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Author(s)	Aapaoja, Aki; Hinkka, Ville; Leviäkangas, Pekka; Hautala, Raine; Kinnunen, Tuomo K.
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IMPACT OF INTEGRATED WINTER ROAD MAINTENANCE ON TRANSPORT SYSTEM RESILIENCE

Aki Aapaoja, Ville Hinkka, Pekka Leviäkangas, Raine Hautala & Tuomo K Kinnunen
VTT Technical Research Centre of Finland Ltd., Finland
aki.aapaoja@vtt.fi
co-authors: firstname.lastname@vtt.fi

ABSTRACT

Winter sets particular requirements for winter road maintenance to keep roads and highways open to traffic. Extreme winter conditions present risks for transport system as snowy and icy weather extends travel times, increase risks for accidents and may even restrict the use of the road. Indeed, snowfalls, low temperatures, and blizzards are identified as being the most significant extreme weather phenomena for winter time mobility and transports. Hence, winter road maintenance activities generate significant benefits to the society and contribute to the resilience of the entire system. This article discusses how the transport system resilience can be increased by deploying advanced and emerging technologies and solutions to winter road maintenance. Integrated winter road maintenance and related intelligent transport systems (ITS) enable winter maintenance vehicles to collect sensor data about road surface conditions, and transmit, analyze and utilise the data in real-time. By making use of technologies, it will be possible to increase transport system resilience, e.g. by using existing winter maintenance capacity more efficiently. In practice, integrated winter road maintenance approach enables directing the vehicle fleet to the most critical places, ensuring the correct use of vehicles, clarifying the roles of different actors, and better timing of maintenance operations.

1. INTRODUCTION

European societies among other societies in developed world are built on the efficient movement of people and goods. Especially, in northern or mountainous regions, winter sets particular requirements for the winter road maintenance to keep roads and highways open to traffic [1,2]. Even if climate change has shortened winter time almost everywhere, it has similarly strengthened extreme weather phenomena. Therefore, in the areas where the snowy and icy weather is possible, winter conditions are encountered less frequently, but when they occur, the conditions are often harsh.

In Finland, enhancement of transport system resilience is named as one of the national priorities to ensure the supply security of the nation and different parts of the country in every circumstance. The state authorities are responsible for securing the functioning of the transport system and the particular functionality of infrastructures that are nationally critical [3]. Juntunen and Hyvönen [4] describe resilience as an ability and capacity of the system to absorb shocks, impact or disturbances while still being able to maintain its capability to function and to recover to its original state. Another definition of resilience provided by Ayyub [5] reads as following: “Resilience notionally means the ability to adapt to and prepare for changing conditions and withstand and recover rapidly from disruptions. Resilience includes the capacity to withstand and recover from disturbances of the deliberate attack types, accidents, or naturally occurring threats or incidents. System resilience for a particular function can be measured based on the uncertainty persistence of a similar system’s performance in the face of disturbances.”

Damages caused by the extreme weather hazards and climate change have gained much attention recently. Both aspects require actions especially considering the life-cycle of any transport infrastructure and system asset. Apparently, the more durable and resilient system is built and maintained, fewer resources are needed to keep it running and in a good condition. However, the approach does not concern only the new investments, but also the existing infrastructure must be taken into account too and therefore management strategies, maintenance programs, etc. should not only be considered as a money spending but more as an investment [6,7]. Moderate upgrades, enhanced and proactive maintenance, deployment of new enabling information and communication technologies (e.g. Building Information Modelling, mobile technologies) are examples which implementation could decrease life-cycle costs [8,9].

Resilient transport systems are built to serve society in every condition and, for instance, changing climate with extreme weather conditions are challenging the transport systems. Indeed, snowfalls, low temperatures, and blizzards are identified as being the most significant extreme weather phenomena for winter road mobility and transports [10]. Hence, winter road maintenance activities provide some benefits – direct and indirect – to the society [11] such as increased reliance. Ultimately, like any system, a resilient transport system, will also be more efficient, reliable, safer and sustainable [12].

