA depends on the friction values provided by RoAR for control and verification of the required road surface friction level for different roads. There are only five RoAR cars available in Norway, so having data available from a fleet of cars, could increase the possibilities of the NPRA to control and verify of the winter maintenance level for contractors.

Also, RSI data would provide a massive data set for use in creating historical statistics of the road status in Norway. This could support many of the processes involved in winter maintenance, including evaluating new contractors, and transferring knowledge between contractors. The historical RSI data could furhter assist new contractors, particularly during their first winter in a new contract area. The new contractor could then use the historical statistics from the area and anticipate which areas they should pay special attention to.

4.2.1. HYPOTHESIS

The RSI decision support system could enable the NPRA to control and verify winter maintenance in a different and improved way. With a fleet of cars available for measuring road surface friction, this could imply that today's system could be improved. We therefore suggest the following hypothesis:

Hypothesis$_2$: AN RSI decision support system improves the NPRA's control and organization of winter maintenance.

4.3. User acceptance

Although the RSI decision support system could have an important impact on winter maintenance, it will only have a consideable impact if it is accepted by its users. Acceptance here includes acceptance among the users identified in this evaluation: the contractors and the NPRA. Since there are few previous experiences with collecting and using data from the car as a sensor among these user groups, the users are likely to base their evaluation of the RSI decision support system on experiences with other, similar technologies that are used today for collecting friction data. These include the break retardation tests and the RoAR vehicles.

4.3.1. Hypothesis

A necessary precondition for RSI decision support system is the acceptance of the users of this system. Only when the users trust the technology and the outputs that the technology provides, will they accept the technology in their daily work.

Hypothesis$_3$: User acceptance is a precondition for implementing an RSI decision support system.

5. Evaluation design

As described above, the Norwegian evaluation consists of two main aspects, with two different methodologies. Each of these two methodologies are described below.

	Actors		Methods	
	Contractors	NPRA	Interviews	Technical
$Hypothesis_1$	X		X	X
$Hypothesis_2$		X	X	X
$Hypothesis_3$	X	X	X	

5.1. Evaluation criteria

For evaluating whether and how RSI can be used in a decision support system for winter maintenance, the quality of the data collected from RSI must first be evaluated. If the quality is not satisfactory, the data may not be suited for a decision support system. When deploying big data methodology, one typically relies on that larger amount of data will increase the quality of the estimate of the objective in focus. A interesting question is therefore how many passing vehicles are nessesary to estimate the true friction value with high quality. One important element to keep in mind is that friction is an ever-changing parameter, and has potential to change rather quickly. This means that the quality of each RSI-measurement will be of great importance, especially on roads with less traffic. We base our technical evaluation on test runs of Volvo and RoAR vehicles on real world roads in Norway, where friction measurements of the RSI system and the RoAR system are compared.

Secondly, evaluating the RSI as a decision support systems requires an evaluation of user acceptance of the RSI decision support system. Because the system is not implemented, we b*ase our evaluation on how the actors expect that such a system would work based on previous experiences with similar technologies*. The RSI decision support system is not yet implemented, and experiences with similar technologies are therefore an important reference. We therefore focus our evaluation on whether the RSI decision support tool would be a useful addition to the current data sources of road surface friction.

These two evaluation approaches are complementary. In particular, we examine whether the technology provides reliable information that is accepted by the users. Both the technical evaluation and the evaluation of the user acceptance are necessary to answer our research question. A description of the methodology of each of the two evaluation approaches is found below.

5.1. Technical evaluation

We base our technical evaluation on test runs of Volvo and RoAR vehicles on real world roads in Norway, where friction measurements of the two systems are compared. Firstly, we compare data from two RoAR vehicles to ensure proper reproducibility of this system. Secondly, we compare friction estimates from Volvo RSI to the estimates of RoAR.

In this evaluation we choose to, firstly, separate the road into disjoint intervals of 10 meters. Secondly, the mean of the estimated friction values within each interval is calculated for each Volvo car and RoAR vehicles, and finally the results are compared.

