



Road condition detection technology

A benefit analysis

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Preface

This benefit analysis on vehicular road condition detection technology is a customer project conducted by VTT, and commissioned by EEE Innovations Oy and Posti Oy. The research team of this study comprised project manager and Research Scientist Toni Lusikka (M.Sc.), Senior Scientist Petri Mononen (D.Sc.) and Professor Pekka Leviäkangas from University of Oulu (formerly VTT).

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Appendix A: Annual benefits potentially achieved through vehicular data collection.

Abstract

Tiivistelmä

1. Introduction

1.1 Scope, aims, objectives and methods

Purpose of this study is to find out benefits and savings that could be realised with vehicular road condition data. Study is limited to Finnish road management.

Research was done mainly as literature review consisting of journal and conference articles, authoritative reports and guidelines, and trade journals. Also, one semi-structured group interview with experts from logistics company was conducted discover benefits that could be achieved on a company level.

1.2 Report structure

The report is divided in five main chapters: 1) Introduction, 2) Finnish Road Transport Infrastructure Management, 3) Slipperiness & Road Condition Detection Technology, 4) What Can Be Achieved With New Technology: A Benefit Analysis, 5) Discussion and Conclusion.

In the first chapter, scope, aims and objectives, and methods of the study are described. Chapter two, Finnish Road Network Management, presents the overall description of Finnish road network and management actions. Chapter three introduces vehicular technologies for collecting road condition information. Also, the system costs and two different scenarios with different vehicle fleets are compared. In chapter four, benefits of road condition and road weather information are estimated, and conclusive analysis is formed. Results, implications and future possibilities are discussed in chapter five.

2. Finnish Road Transport Infrastructure Management

This chapter gives a portrait of Finnish road network and how it is governed. Also, Finnish road weather conditions are described to show how they are related to accidents and traffic management. Last, the applied road maintenance methods are described.

2.1 Road transport infrastructure

Finnish road network consist of state-owned highways, municipal roads, private and forest roads. State-owned road network is 78 000 kilometres in length, while municipalities are responsible of 26 000 kilometres. Private and forest roads cover 350 000 kilometres adding the total length of the road network up to 454 000 kilometres. (Väylävirasto 2020)

The state-owned network is divided in three types of roads: main roads, regional and connecting roads. 17 %, 13 300 kilometres, of the state-owned network is considered to be the main road network, including 900 kilometres of motorways (Wihlman 2019, Väylävirasto 2020). The majority (64 900 kilometres) of the state-owned roads are regional and connecting roads. Approximately 50 000 kilometres of the state-owned roads are paved. (Väylävirasto 2020)

Book value of the state-owned road infrastructure assets is approximately 15 billion euros (Valtiovarainministeriö 2020). Maintenance backlog of Finnish transport infrastructure is 2.6 billion euros. (Wihlman 2019) Around 50 % of the maintenance backlog are result of road network in need for repair (Männistö 2016). Maintenance backlog means a monetary amount, which is needed to repair all roads into good condition that meets current needs. Good condition means such a techno-economic level at which the service level of the road network is sufficient in relation to the traffic volume and significance of the road, and the maintaining of the service level does not become unreasonably expensive. (Valtiovarainministeriö 2020)

2.2 Road transport infrastructure governance

Finnish Transport Infrastructure Agency and Centres for Economic Development, Transport and the Environment are responsible of state-owned road infrastructure governance (Highways Act 2005/503). In this study, these organisations are comprised to one term, state authorities, who are jointly responsible for state-owned road network.

In addition to state authorities, municipalities are responsible for governance of other publicly owned road network. Each municipality is responsible for roads and streets, except of state-owned roads, within their boundaries.

There are also privately owned and maintained roads, but those are scoped outside of this study.

State authorities and most of the municipalities nowadays outsource the maintenance to road maintenance operators (Leviäkangas et al. 2014). District Managers, be they part of public organisation or private service providers, oversee the contracts and quality of the maintenance. State authorities also use service providers to monitor the quality of winter road maintenance contracts. Contracts are usually realised by road maintenance operators, who are awarded the maintenance contracts. Contractors are responsible for providing the requested service level. Contractors may use Decision Support Systems (DSS), weather information and other data in the execution of maintenance operations. Decision Support Systems are usually outsourced to specialised service companies. There is also relatively new state-owned company, which is responsible of providing traffic management services and hence is essential part of the road maintenance business (Lusikka et al. 2019B).

Figure 1 presents the summary of Finnish road maintenance business ecosystem and relations between authorities and business actors. Figure is based on and updated from the previous studies on winter road management (Leviäkangas et al. 2014; Lusikka et al. 2019A).

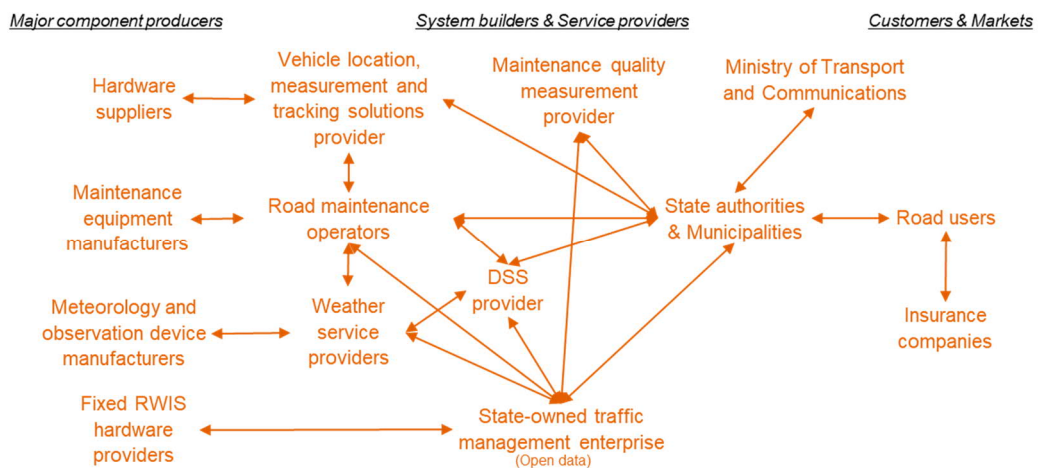


Figure 1. Finnish road maintenance business ecosystem (modified from Leviäkangas et al. 2014; Lusikka et al. 2019A).