This article discusses how the transport system resilience can be enhanced by deploying advanced and emerging technologies and solutions to winter road maintenance. Reaching the purpose requires the answering of the followings research questions:

1. What are the potential emerging technologies and approaches to be deployed into the winter road maintenance?
2. How can transport system resilience be enhanced through integrated winter road maintenance?

Our article rest upon existing literature and empirical material gained through 20 expert interviews in six countries. In this study, the qualitative case study methodology [13] was applied. Also workshops, in addition to literature review and interviews, were held with the relevant stakeholders – e.g., service providers, solutions providers, authorities - in which brainstorming and group work techniques (e.g., brown paper, process building) were used. The purpose of the literature review was to ascertain what has been written to date about transport system resilience and integrated winter road maintenance and emerging maintenance techniques based on information technologies. The particular point of interest is how this integrated approach may affect on the resilience of transport system. Another focus is on the current technological status of integrated winter road maintenance, whether it is technologically feasible to achieve, e.g., real-time data transfer between maintenance vehicles and maintenance management.

2. RESILIENCE AND WINTER ROAD MAINTENANCE

Recently resilience research in transport has been related to climate change and extreme weather conditions [14]. As a term, resilience is not often explicitly mentioned, but alternative or similar terms like reliability and sustainability are used which can be associated with the long-term resilience of the system. Besides, these are often related to long-term resilience of the transport system as well. Systems covering wide geographical areas are more vulnerable if all sub-system or components are relying on each other in reliability sense, whereas the elements of the system that are nodes are at hazard once the shock hits them [15]. Whenever risk and contingency management can be based on the risk and incident assessment made in advance, it provides an opportunity to maintain critical service, which can be lower than normal, so that society can still operate [8].

The concept of resilience is not sufficient and unambiguous yet even if the similar concepts are used in different definitions. Matzenberger et al. [16] propose that resilience is an overarching concept, making it a function of adaptive capacity and vulnerability. Walker et al. [8] have defined resilience as the inverse of vulnerability, which, in turn, can be understood as a combination of exposure, susceptibility and coping capacity as described by multiple sources [17, 18]. According to UNISDR [17], these sub-components are described as follows: 1) Coping capacity is the ability of systems, organizations and people to use available skills and resources to face and manage adverse conditions, emergencies or disasters. 2) exposure is people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses, and 3) vulnerability is the characteristics and circumstances of the society, system or property that make it vulnerable to the damaging effects of a hazard. Equation 1 [18] presents the hierarchy of the concept of resilience:

$$Resilience = \frac{Coping\ capacity}{Exposure \times Susceptibility} \quad (1)$$

Enhancing the resilience of systems (e.g., road transport) at the structure, network and societal levels will probably lead to massive savings through risk reduction, efficient recovery and enhanced reliability [19, 20]. Simultaneously while our climate is changing and extreme weather conditions are getting more frequent, these systems and sub-systems (e.g., technical) face many challenges. As part of technical systems, intelligent transport systems (ITS), are facing the same risks as extreme weather phenomena can cause malfunctioning. ITS is not only vulnerable as a single infrastructure component, but also because it is relying on other infrastructures like ICT and power supply networks [15]. Obviously, the increasing the effectiveness of both ITS system itself and its application areas - winter road maintenance in this particular case - may have a positive impact on the resilience of the whole transport system. In the forthcoming chapter, the potential ways to enhance the transport system resilience through integrated and advanced winter road maintenance are presented and discussed.

In equation (1), the variable of Resilience, Coping capacity, Exposure and Susceptibility can each be operationalised as a set of more specific, measurable (or assessable) sub-variables or attributes. This exercise would result in a ‘resilience index’ which would point out which attributes could be improved most effectively in order to enhance resilience. For example, Coping capacity could include sub-variables such as availability of plowing equipment, winter time maintenance budget constraints, flexibility in winter maintenance contracts and existence of operational winter maintenance management systems. Exposure would naturally include climatic attributes, their frequency and intensiveness, for instance. In the following section, we shall focus on management systems.