5.2. User acceptance

The user evaluation is based on semi-structured interviews to acquire in-depth knowledge of the user acceptance and requirements associated with an RSI decision support system for winter maintenance. Semi-structured interviews were the preferred method of data collection since there is not much pre-existing knowledge on this specific issue. The information collected from the interviews is suited for answering the research question because we are interested in the subjective opinions of the interviewees, or their lived experiences.

We focused our interview guide on mapping today's system for providing information concerning winter maintenance, how an RSI decision support tool could be a useful addition to the current data sources of road surface friction, and what the main needs are for the acceptance of such a system would be.

We conducted interviews with a contractor and several representatives from the NPRA. We focused the individual interviews on the actors' main work tasks. In the interview with the contractor, we therefore focused on how they could utilize an RSI decision support system provided to them by the NPRA, and what their user requirements for such a system would be. In the interviews with the representatives from the NPRA we focused on how the NPRA could use the information provided by the RSI data, and what their user requirements for such a system would be.

5.1. Data collection

This section describes data collection for the technical evaluation and for the user acceptance evaluation.

5.1.1. Technical evaluation

The data used to test the performance of the RSI system of Volvo was collected in December 2015. For several days the NRPA drove five Volvo cars and different equipment for measuring friction, including two RoAR vehicles, on different segments of the Norwegian road network.

Three of the Volvo cars was of the 60-Series (one S60 with 2X4, one V60 with 4X4, and one XC60 with 4X4) and two cars of the model XC90, both with 4X4. The Volvo cars collected data approximately every 10 millisecond, and for this purpose, we are interested in the estimated friction value and the corresponding quality parameters. The quality parameter is given on a discrete scale ranging from 1 to 7, where 1 indicates that friction is not being estimated and 7 indicates a high quality friction estimate.

The measurements from RoAR were gathered every 1 or 10 meter, however if the friction becomes above 0.45, the equipment goes into "surveillance mode" and will measure friction at a lower frequency.

To test the quality of the RSI measurements by comparing them to RoAR, data collected on shown in Figure 3 were used. These roads where chosen because they included a significant amount of both RoAR and Volvo measurements.

Figure 3: Roads used to evaluate the friction measurements from the Volvo cars using RoAR as a reference.

5.1.2. User acceptance

We conducted six interviews with representatives appointed in cooperation with the NPRA. The interviewees we interviewed represent two different user groups: first, a contractor, and second, representatives from the NPRA. We focus on these two user groups because they together have valuable experiences from the different phases of the winter maintenance. We did interview with two different employees with the contractor, and we interviewed five employees with the NPRA. The NPRA have many different responsibilities related to winter maintenance, and it was therefore necessary to interview several employees with different objectives and opinions.

The specific contractor was chosen because they are part of a research and development contract with the NPRA and have, through this contract, acquired knowledge about different approaches to measuring road surface friction. For instance, this particular contractor has experience with an artificial intelligence system being developed called the Case-Based Reasoning system (CBR), where road surface friction is one of the variables used to predict future events.

6. Evaluation results

6.1. Technical evaluation

In the first part of the evaluation, we compare measurements from the two RoAR cars (from now on referd to as Øst and Midt) in order to validate the strategy of using them as a reference for the RSI estimates. This experiment showed a high correlation between the RoAR cars, we concluded that using RoAR as a reference is a reasonable approach (Figure 4 shows an example from "Vestsidevegen").