2.3 Road condition and road weather

Road conditions and adverse weather can cause adversities to traffic. Weather conditions in winter can be harsh, and visibility and road surface conditions can be poor (Pilli-Sihvola et al.2012). In 2017, for example, there were warnings of very poor

road conditions on 45 days. By comparison, there were similar warnings on 28 days in 2015. (Ilmatieteenlaitos 2017)

There are three situations for motorists in adverse weather conditions that can be identified as risky. First, situation where heavy snowfall and clear freeze are present. Second, when there is slight or medium snowfall and slipperiness caused by cold temperatures, and third, high temperature fluctuations, when ground frost is formed or road surface freezes or air warms up quickly. (Liikennevirasto 2018) These conditions contribute to risk of traffic accidents and are thus relevant factors to be identified when measuring road and weather conditions.

Weather information can be channelled straight to road users to raise awareness, or to road maintenance operators who can adjust their actions better to ensure safe road-use conditions (Pilli-Sihvola et al. 2012). Expert estimates conclude that 10 % of accidents with personal injuries can be reduced just by providing good weather and road condition information (Liikennevirasto 2018).

Furthermore, to provide good quality winter maintenance, it is important to have knowledge of approaching weather phenomena and a continuous follow-up of weather conditions can further improve maintenance quality. General weather monitoring includes meteorological observations and forecasts. The Finnish state authorities currently provide the following weather services to contractors: road weather forecasts, graphic material of rain radars and satellites, road weather stations' measurements, and footage of weather condition cameras. Interpretation of weather data require expertise and human resources. (Liikennevirasto 2017)

2.4 Road maintenance

2.4.1 Road maintenance and asset management

The base line road management budget that excludes capital investments includes the following: day-to-day maintenance for both winter and summer time, attached infrastructure maintenance (lighting, signals, portals, etc.), repairs and upgrades of smaller scale, operating of ferries, traffic management. Wintertime maintenance includes snow plowing and anti-skid surface treatments. (Liikennejärjestelmä.fi 2019A).

There is a widely accepted perception that a correlation exists between the condition of road infrastructure and road safety, although the correlation involves many contextual factors (e.g. differences between countries). However, the condition of road infrastructure has an impact on safety and driving comfort (Malin et al. 2016).

2.4.2 Winter road maintenance

The purpose of winter road maintenance is to ensure safe and effortless road use in all conditions (Pilli-Sihvola et al. 2012). Condition of the road surface is the most important factor when considering traffic safety. A 10% improvement in road surface condition reduces amount of accidents by 20% (Usman et al. 2012). In Finland, the

road surface is not required to be bare, but it is considered sufficient that enough grip is achieved for safe road transport (Malmivuo 2016). Acceptable grip can be achieved by de-icing operations. In Finland, 80 000 to 120 000 metric tons of road salt is used on state-owned road network in de-icing operations every year (Mustalahti 2001).

Use of road salt reduces collision accidents by about 80% and injuries by 85%. On roads with four lanes, the reductions can be up to 95%. (Fu & Usman 2013) De-icing is considered to be very cost-effective as previous studies state that de-icing's repayment period is only 25 minutes (Kuemmel & Bari 1997).

New de-icing techniques are developed continuously. With predictive salting it is possible to prevent ice formation altogether. Predictive de-icing operations are also more resource-efficient, because less salt is required if salt is used beforehand. (Liikennevirasto 2017) Salt can be used in preventive maintenance operations besides the de-icing. For example, salting that is done before the snowfall prevents the snow from adhering to the road surface (Väylävirasto 2019).

Although salting has many obvious advantages, there are also some drawbacks. Salting can cause environmental detriment by salinization of ground water and thus adversely affecting flora and fauna (Bailey & Haavasoja 2016). Salt also damages infrastructure and vehicles as it increases corrosion (Mustalahti 2001). There are more environmentally friendly alternatives to sodium chloride, such as potassium formate, but potassium costs some ten times as much as traditional road salt (Pitkänen 2016).

Weather and road condition information are used to enhance winter road maintenance operations. Weather and road conditions are monitored with multiple methods using, e.g. Road Weather Information System (RWIS), road weather cameras, radar and satellite images, forecasts and automatic traffic measurement points. The Finnish state authorities offer extensive data from those systems free of charge for maintenance contractors to use in their operations. (Liikennevirasto 2017)

2.5 Road Weather Information Systems

Road Weather Information Systems (RWIS) and weather forecasting play important role in winter road maintenance. RWIS provides site-specific real-time information on road conditions, temperatures and environmental conditions (Sisiopiku 2001). Consistent and reliable RWIS has great importance in winter road maintenance, because inaccurate information may cause unnecessary actions. The RWIS is based on measurements of road weather stations, which measure road surface, road and air temperatures, and air humidity with different sensors. (Riehm & Nordin 2012)

In Finland, RWIS consists of 370 road weather stations and some 500 cameras (Myllylä 2017). The operating costs of Finnish RWIS are some three million euros per year (Lusikka et al. 2019B). On the benefit side, RWIS reduces societal economic costs of traffic accidents by 4.6-9.2 million euros per year (Liikennevirasto 2018).