2.1. Integrated winter road maintenance management

Most information technology solutions developed for winter road maintenance are related to weather measurement. Road weather information systems (RWIS) stations are one such solution [21]. An RWIS station is a network of sensors connected and commonly configured to provide accurate real-time site-specific pavement conditions and weather data. The observational data usually include at least air and pavement temperature, relative humidity, wind speed and direction, and precipitation rate, but it can also detect ice formation [22]. RWIS stations may also include cameras and road surface image recognition can be used to provide timely warning of snowy or slippery conditions [23]. For a mobile measuring, continuous friction measurement (CFM) technology measures directly or indirectly the friction coefficient between the vehicle tires and the road surface [24]. When using these technologies, this sensor network resembles the definition of Internet of Things by the International Telecommunication Union. The Internet of Things (IoT) is the network of physical objects, devices, vehicles, buildings and other items which are embedded in electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data [25].

Weather condition measurement is one aspect of winter road maintenance, but the other aspect is to use the measurement information efficiently to minimize the adverse effect of winter conditions on traffic. Currently, decision making related to winter road maintenance is often decentralized, and different actors make decisions based mainly on their viewpoint [26]. Use of the information from integrated systems in winter road maintenance would help various actors see the comprehensive picture, but testing in this area focused until recently mainly on reporting and solving technological defects [27]. However, Hinkka et al. [28] presented findings of the pilot implementations related to real-time information exchange technologies in winter road maintenance and stated that it is technologically possible to build a system where maintenance vehicles can collect relevant weather information data on the move and send it directly to the server for analysis. Hinkka et al. [28] named this particular approach as integrated winter road maintenance management. In this approach maintenance vehicles collect data during their activities, send this data in real-time for server and decision support systems for analysis, and where the system or system user could send back instructions for maintenance vehicles or vehicle drivers based on analyzed data.

The use of real-time information from maintenance vehicles could reorganize current winter road maintenance ecosystems [28, 29] considerably, and increase the resilience of the transport system: first by integrating two functions - weather observations and measurements and maintenance activities – and second by enabling visibility between the road authority and a contractor. An additional application of visibility is to allow real-time adjustment of the activities of a single vehicle or entire vehicle fleet, based on observational data and decisions of representatives of the traffic authorities or the main contractor company. [29].

3. THE CONTRIBUTION OF INTEGRATED WINTER ROAD MAINTENANCE MANAGEMENT TO IMPROVE TRANSPORT SYSTEM RESILIENCE

The authors arranged a workshop for Finnish experts in winter road maintenance and transport system resilience. In the workshop, the summary of the results of 20 expert interviews conducted in six countries and some of the relevant journal articles on the topic were presented. The purpose of the workshop was to raise potential risks that winter weather may cause for road transport and to figure out, how integrated winter road maintenance management and related ITS technologies could contribute to these risks by improving transport system resilience. Based on the discussions, the potential risks were seen to be involved in situations where maintenance capacity is not sufficient to keep roads passable.

The amount of available winter road maintenance vehicles is a result of optimizations between costs and capability. Despite some arctic areas, the need for winter road maintenance is seasonal. In some north or remote inhabited parts of Europe, there might be a need for winter road maintenance activities between September and May. However, in most of the regions the winter season is relatively shorter, and in Central Europe, for instance, winter road maintenance activities are needed only a couple of times a year, and in Southern Europe not even every year. Therefore, despite the frequency of winter weather, there is a problem of the capacity of winter road maintenance vehicles everywhere when the weather requires road maintenance activities [30].

As the maintenance capacity is restricted, it is critical to making the most of it, and ensure the vehicles are already on the roads when they are needed. The workshop discussions were summarized as four different contribution possibilities which all are somehow related to limited maintenance capacity.