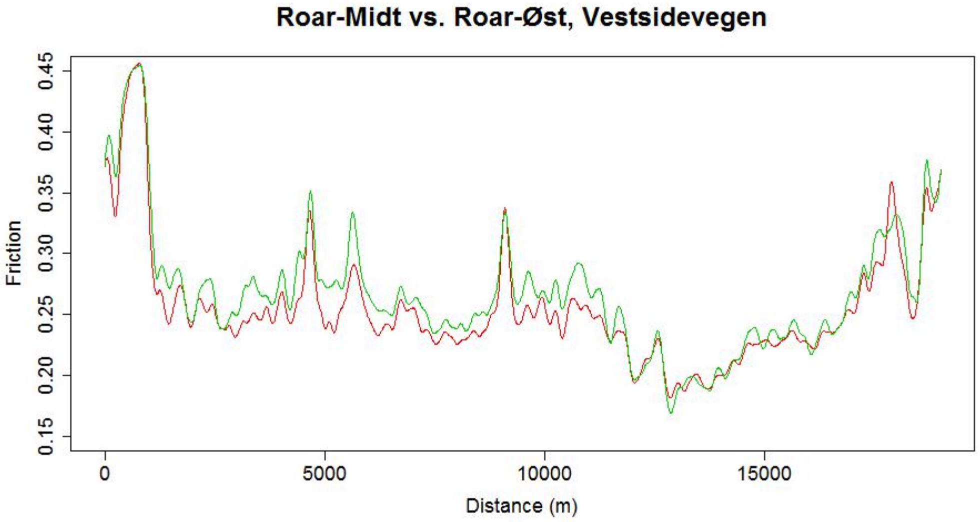

Figure 4: Comparing the estimated friction from RoAR-Midt (red) and RoAR-Øst (green).

The lines in Figure 5 is made by smoothing the measurement from RoAR using a hidden Gaussian Markov random field (GMRF) model, in particular an RW(2) with the Gaussian noise set to $\sigma^2 = 1000$. Comparing these smoothed estimates for the Øst and Midt RoAR cars we get a correlation of 0.9753. As we know that the measurements from the Øst and the Midt cars are completely independent of each other, these results are very appealing in the sense that the RoAR measurements seems to be trustworthy.

Next, we compared the RoAR measurements to the estimated friction values of the Volvo cars. We only considered friction measurements from the Volvo cars with a quality parameter larger than or equal to 5 (recall the scale from 1 (low quality) to 7 (high quality), which resulted in much more sparse measurements of friction than that of RoAR, i.e. longer distances with no high-quality friction measurements (see Figure 5 for an example).

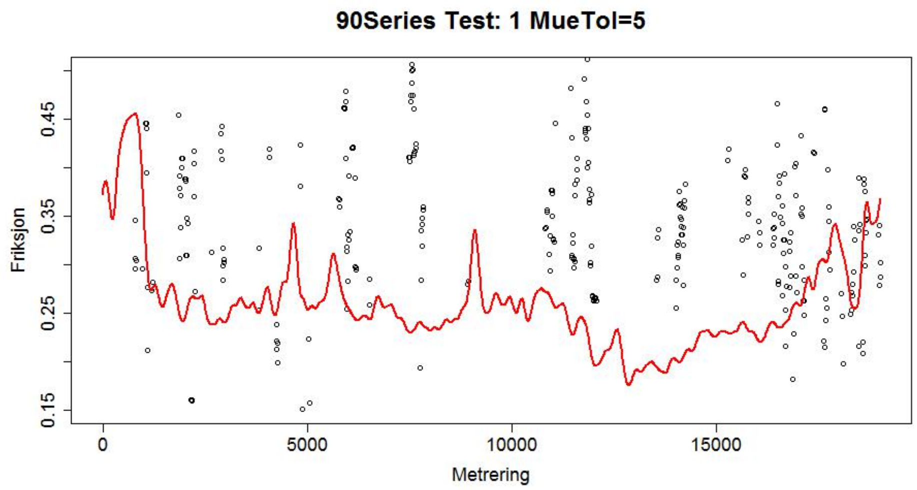

Figure 5: Comparing measurements from RoAR (red) with friction estimates from the two XC90 Volvo cars with quality higher than or equal to 5.

As we can see, the *measurements from the Volvo cars do not recreate the measurements of RoAR*. As expected, we do not have any measurements from the Volvo cars with high quality for a number of the intervals. It is important to point out that this is not because the cars measure large friction values here, but simply that the system is unable to measure friction values in these intervals (typically a straight road segment with no acceleration or deceleration).

Comparing RoAR measurements with all the Volvo cars driven on all the roads (Figure 3), we can sum up the performance of the RSI system as shown in Table 2. This table shows a three-bin scale of friction values: below 0.25, between 0.25 and 0.35, and above 0.35. We then compare the RoAR measurements to the Volvo – RSI estimates within each defined 10 meter interval and calculate the accuracy in terms of the amount of equal and unequal measurements.