Kwon et al. (2017) conducted a case study in Minnesota, USA, which shows that adding new road weather stations could improve the effect of the RWIS. In their study, the performance of the current network was improved by 8.4%, when five additional stations were deployed, and 12.6%, when 15 stations were added. New stations were planned to fill in the gaps in current network on areas that had most frequent collisions. (Kwon et al. 2017) However, new stations are quite expensive, over 50 000 euros per station (Lusikka et al. 2019B), so it might not be feasible option to add multiple new stations to fill vast gaps in Finnish RWIS. Thus, new data collection methods need to be developed and tested.

The State authorities are continuously developing road maintenance. One development target is the timely targeting of maintenance measures based on real-time condition information. To take measures timely, prediction and forecasting methods are needed. Also, quality assurance methods and management tools are being developed. To make these systems and methods usable and compatible, there is growing need for more and better quality data. Multiple pilots and experiments are in progress to measure weather and road conditions with vehicles and on crowdsourcing methods. (Liikennevirasto 2017)

3. Slipperiness & Road Condition Detection Technology

3.1 Vehicular detection technology

Vehicular detection technology used and developed by the commissioning organisations gathers information of the rotational speed of vehicle tires and the engine power used through vehicle's data buses. When the rotational speed of tires with low engine power is significantly higher than free-rotating tires, the road is likely to be slippery. (Tergujeff et al. 2014) In addition to slipperiness and road weather conditions, the system can be used to detect road structure condition, such as potholes. The system is suitable for both passenger and heavy traffic vehicles. Figure 2 presents the operational principle of the system.

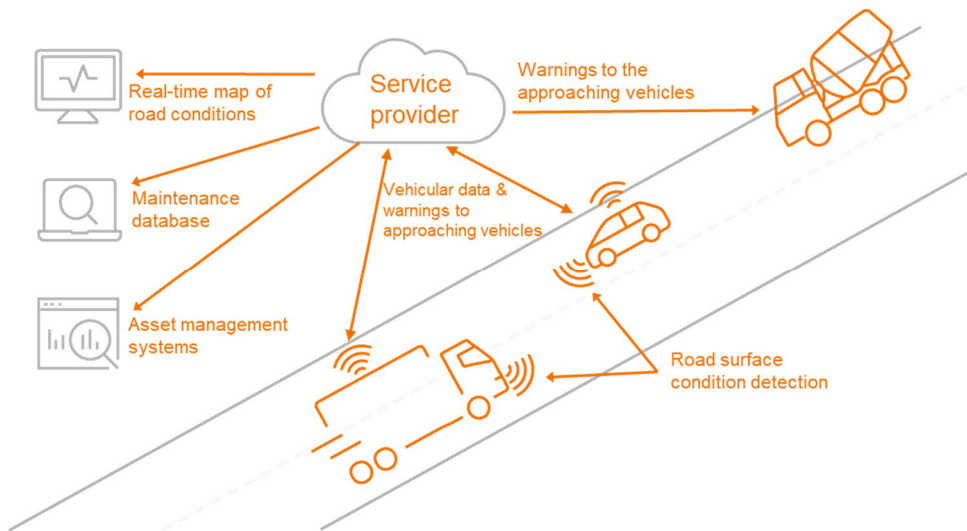


Figure 2. Vehicular detection technology in operation (modified from Tergujeff et al. 2014).

The advantages of the method are low unit costs and automation. The driver is not required to take any measures with regard to the measurement. In addition, variable costs of the system are low. However, to make reliable conclusions about road conditions, several vehicle observations are needed in the same region (Malmivuo 2016). Also, when considering winter road maintenance, observations are needed around the clock and on every day of the week (Lusikka 2018).

In this study, costs of the system are estimated using information provided by the technology provider. Costs are compared in two different scenarios:

1. The first scenario involves the vehicle fleet of Finnish postal services (Posti Group Oyj)
2. The other scenario involves all heavy traffic vehicles registered in use in Finland.

These fleets were selected, because it was desirable to discover differences between limited, highly operated system and very vast system with highly operated vehicles. Information about Posti Group's fleet was gathered through group interview, while information about all heavy traffic vehicles was collected through literature review.

Costs are calculated so that the system is in use year-round as the technology can be used to monitor both road weather and condition information, and pavement condition. Technology is considered to be offered as a service and it is scalable, meaning that costs are depended on the number of vehicles connected.

Geographically, state-owned and municipality road networks, total of 104 000 kilometres, are observed. One third of traffic occurs on regional and connecting roads (65 000 kilometres) and two thirds on main roads and cities (39 000 kilometres). Part of the driving performance of observed fleets takes place outside the examined road network on private and forest roads of some 350 000 kilometres. The effect is not taken into account in this report.

3.1.1 Scenario 1 – Posti Group's fleet

According to the group interview, Posti Group's fleet consists of some 4000 vehicles that travel over 110 million kilometres annually, so on average each vehicle travels about 27 500 kilometres every year. Posti's vehicles travel all inhabited roads approximately five times per week.

On average, postal vehicles travel every kilometre of the observed road network some 1058 times annually, which means that every kilometre is travelled 2.9 times per day and thus about every 8 hours. This is the frequency of measurements in Scenario 1.

Cost of the system of this size are 36 euros per month per vehicle, so in total the system for the fleet costs around 1.73 million euros annually. Costs of the system are summed in Table 1.

Table 1. Costs in Scenario 1.

Costs of the scenario 1	Number of units in the system	Per vehicle (€/kk)	Per vehicle/year (€/a)	Total (€/a)
Equipment etc.	4000	24	288	1 152 000
Telecommunications	4000	12	144	576 000
Total	4000	36	432	1 728 000

3.1.2 Scenario 2 – all registered heavy vehicles

According to Traficom (2019), there were some 108 000 heavy traffic vehicles (trucks and buses) registered to use in 2018. With those vehicles, approximately 1.9 billion kilometres were travelled (Tilastokeskus 2019), so on average each vehicle travels about 17 600 kilometres per year.