The first contribution of integrated winter road maintenance is related to correct location of maintenance vehicles. Maintenance vehicle fleets usually consist of vehicles that are operated by numerous subcontractors. A single subcontractor may have a few vehicles and therefore, he is not able to see the whole picture. When there is a real-time information about road network conditions and locations of maintenance vehicles, managing actor can direct vehicle fleet to operate where they are needed most. The authorities usually have priorities where they divide roads depending on their importance. Steering the fleet helps to ensure that at least the main roads are passable during severe weather conditions. Also, weather conditions may differ even in a small area. For these situations, it is important to be able to direct the maintenance vehicles to correct roads.
The second contribution is related to the proper use of the maintenance vehicles. Driving winter road maintenance vehicle is usually seasonal and occasional work for a driver. Therefore, the know-how of drivers has a great variety. However, the driver is responsible for rather hard choices, such as which kind of de-icing chemical should be used in particular weather condition. When the maintenance vehicle can send real-time information about the surface conditions of the operated road, the system user or decision support system can guide the vehicle or vehicle driver to adjust its activities to contribute better in current road condition circumstances, e.g. by changing the compound or amount of spread de-icing chemicals.

The third contribution is related to the roles and incentives of different actors. In the road maintenance, the different players have different incentives. The authorities want to ensure fluent and safe traffic with low costs when the main contractor wants to minimize its efforts if it gets fixed compensation, and while the subcontractor wants to maximize its activities if it receives payments based on performed procedures [28]. In severe weather conditions, unclear roles may delay activities. Real-time information about the location of maintenance vehicles and conducted activities helps the authorities to ensure that the main and subcontractors are doing the right things and not try to optimize their own company's performance. For a road user viewpoint, e.g. in situations, when there is need for emergency vehicles to go to a certain place, it is easier when they can contact directly to authorities who direct the closest maintenance vehicle to operate the correct road instead of the situation, when the emergency vehicle driver needs himself to find a suitable subcontractor.

The fourth contribution is related to the timing of maintenance activities' start. The ideal situation is that maintenance vehicles are already in activities e.g. in cases when it starts to snow. Also, some of the de-icing chemicals can be spread before the road surface temperature drops to zero. As described above, subcontractors will gladly conduct preventive maintenance activities just in case while main contractors aim to avoid excessive activities. Therefore, sharing correct road weather information forecasts between different actors is needed to ensure that proper maintenance activities can be started early enough.

4. DISCUSSION AND CONCLUSIONS

Transport systems are vulnerable to extreme weather conditions. Especially winter conditions, snow and ice, cause disturbance to traffic, which can be seen as longer travel times, increased number of accidents or even closure of certain roads causing serious problems for the reliability of transport systems.

It would be possible to improve the resilience of transport systems by building infrastructure where winter weather does not disturb traffic (e.g. by constructing covered roads, or heating systems under road surface). However, using ITS solutions to response extreme weather conditions is often more realistic and cost-effective way than building complex infrastructure. Integrated winter road maintenance management is one approach to improving transport systems resilience in extreme weather conditions. In that approach, all the actors of the winter road maintenance ecosystem have the same information in real-time to use for decision making.

By using integrated winter road maintenance approach, every actor knows where the maintenance vehicles are operating and which kind of activities they are conducting. When the information is exchanged in real-time, it is possible to direct decision making for an actor who has the best information about the entire picture and related factors, and also ability to handle the collected data. This kind of cooperative approach ensures that maintenance fleet is in the best possible use when extreme winter weather conditions are encountered. Table 1 summarizes the opportunities of integrated winter road maintenance and related ITS to improve the resilience of transport systems.

Table 1 - Opportunities of integrated winter road maintenance and related ITS to improve the resilience of transport systems.