Table 2: Result from comparing RoAR measurements of friction with the estimated friction for the Volvo cars. Grey cells indicate a less critical mistake, yello indicate a critical mistake, while the red cell indicate a very critical mistake

		Volvo-all Cars		
		<0.25	[0.25-0.35]	>0.35
RoAR	<0.25	45 %	40 %	15 %
	[0.25-0.35]	54 %	30 %	16 %
	>0.35	50 %	20 %	30 %

As we can see, the RSI system tends to estimate too low friction values compared to RoAR. The most critical error, estimating high friction in cases where the friction is low, is the least frequent mistake made by RSI.

Given the current evaluation of the RSI measurements in the real-world driving case presented here, it is hard to conclude that the system has the quality necessary to be used for winter maintenance purposes. However, several factors need to be addressed before one can conclude that the system does not provide useful information.

Firstly, how many cars must drive a given road segment in order to achieve friction data of suffiecient quality? The maximum number of Volvo cars driven on the same road at approximately the same time as a RoAR, was five. Would quality of the friction estimate be improved by increasing the number of cars? Secondly, the method used to analyze the data splits the road into ten meter segments. There is no doubt that GPS uncertainty could result in positioning GPS points in the wrong segment at this level. Third, the friction value might vary significantly over the cross section of the road. Remembering that RoAR measures friction using one wheel, which is actively positioned where the drivers assumes the cross-section to be most slippery, the RSI system uses all four wheels positioned at "normal" positions on the road. This could indeed result in very different perceptions of friction, which does not mean that any of the systems are right or wrong. Lastly, the defined three-bin scale for friction used to compare RoAR to Volvo, can result in observations being classified as wrong, although they are very close to correct.

Most of the concerns presented in the previous paragraph were, when possible, tested. For instance, both different length of the road segments and different binning of the frictions, including a continuous scale, was investigated. However, none of these test gave significantly better results. In fact, for a large majority of these, the accuracy shown in Table 2 decreased.

To really evaluate the quality of the RSI data at the current stage, the experimental design needs to take a step back; from evaluating a large number of real-worlds roads with few Volvo cars, to evaluate fewer roads with more controllable surface(s) and with many more vehicles. Ideally, a road including many different values of friction should be driven by one, or at least multiple cars with very similar properties, many times within a short timeframe. If such an experiment gives favorable results towards RSI, one should again look at more real-world experiments. This time, with a more precise understanding of the quality of these data.

6.2. User acceptance

All interviewees in the semi-structures interviews highlight that a precondition for using the RSI data is that the data have sufficient quality. The interviewees from the NPRA all have experiences with measuring friction and using these data in work related to winter maintenance. This fundamentally shapes their expectations and attitudes toward the RSI system. All interviewees (including the contractors) mention that a major challenge with the RSI data, is that all cars have different attributes and different tires, which could cripple data quality. At least this is true in terms of the objectivity of the data, because this feature causes individual cars to experience the road differently.

The NPRA is attempting to phase out break retardation as a method for measuring friction, due to for instance security and data quality issues. In the interviews, the representatives from the NPRA is therefore not convinced about the quality of RSI data, which also is a point measure. Furthermore, the RoAR car is also based on the logic that individual cars experience the road surface differently. The trailing wheel on RoAR is based on given standards for given road conditions. For instance, in the summertime, the wheel used on RoAR is always slick and a water film is always applied in front of the wheel to simulate the "worst-case"-scenario.

A key issue for user acceptance is therefore to provide the users with documentation of data quality and to include the users in the implementation of the technology. The results from the technical evaluation is therefore particularly interesting since they highlight that the data quality may not yet be satisfactory, which is likely to mean that the users will not accept the technology in the current version.

Another issue concerning data quality is stability of the hardware and software providing the users with the RSI decision support system. The contractor states that a necessary precondition for an RSI decision support system is that the system must be stable. A drawback of weather stations is that their operation is unstable when the weather is particularly harsh. The contractor states that they usually have at least one employee located at the mountain pass for observing the development on the road when the weather is particularly harsh. It is thus important to have information on weather available for an overall evaluation, particularly when closing the mountain pass is under consideration. To have no interruptions in data collection is of great importance for learning from past experiences. Another precondition mentioned in the interviews is that the data need to be presented in real-time with no time lag and with spatial information.