On average, vehicles of scenario 2 travel every kilometre of the observed road network some 18 270 times annually, which means that every kilometre is travelled 50.1 times per day and thus about every half an hour. This is the frequency of measurements in Scenario 2.

Costs for the system of this size are 18 euros per month per vehicle, so the total system costs are 23.33 million euros annually. Costs of the system are summed in Table 2.

Table 2. Costs in Scenario 2.

Costs of the scenario 2	Number of units in the system	Per vehicle (€/kk)	Per vehicle/year (€/a)	Total €/a
Equipment etc.	108 000	14	168	18 144 000
Telecommunications	108 000	4	48	5 184 000
Total	108 000	18	216	23 328 000

3.1.3 Comparison of the Scenarios

The estimation does not take into account true driven routes of vehicles, but is based on average values that can be counted with available figures.

Scenario 2 would have approximately 17.26 times better coverage than Scenario 1, but would also cost about 13.5 times as much as system of Scenario 1. In addition, with vehicles in Scenario 1, the annual driving performance per vehicle is 56% higher than vehicles of Scenario 2. If the better driving performance would be directly degrading in comparison, Scenario 2 would cost some 21 times more than Scenario 1. However, previous studies show that frequency of measurements should be from two minutes to two hours, depending on the purpose of use (Malmivuo 2016, Lusikka 2018). Thus, the average measurement frequency of the Scenario 1 would not be enough, but frequency of Scenario 2 would be highly satisfying. That being said, it is very probable that Scenario 1 would be sufficient to provide a view of the situation on main roads and cities, where most of the driving performance takes place in reality.

Therefore, closer to actual situation would be to consider only the roads with busy traffic. This comparison is presented in Table 3 by hypothesizing that two thirds of traffic (Whilman 2019) occurs on the main roads and streets (39 000 kilometres). From the Table 3, it can be seen that on busy roads frequency of measurements are clearly shorter.

Table 3. Costs of Scenarios 1 and 2 on roads with busy traffic.

Variable/Scenario	Scenario 1 (busy traffic)	Scenario 2 (busy traffic)
Units in the system	2666	72000
Cost of the system M€/a	1.15	15.55
Road measurement coverage	73.33 million km	1.267 billion km
Frequency of measurements (a)	1880	32478
Frequency of measurements (d)	5.2	89
Frequency of measurements (h)	4.6	0.25

It is advisable to choose vehicles with the highest possible driving performance to be used in the system. The average route of vehicles should also be taken into account in order to obtain geographically and timely comprehensive information relevant to the need of winter road maintenance, complementing the information available from fixed road weather stations. No significant conclusions can be drawn from the observations of a single vehicle, but observations from several vehicles can be used to estimate road weather and conditions (Malmivuo 2016), so the observation fleet should be selected carefully. It is very probable that the best coverage can be achieved by selecting the used vehicles by driving performance, route and time of day.

4. What Can Be Achieved With New Technology: A Benefit Analysis

Key focus of this study is benefits that can be realised in and through winter road maintenance, but other expected benefits are considered also as the technology can be used to detect, measure and analyse other attributes apart from friction values. In addition, known costs are visited and compared to expected benefits.

4.1 Societal damages

Societal damage costs caused by transport were approximately 2.7 billion euros in 2018. Road transport emissions and accidents cause 95 % of those costs. Emissions of road transport cause damage costs around 500 million every year, while accidents cost every year 2.2 billion euros for society, which is around 0.8% of Finnish Gross Domestic Product. (Liikennejärjestelmä.fi 2019B) Thus, road transport accident damage costs are significant expense.

Accident costs can be divided in internal and external costs. Material damage is an internal cost in one way or another because provision has been made for it, e.g. by insuring. External accident costs include alert and authority costs, production losses, and human well-being. Approximately 20 % of the accident costs are external. (Saarinen et al. 2014)

According to Saarinen et al. (2014), as a result of weather and road condition information, motorists primarily change time to safety. They argue that because of this in socio-economic point of view, total benefit does not change, but reduction of traffic accident costs goes in compensating disadvantages of increasing time costs. It is said that motorists do not take into account external accident costs in their choices. Thus, it is argued that only external costs of traffic accidents should be taken into account as a societal benefit. (Saarinen et al. 2014)

According to Liikennevirasto (2018), weather and road condition information reduces external costs of traffic accidents by 4.6 to 9.2 million euros per year. The estimate is probably based on the report by Saarinen et al. (2014). They argue that the impact of weather and road accident costs can be calculated by multiplying external traffic accident costs by 1-2%, which is based on the report of Hautala & Leviäkangas (2007), who state that traditional weather information services reduce amount of injuries by 1-2% and advanced information services by 2-4%.

Furthermore, Hautala & Leviäkangas (2007) have estimated that societal benefits of reduced accidents is 15.7 to 31.6 million euros, while Nurmi et al. (2013) have estimated safety impact to be 36.8 million euros. Estimate of Saarinen et al. (2014) diverge from these, because they only account the external costs. They reason that in this way, costs of protracted travel time are taken into account.

Besides the accident costs, road weather and condition information can be used in quality monitoring. By using vast amount of data, it is possible to monitor the quality more closely, and thus gain better quality-cost ratio. In addition, if quality of

winter road maintenance can be scaled up, road safety and travel times could be improved. (Lusikka 2018)

From a larger point of view, society could receive other benefits through new businesses. Vehicular data can be used to develop e.g. navigation services, route optimisation services or other traffic management services, such as Cooperative Awareness Messages (CAM) and Decentralized Environmental Notification Messages (DENM). By developing new businesses through vehicular data, export of goods could also be increased. Furthermore, future traffic systems such as platooning and autonomous vehicles will need accurate data about road conditions, so it could be sensible to develop and test vehicular road weather and condition sensing in advance. (Lusikka 2018)

Environmental benefits can also be gained through reducing the usage of salt and other harmful materials (Lusikka 2018).