Context and issue	**Opportunity**
Clarifying the roles and responsibilities of different actors	Real-time information exchange enables the authorities to make sure that contractors are operating by the agreed guidelines
	If road users have notice or requirements concerning maintenance activities, it is possible to concentrate all the contacts to suitable actors and share the information between them.
Proper and efficient use of maintenance vehicles	Possibility of centralizing decision making related to, e.g., the selection of appropriate de-icing chemical based on collected data
	Easier to reassess weather conditions during the activities and, e.g., change the compound of used de-icing chemicals during activities
	Easier to take a hand with unprofessional ways for conducting maintenance work (e.g., too fast driving)
Real-time location of maintenance vehicles	It is possible to direct entire maintenance vehicle fleet to focus on areas where the driving conditions are the most difficult
	Possible to redefine priority roads for activities based on changing weather and road conditions
	Possibility to inform the movements of maintenance vehicles and recently operated roads
Correct timing of	Different contractors can get same weather forecasts and made aligned decisions regarding starting of maintenance activities

maintenance activities	Better possibilities to align and complete activities of various contractors

The results of the study indicate quite clearly that accurate real-time information is one of the most efficient and cost-effective means to enhance the resilience. Once one sub-system of transportations (e.g., trains) or road goes down, the information about the failure, its possible duration and alternative routes or services can be immediately shared with users, authorities and mobility service providers. User and passenger information have usually been connected with service quality and comfort, but obviously, as an attribute of resilience, the nature of information is more complex and has more dimensions than just service level and support. One illustrative example is a snowstorm at London's Heathrow airport in December 2010 that paralyzed Britain's largest airport and caused unexpected disruption and difficulties to airlines, airport and passengers. An hour-long snowstorm dumped about 13 cm of snow - twice as much they have ever had - at the airport. The storm was followed by a sudden drop in air temperature which froze airplanes to their parking stands. Even though the storm lasted only an hour, the airport was fully reopened only after five days which cost 24 million British pounds to the airport group, £50 million to British Airways and £10 million to Virgin Atlantic [31]. Since the storm, Heathrow airport established a winter resilience inquiry to find out how the airport could increase their resilience towards future extreme weather events. Six months after the storm, in September 2011, the airport [32] published an updated snow plan consisting significant improvements and implementations in fourteen different areas:

- Enhance snow plan
- Review aircraft de-icing processes
- Regular snow plan review
- Early collaboration on contingency planning
- Dynamic management of consumables
- Strengthen crisis management process
- Define clear escalation triggers
- Strengthen capacity constraints group
- Sustainable crisis resourcing
- Enhance flight information and passenger communications
- Establish a single airport command and control center
- Improve situational awareness
- Jointly strengthen current welfare arrangements with airlines and Civil Aviation Authority
- Routinely plan and test welfare arrangements

When the updated snow plan was published, the airport was already invested over £30 million in new technology, e.g., snow equipment, ICT, facilities, de-icing systems and management process, and it is assumed that further investments still require £20 million. It goes without saying technology, whether it is an existing or an emerging one, plays a central role when the resilience and a flow of information are improved. However, technology acts more or less as an enabler for the services and improvement of resilience. The way how information is used and for what is the priority, because all the technology is almost useless if it cannot be managed and used effectively.

Being identified as an attribute of transport system resilience and an essential part of everyday life in the northern hemisphere, the future research activities regarding winter road maintenance and its impact on the resilience could focus on identification and impact assessment of adaptation measures and emerging technologies, and possibilities coming with the digitalization of road traffic and infrastructure.

This paper also has its limitations. First, the amount of quantitative data justifying the benefits of integrated winter road maintenance is scarce. It may affect how different research topics are presented, as it is hard to compare the impact of different research topics. Secondly, even though the Finnish winter road maintenance is well recognized and world-class, it is still possible that results and conclusions of the study are slightly biased since the analyzed data was based on the workshop arranged in Finland. However, this paper works well as a stepping-stone to new academic discourses as well as planning practical solutions on winter road maintenance management.

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