7. The impact of the service

7.1. Hypothesis1: *An RSI decision support system improves the efficiency and the quality of winter maintenance for the contractors.*

The contractor emphasized in the interview that an RSI decision support system could make it easier to prioritize the use of resources, given that the data quality is high enough. With more precise information on road friction status, it could become easier to prioritize resources, particularly on the most problematic areas. In this view, the RSI decision support system could increase the effenciency and quality of winter maintenance by enabling more careful consideration of where and when it is most effective for the contractor to use resources. This finding depends on the data quality being high enough.

On the other side, contractors always base their actions on an overall assessment of all available information, particularly when it comes to larger incidents, for instance when closing a mountain pass is considered. Excluding other data sources, such as observations from employees, might not be possible in such areas because they need several data sources to make decisions concerning winter maintenance, and observations from employees are among the most important sources. The contractor we interviewed emphasized for instance that even though tools such as the RSI decision support tool may give a good indication of the current situation on the road, there are some areas where employees of the contractor must use real-time observation due to rapidly changing weather and the importance of these areas. This is particularly true for important areas such as mountain passes, where weather and road conditions change rapidly and there might be few other available routes. In such areas, reducing the number of employees might not be possible due to the complexity of the weather and road conditions. However, there might be other areas where an RSI decision support system would be more appropriate.

Another aspect that might lead the RSI decision support system to increase the efficiency and quality of the winter maintenance, is that it reports real time information directly to the contractors. This could make it easier for the contractors to be one step ahead of the weather events. The contractor we interviewed stated that it is of great importance that the RSI data is presented to contractors in real time, and that there is no time lag before they receive the data. The contractor states that they today usually quickly get reports from their own employees, the VTS or the audience on changing road surface conditions when they experience the road as slippery. However, a real-time decision support system could help them to be ahead of the event, rather than acting after the road is experienced by road users as slippery. Hence, by *moving the focus from when drivers experience the road as slippery to when the car experience the road as slippery, the contractors might be able to be one step ahead of the weather event*. However, this shift in focus opens new questions that need to be clearly answered. For instance: How many cars that experience the road as slippery should the system allow before reporting the road as in need for maintenance?

Given that the RSI technology can be brought up to a higher level of quality than what was possible to prove in the technical evaluation, the data collection should be extended both in the temporal and spatial dimension. Currently, the road surface friction is measured by the authorities using static weather stations with high temporal resolution. Alternatively, friction is measured by using RoAR vehicles with high spatial resolution, but with both low temporal and spatial coverage. By using the RSI system of Volvo, the data collection can be conducted with both high temporal and spatial coverage, although this will depend on the number of cars with the RSI system installed. In addition, the RSI system requires some kind of acceleration to be able to deliver data of higher quality parameter, such as accelerating to higher speed, breaking, or driving through turnsOne must therefor determine how many Volvo cars must pass given road segments with different geometries in order to provide a suffient number of measurements.

In relation, the contractor highlights that a weakness with the data from the weather stations is that a weather station is not necessarily representative for other nearby locations. This is particularly true for mountain passes, where differences in altitude make it particularly problematic to generalize to other nearby locations. In these locations, extended spatial and temporal scope on data sources could be of great importance to the contractors. The contractor also highlights that having available data from a larger number of sources could make the information system less vulnerable to interruptions.

Another interesting aspect brought forward by the contractor, is that if they knew the road surface friction levels for neighbouring contract areas, they would be better equipped to be one step ahead in their own area. For this system to work, all contractors working for the NPRA should have access to all available data, also for areas other than where the contractor is located. Contractors acquire a special knowledge about local weather patterns, which in combination with an RSI decision support system could give a solid indication of what measure should be taken for maintaining the required winter maintenance level.