4.2 Road maintenance and asset management

The baseline annual transport infrastructure maintenance costs yield to approximately 1.7 billion euros (Valtiovarainministeriö 2020). Of this sum, road maintenance and investments consume 825 million euros (Valtiovarainministeriö 2020), of which 70 % is the basic maintenance costs (578 million euros) (Autoalan Tiedotuskeskus 2020).

Assessing the condition of the asset (e.g., the road network) and determining the optimal investment for maintenance, upkeep, upgrades, and full renewal / replacement investment is a typical asset management problem for which there is not yet an ideal solution. This is not a problem only in road infrastructure asset management, but affects other immovable assets that require management over life-cycle (Di Sivo & Ladiana 2011, Keizer et al. 2017, Leviäkangas et al. 2019). There is abundantly literature (including international guidelines) that has shown how different deterioration models and life-cycle approaches can be used in financial management and asset valuation (CPA 2013, European Union Road Federation 2013, OECD 2001, OECD & ITF 2013).

New technologies (e.g. wireless sensors, networks, ground radars) offer new opportunities for infrastructure asset management (Fontul et al. 2016, Hodge et al. 2015). Proactive asset management using e.g. mass data is a new concept that can enable more efficient management of infrastructure assets. New technologies use longitudinal data or mass data. The large amount of data collected over a longer period of time allows the development of new monitoring concepts. (Känsälä et al. 2017)

Repeated or continuous measurements would allow analysis of the data, as individual measurement errors have less impact on the overall accuracy and reliability of observations. In order to reap the full benefits of the new mass data, more intelligent asset management systems must be developed. An intelligent asset manage-

ment system would allow continuous monitoring of the condition of the infrastructure, detect emerging trends of deterioration and condition attributes, and ultimately result in cost and life-cycle savings. (Känsälä et al. 2017)

However, the tools and practices used to manage assets efficiently and sustainably are often simplified, because they focus only on specific parts of the asset or certain components of the asset. One reason for this unsatisfactory situation is the lack or incompleteness of data (Crist et al. 2013). In addition, new technical and financial assessment tools are needed to translate the data into optimal road maintenance decisions.

One example of new type asset management tool is tested in Finland. It was shown that with the help of more detailed data and pavement condition information, savings of 50 to 100 million euros (12-30% of total pavement maintenance costs) can be achieved annually in road maintenance in Finland (Väylävirasto 2018, Road-scanners Oy 2020).

4.3 Winter road maintenance

On the state-owned road network, winter road maintenance operations cost approximately 120 million euros per year for state authorities. About 40% of the costs fall upon main road network, and rest to regional and connecting roads. Sixty per cent-ages of the maintenance costs are caused by snow removal and surface flattening operations, while forty percentages go toward de-icing operations. Costs of de-icing operations are growing in relation to snow removal costs. (Liikennevirasto 2018)

State authorities sanction contractors annually roughly quarter million euros for insufficient winter road maintenance quality on state-owned road network (Malmivuo 2010). If contractors have more accurate information available, it is possible for them to provide better maintenance services without significant cost increase. On the other hand, quality monitoring (by independent consultants) costs around 200 000 euros annually for state authorities (Malmivuo 2010). With new monitoring systems, it is possible to improve quality-monitoring processes. In addition, with continuous measurements with commercial vehicles, homogeneity of maintenance in different contract areas can be monitored (Lusikka 2018).

In addition to state authorities, municipalities use significant amounts of money to winter road maintenance. For example, city of Helsinki used 24 million euros in 2019 (Pölkki 2019), city of Tampere used 5 million euros in 2016 (Rissanen & Häkkinen 2017), and the municipality of Kirkkonummi used 1.4 million euros in 2019 (Kirkkonummen Sanomat 2019) to maintain roads in winter time.

According to Suomen Kuntaliitto (2008), Finnish municipalities use around 400 million euros to road maintenance and 25% of their road maintenance budget is used to winter road maintenance. Thus, it could be estimated that all Finnish municipalities use in total around 100 million euros annually to winter road maintenance. Hence, it can be evaluated that winter road maintenance costs of state and municipalities are in total 220 million euros.

Information from fixed road weather stations reduces winter road maintenance costs approximately five to ten percentages (Boselly 2001). With more accurate road weather and condition information, it is possible to optimise winter road maintenance further and ease the decision-making processes. For example, better weather forecasts can improve optimisation of winter road maintenance up to six percentages (Fu et al. 2009). With more accurate information it is possible to select right measures and allocate resources timely.

With road weather and condition data from vehicular observations, it is possible to reduce five to fifteen percentages of machine hours and materials (Odelius et al. 2018). By using dynamic methods, benefits can be over fifteen percentages (Odelius et al. 2018). Benefits gained through machine and material savings can reduce the total cost of contracts. Thus, it is possible that savings in winter road maintenance operations can result in lowering the total costs of road management.