7.2. Hypothesis2: AN RSI decision support system improves the NPRA's control and organization of winter maintenance.

Because they do not have the capacity to control the entire road network, the NPRA currently bases their control and verification of contractors on random checks. RSI data could be used for indicating where the NPRA should do their random inspections. Further, a representative from the NPRA highlights that RSI data is interesting as a supplement to other data sources, but that one should be careful about assuming one can replace the existing data sources with RSI data. This statement seems to be supported by the technical evaluation in this report. The RSI system alone seems to be far from able to replace the current equipment and standards. However, a decision system which incorporates big data sources along with more precise, but less dense data sources (like weather stations and

RoAR), could ba an interesting approach. For instance, a representative from NPRA highlights that, due to uncertainties concerning data quality, RSI values from one car may not provide a satisfactory foundation for making decisions concerning winter maintenance. However, with a fleet of cars reporting RSI values, the data becomes more interesting for planning and controlling winter maintenance. When making decisions based on a fleet of cars one is not equally vulnerable towards the measures done by individual cars.

For the RSI system to serve as a data source for deciding where and when to perform inspection of the contractors, the quality of the data again needs to be higher than was proven in the technical evaluation. One should also be aware of possible biases of the RSI system compared to the RoAR measurements, which is the golden standard for friction measure on the Norwegian road network. For instance, the results presented inTable 2 indicate that RSI tends to estimate lower values of friction than that of RoAR. Also, a significant number of vehicles with the RSI system should be able to deliver trustworthy data before the road surface changes again.

As a non-real time data source, RSI data could be collected and analysed to provide important statistics for further uses. For instance, how many days with low friction on each mountain pass were detected? Where are the historically most problematic areas? When a new contractor wins a contract, the local knowledge acquired by the previous contractors could be lost. Local knowledge is particularly important in areas that have large variations in weather and road conditions. With historical RSI data, it is possible that the hang-over-phase between contractors could be minimized. In addition, the contractor also emphasized in the interview that RSI data would provide both contractors and the NPRA with valuable historical figures for road conditions. RSI data could help the NPRA with planning the process of finding new contractors, by providing more specific data on a much larger spatial and temporal scale.

A representative from the NPRA suggests that RSI data could also help determine whether the winter maintenance class determined by Handbook R610, chapter 9 (NPRA, 2014) is correctly specified. The winter maintenance class may not be correct if overall friction values are too high or too low according to what is described by the handbook. Hence, the foundation for determining winter maintenance class may become more sound with RSI data from a fleet of cars.

Although the NPRA has accelerated the move towards transparency by making big data available, this does not automatically mean that they can utilize these data, such as large scale friction data. Through the interviews, several of the interviewees from the NPRA explained that there are organizational barriers within the NPRA that make it difficult to utilize the data provided by sensors that provide big data. This is not a unique feature of the NPRA and is a well-known challenge within other areas of public sectors (e.g. the health sector). The organization is also struggling with issues related to ownership, privacy and security when it comes to big data. For instance, information should not be directly traced back to individual cars. This is a very challenging subject when it comes to utilizing big data, and is a subject that should be further investigated.

7.3. Hypothesis3: User acceptance is a precondition for implementing an RSI decision support system.

To a large extent, the interviewees refer to experiences that they have made in the current winter maintenance system (including break retardation tests and the RoAR machiene) when they are asked about the RSI decision support system. Due to these experiences, the interviewees highlight that they believe that it will be problematic to replace the current system with an RSI decision support system. The representatives from the NPRA are particularly concerned due to previous experiences with point measures from break retardation tests, and given the RSI systems need for acceleration/retardation/turns they compare RSI to break retardation tests. These tests are also about to be replaced by better and more effective friction measures, such as trailing sensors.

Through the interviews, we uncovered that the RoAR data have high user acceptance, since this method tries to eliminate some of the drawbacks related to point measures, i.e. through using wheels that are standardized. The users are concerned about how such quality challenges will be deat with by an RSI decision support system, since differences between independent cars and tires might cripple data quality. Will it be sufficient to have a large number of cars? And if so, how many cars are needed? These questions are beyond the scope of this evaluation, but are questions that the interviewees are concerned with.

Another issue that raises concern among the interviewees, is that friction can change rapidly, which makes it difficult to base decisions concerning winter maintenance on friction. Friction values are most interesting when combined with other data from the car, such as video and temperature, as these additional data source will give more detailed picture of the road surface conditions. Rather than developing an RSI decision support system, the RSI data should therefore be used in other available applications, such as for instance Vegvær. Vegvær is a Norwegian database where all contractors of the NPRA can see what the prognosis are for road and weather conditions in Norway. In this way, the RSI data could be added in Vegvær as an additional data source rather than replacing existing ones.

One of the interviewees from the NPRA highlights that the break retardation test is better suited than the current RoAR vehicles in one specific context: to measure friction values on surfaces with fresh snow. This is due to the fact that the wheel on the RoAR vehicles has problems with breaking through the snow, an issue that the developers are working on for the next version of the RoAR vehicle. This is, however, no problem when executing a break retardation test. The drawbacks are,however, so considerable that this technology still will be replaced.

The contractor highlight that an RSI decision support system has to explain or show the relevant data that its decisions are based on. They have no particular opinions on how the human machiene interace (HMI) of this system should look like, but they highlight the neccecity of having the underlying data available. As described above, combing the RSI data with video and temperature data from the car would also be a useful addition to such a decision support system.

The contractor emphasized that is crucial to accumulate experiences with the technology before preparing full scale implementation. The experiences with the RSI data in this project are therefore of great importance. Fully developing technologies before one starts using them may not be the most useful approach. In this view, experiences this contractor has made with the CBR system is particularly useful, because CBR is a new technology developed in a research and development (R&D) project. Only by working with the technology, in close coopertation with the users of the technology (in this case winter maintenance personel), will the users of the technology learn to trust the new tools derived from it.

8. Transferability of the results

Overall, we find that the RSI data is an interesting data source that could be used for the purpose of winter maintenance. The data cannot, however, be used for the same purposes as RoAR data is used today.

8.1. Lessons learned

Based on the results from this evaluation, we suggest that it is unlikely that one can use RSI data for exactly same purposes as RoAR data are used today, such as verification of contractual obligations. Based on the findings made in the technical evaluation, we find that the RoAR data have a higher quality than RSI data, which highlights the importance of discussing the purpose and aims of the RSI technology. We find that it is also questionable whether the RSI system can be used for a real-time decision support system for connected vehicles. However, historical data from RSI could be an important tool for aiding the authorities in decision-making and monitoring of the transport system. With historical data, the authorities could be more able to identify critical areas where one should use more resources. In this way, the winter maintenance level might be improved with RSI data, although it is required that there is data available from a sufficient fleet of cars.

We argue that the major advantages from RSI data are, however, likely to be realized when they are combined with other data sources, such as for instance temperature and images of the road. Hence, by using a variety of data sources (for instance from the car) one can complement the available information from RSI and provide invaluable information on winter maintenance. This requires that the NPRA is able to use data that becomes available from the increasingly more advanced technology. In this view, experiences made with RSI data are highly valuable for preparing for future integration of big data, necessary for instance in autonomous transport systems. The contractor we interviewed also specified that new tools are of importance for developing winter maintenance for the future, and that it is critical to use the tools for generating experience and knowledge.

Until the system with different data sources from the car as a sensor is realized, traditional data sources are likely to keep dominating as the main information sources for winter maintenance. Even though it might not be possible to exclude other high-cost data sources immediately, it is important for contractors to start using new tools. The tools should not necessarily be developed to perfection before one start to use them. It is equally important to start using new tools, such as the RSI decision support system, to get experience with it.

Based on the technical evaluation reported in this report and the eavluation presented by NTNU[1] the RSI system cannot be said to have reached TRL4 or TRL5 (see Figure 2) . One should, however, conduct more tests to evaluate whether the RSI technology can reach TRL4, for instance by performing an experiment like the one outlined in the last paragraph

[1] Giudici, H. and Klein-Paste, A. (2016) "Road friction estimations on winter conditions" Technical report, NTNU,

of section 6.1. Each of the TRL levels must be documented and verified before moving on to evaluate the next level.