In previous study by Pilli-Sihvola et al. (2012), it was calculated that weather services provide savings in salt usage up to 400 000 euros per year in Finnish public roads. Furthermore, savings in contractual penalties and personnel costs can be up to 2.2 million euros. (Pilli-Sihvola et al. 2012)

4.4 Road users and logistics companies

Roads with low traffic are those that are usually in poor condition. For the time being, the greatest importance of the condition of the low-traffic road network is focused on the costs and opportunities for wood procurement in the forest industry (Rantala et al. 2004). Frost heaves increase logistic costs up to 100 million euros as some roads are unavailable for heavy traffic and shipments are delayed. In addition, damages on the road surface can cause harm to transport equipment (Finnish Forest Industries 2011, Rantala et al. 2004). Therefore, road surface condition can affect to life-cycle costs of vehicles. For example in U.S., pothole damage costs drivers around three billion dollars annually (AAA Oregon/Idaho 2016).

Inefficiency of commercial transportation is extremely expensive (Lusikka 2018). Thus, road weather and condition information can be very valuable for road users and companies. Value can be realised through enhancing operations, improved reliability or savings in costs. For example, logistics companies can use information in route optimisation and scheduling. In addition, information can be used to raise awareness of drivers and to determine the target speed of delivery. Raising awareness of drivers could result in reduction of accidents, as the information has an effect to traffic behaviour and choices regarding the characteristics of the journey (duration, accident risk, comfortability). (Saarinen et al. 2014)

The use of road weather and condition information does not affect the existence of connections. Reporting of delays due to weather increases the expected value of transport time, which is a negative effect. Predictability is most affected by adding transport equipment to the distribution head during poor conditions. Route selection can also have a negative effect on travel time but reducing the risk of an accident

or vehicle being stuck improves cargo delivery and safety. Notice of a delay in advance potentially reduces the end customer's variable costs, but also contains a risk of lower customer satisfaction. Most importantly, road weather information improves the accuracy of providing for changes and thus reduces the cost. (Saarinen et al. 2014)

In transport companies, obtaining road weather and condition information has a particular effect on maintaining customer satisfaction and minimizing accident risks. Road condition information improves the conditions for developing transport management. The costs of accidents are significant for a company, even if no personal injuries occur. Accidents can cause indirect costs to the customer company in the event of a delay in delivery. In public transport and taxis, road information has a particular impact on safety and travel comfort. (Saarinen et al. 2014)

According to previous studies, the practice in transport companies is for a driver to call their company's transport management when they notice an unexpected weather risk. However, road weather monitoring is not part of anyone's job description, so there is a need for automated warning services in professional transport. Actively provided weather information improves the awareness of transport management and drivers about the road conditions. Thus, transport companies could potentially be willing to pay for automated services. (Saarinen et al. 2014)

4.5 Summary

Professional motorists need exact, targeted and automated warnings about road weather and conditions (Saarinen et al.). To provide such warnings, accurate data is needed. Interviews of previous studies (Lusikka 2018 and Saarinen et al. 2014) show that there is shortage of geographically accurate and non-delayed warning services. From the social economy point of view, it would be justified to increase resources to improve the quality of up-to-date road weather and condition information, and to increase the accessibility of services (Saarinen et al. 2014).

There are many benefits in road network management that can be achieved through data gathering, and with proper tools and methods to interpret the collected data. Some estimations were presented in previous chapters of figures that could be potential benefits of vehicular data. These annual benefit estimations are concluded in Appendix A and summarised in Table 4. Benefits of municipalities are estimated by proportioning them to the maintenance costs of state authorities. Furthermore, reduction of societal damage is based on assumption that vehicular data would have similar effect than current road weather information systems. Other savings are calculated by using percentages and figures from previous studies and pilots.

Table 4. Summary of annual benefits potentially achieved through vehicular data collection.

Winter road maintenance	Savings
Reduction of societal damage	Per year
Minimum	4 400 000.00 €
Maximum	88 000 000.00 €
5 % of machine hours and materials	
<i>e.g. amount of machine hours 60 000 hours, 64 eur/h and salt 30 eur/ton</i>	522 000.00 €
>15% of machine hours and materials	
<i>e.g. amount of machine hours 60 000 hours, 64 eur/h and salt 100 eur/ton</i>	3 876 000.00 €
Road infrastructure asset management	
Maintenance of pavements	
Minimum	50 000 000.00 €
Maximum	100 000 000.00 €

From the Table 4 it can be seen that societal damage costs could be potentially reduced at least 4.4 million and possibly as much as 88 million euros. From machine and materials usage, it is possible to save at least five hundred thousand euros and possibly over 3.8 million euros. Furthermore, in pavement maintenance, savings could go up to 100 million euros annually. With these estimations, total savings could be from some 5 million to close to 200 million euros annually. Total savings could be even higher if road user savings (e.g. logistic costs, pothole damages) could be estimated more closely. Annual ratio of benefits and costs is described in Figure 3.

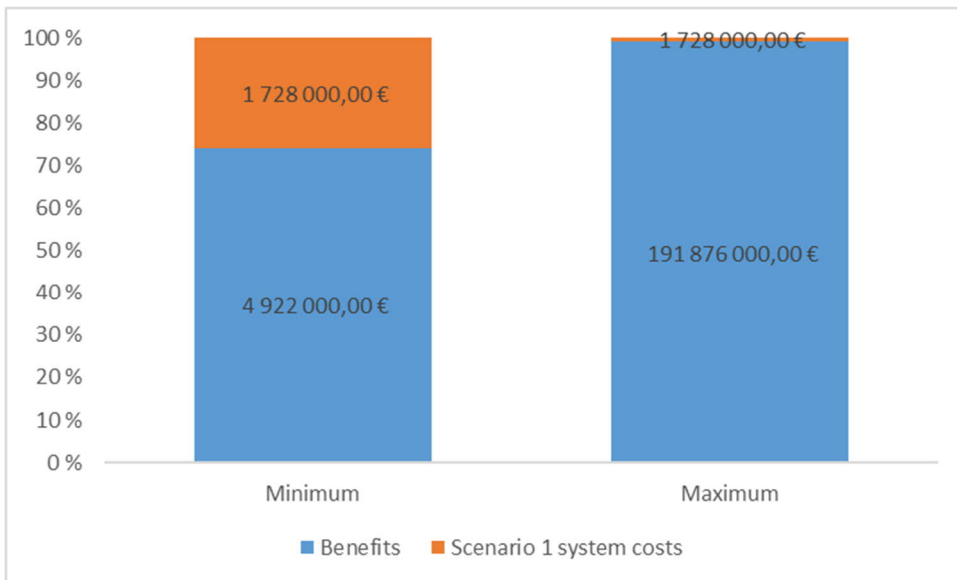


Figure 3. Annual ratio of benefits and costs (Scenario 1 costs).

There is vast potential in new data gathering and analysing methods, but they have to be tested and implemented to realise the true benefits. The role of obtaining information is well suited to the road authority (e.g. the requirements of the ITS Directive and current practice) (Saarinen et al. 2014). The Road Authority has transferred traffic management to a new state-owned company (Traffic Management Finland Group), so the role of acquiring information is also suitable for them. There might be other potential customers for data also, but the largest benefits lay in infrastructure asset management and accident reduction, so it is justified that public authorities would assume the role of obtaining vehicular information.

Furthermore, new and further processed data and information could open up new business opportunities. Transport companies might be interested in paying for the service if professional drivers can be given targeted warnings in vehicles. Also, insurance companies can distribute road weather and condition information to their customers and gain mediation in reduction in payment of indemnities (Lusikka 2018). Weather service providers could use the information to produce more accurate forecasts (Lusikka 2018). Other potential customers can also be found through market research, but more importantly, it is possible for road users to gain multiple benefits, such as increased safety, comfortability and reliability.

New technology and service providers also changes the Finnish road maintenance business ecosystem. Vehicular data providers are described in Figure 4 as part of the maintenance business ecosystem, which was described in Chapter 2.2. New main actor roles are framed with red colour and new relations between actors are highlighted with green arrows.

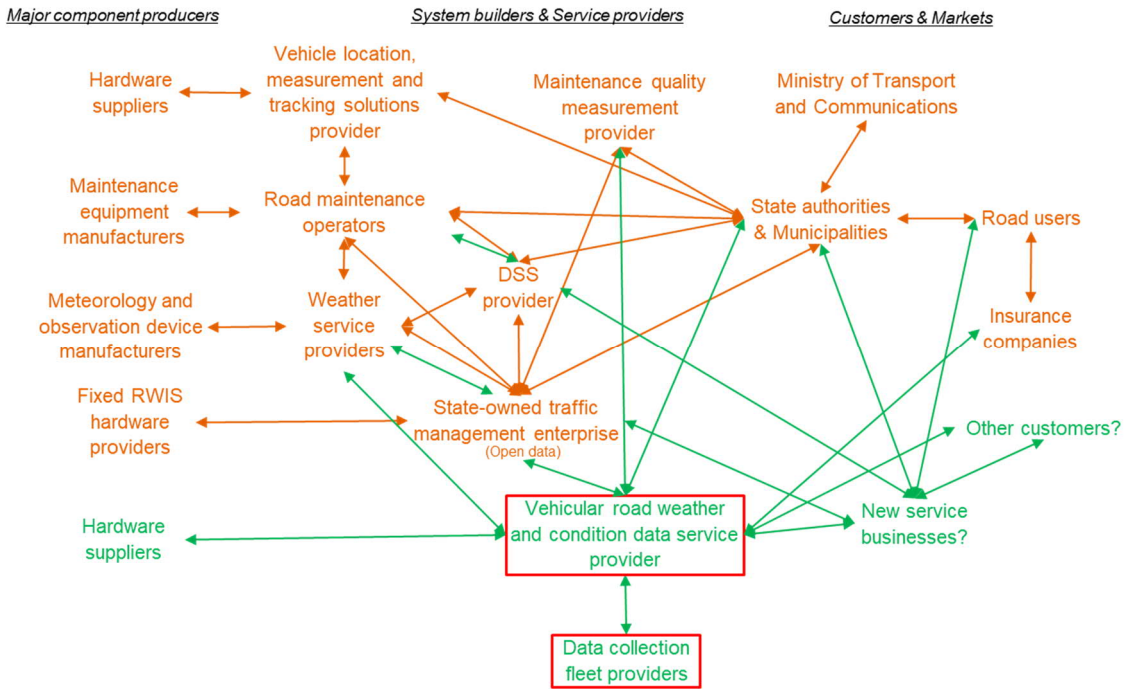


Figure 4. Finnish road maintenance business ecosystem complemented with vehicular data providers.

5. Conclusion and Discussion

To conclude the benefit analysis, a system with 4000 vehicles would cost approximately 1.7 million euros annually and the fleet would probably be large enough to provide situational outlook on main roads and streets for winter road maintenance needs. Cost of the system is low in comparison to potential benefits that could be achieved on multiple fronts. Highest potential is in asset management, where 100 million euros could be saved only in pavement maintenance. Second highest potential is in accident costs that could be achieved through advanced information and decision support systems in wintertime. Total savings of a year-round system could be close to 200 million euros annually. However, the new data alone is not enough, but methods, information and decision support systems need also be developed so that the full potential of the data can be reached both in winter road maintenance and whole infrastructure asset management.

A more detailed analysis would require data on the time-utilization of the fleet, i.e. what percentage of vehicles are in traffic on different days of the week and at what time of day, and what percentage of driving performance takes place on the road network for which data is to be collected. In conclusion, it is very probable that the best coverage can be achieved by using multiple fleet providers and selecting the used vehicles by driving performance, route and time of day.

As stated, system with 4000 vehicles would cost annually approximately 1.7 million euros and system with 108 000 vehicles some 23.3 million. In comparison, Sweden has implemented a similar test system (complemented with optical road surface sensors) of 200 vehicles for years 2018 to 2021. System cost is estimated to be around 1.57 million euros for the three-year period (European Union 2017), so annual cost is close to 500 000 euros. Therefore, when considering fleets' size, road measurement coverage and system costs, proposed system of 4000 vehicles could be more cost-effective than the one implemented in Sweden.

This analysis focused only on Finnish data and context. Taking a wider view, for example in European Union, there is over 5.5 million kilometres of roads and the road network is valued at around 8 000 billion euros. Benefits that can be achieved globally are quite substantial. For example in USA, about 850 million euros are used in de-icing operations (NBC Universal 2015). Savings that could be achieved with vehicular road weather and condition data are about 5-15% of USA's de-icing budget, which could result in savings of 43-130 million euros. The whole winter road maintenance budget in USA is over two billion euros (NBC Universal 2015), so potential savings are much higher than in Finland.

Besides the monetary savings, in EU, the goal is to have near zero deaths in traffic accidents by 2050. To achieve this goal, it is important to take all measures possible into account. Regarding the road condition and weather information, there are already requirements in ITS-directive for member countries to take action on. Among other things, the directive obligates authorities to offer information to citizens without charge about surprising slipperiness, poor visibility or otherwise unusual

weather and road conditions (Saarinen et al. 2014). Finnish authorities already distribute this type of information for citizens through online portal called 'Traffic situation service'. The service uses a map to visualize traffic related data collected by government owned enterprise Traffic Management Finland Group (Traffic Management Finland Group 2020). Thus, the road condition and weather data collection and distribution is not new service anymore, but now it is more a question of what is optimal system structure (e.g. number of fixed road weather stations, number of vehicles and relation of fixed and vehicular system sizes) and what additional systems or services (e.g. automatic warnings for road users) are needed to realise the most benefits. Therefore, to achieve more benefits in future, supporting systems need to be developed round the condition and weather data. Systems that can interpret the data correctly and automatically, and even simulate and forecast changes in road weather or road structure condition, are needed to gain full benefits of the collected data.

Thus, for further research, it is suggested to study proactive asset management and develop models and supporting systems that are needed to translate and enhance the vehicular data into a format that can be fully utilised in road maintenance and asset management. As part of this research, life-cycle of road structures and their condition modelling should be studied. In addition, road user costs (e.g. damages to vehicles, delays) caused by road structure condition (e.g. by potholes) and road weather conditions should be researched more closely to find out potential savings that could be achieved with improved road asset management. Furthermore, as autonomous vehicles are developed further and predicted to become more common, it should be researched, what type of road condition data is needed for autonomous vehicles to function correctly (e.g. visibility and condition of lane markings). It should be noted that collecting road condition data with other vehicles could possibly enhance the operation of autonomous vehicles and thus speed up the deployment of autonomous vehicles.

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Appendix A: Annual benefits potentially achieved through vehicular data collection.

Winter road maintenance	Savings
Reduction of societal damage	Per year
1 % of external accident costs	4 400 000.00 €
4 % of external accident costs	17 600 000.00 €
1 % of total accident costs	22 000 000.00 €
2 % of total accident costs	44 000 000.00 €
4 % of total accident costs	88 000 000.00 €
Range of previous studies, min.	4 600 000.00 €
Range of previous studies, max.	36 800 000.00 €
Chemical and machine hour savings	
5 % of machine hours	
<i>e.g. amount of machine hours 60 000 hours, 64 eur/h</i>	192 000.00 €
5 % of materials	
State authorities	
Total amount of salt used, tons	120000
5 % of salt, tons	6000
Salt 30 eur/ton	180 000.00 €
Salt 100 eur/ton	600 000.00 €
<i>Potassium formate 300 eur/ton</i>	<i>1 800 000.00 €</i>
Municipalities (proportioned to state costs)	
Total amount of salt used, tons	100000
5 % of salt, tons	5000
Salt 30 eur/ton	150 000.00 €
Salt 100 eur/ton	500 000.00 €
<i>Potassium formate 300 eur/ton</i>	<i>1 500 000.00 €</i>
>15% of machine hours	
<i>e.g. amount of machine hours 60 000 hours, 64 eur/h</i>	576 000.00 €
>15% of materials	
State authorities	

Total amount of salt used, tons	120000
15 % of salt, tons	18000
Salt 30 eur/ton	540 000.00 €
Salt 100 eur/ton	1 800 000.00 €
<i>Potassium formate 300 eur/ton</i>	<i>5 400 000.00 €</i>
Municipalities (proportioned to state costs)	
Total amount of salt used, tons	100000
15 % of salt, tons	15000
Salt 30 eur/ton	450 000.00 €
Salt 100 eur/ton	1 500 000.00 €
<i>Potassium formate 300 eur/ton</i>	<i>4 500 000.00 €</i>
Road infrastructure asset management	
Maintenance of pavements	
min. /year	50 000 000.00 €
max. /year	100 000 000.00 €

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Road condition detection technology

A benefit analysis

This research report describes the results of a benefit analysis on road condition detection technology. Research is limited to Finnish road management. This study focuses on benefits that can be achieved through monitoring road weather, road conditions and road infrastructure conditions with vehicle sensors. Study also presents costs of road transport infrastructure management and costs caused by adverse weather conditions and infrastructure conditions in road transport sector. System costs and characteristics of the case technology are compared with two different scenarios with different vehicle fleet sizes. Multiple benefits can be achieved with new data gathered with vehicles. Extensive savings can be realised through proactive winter road maintenance and reduction of road accidents. Highest savings potential is achievable in road infrastructure asset management. However, to reach full potential of the vehicular data, extensive further research and development of supporting systems, simulations and modelling is required.

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