

Increasing the economic sustainability of winter road maintenance processes through the use of technological innovation

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Abstract. Effective road management requires the constant generation of new approaches. It is our duty to focus on improving all technical and process areas of road management, especially in the context of environmental and economic sustainability. Otherwise, we will face the fact that neglected parts will slow down the progress of the whole system. This will be reflected in a reduction in the quality of the infrastructure and increased costs over its life cycle. The approach must be systematic and therefore it is necessary to address the elements that, at first sight, do not have a major impact on other elements contained in the whole structure of road infrastructure management. One of the key areas for improvement is the process of winter road maintenance. It must reflect global climate change, new approaches to the cost-effectiveness of finances spent by users and road managers and, last but not least, the need for modern and safe mobility of goods and people. Advanced technologies such as automated anti-icing spraying systems or predictive monitoring of road structure temperature development are one example. However, these innovations bring not only positive but also negative effects.

1. Introduction

The sustainability of road infrastructure must be seen as a comprehensive concept highlighted by the need to apply a multidisciplinary process. It is relatively easy to define, but very difficult to fill. And it is even more difficult to determine the extent to which the implemented solutions have contributed to progress in ensuring sustainability. Within standardly applied schemes, it is known that it is necessary to look for compromise solutions to a large extent. Solutions that, by interconnection, lead to specific environmental, economic and social effects. However, this approach is still exposed to new impetus. These need to be seen as a demand from road users as well as society as a whole, linked to natural technological progress, a more sensitive approach to the environment and an overall view of the future of mobility. On this basis, it will be necessary not only to deal with changes in the view of the concept of sustainability, but also to actively address the possibilities of implementing new approaches and elements that will have to be introduced into the entire road infrastructure environment.

One of the areas that is under great pressure in terms of sustainability is the technical maintenance of the road structure. Routine maintenance and repair processes still represent a large amount of expenditure within the communications managers' budget. It is no different in the conditions of the

Slovak Republic either. However, despite the growth trend in maintenance expenditure, it is not possible to call this state of road infrastructure satisfactory. Occupying the last ranks in the reports below should not be considered an acceptable state.

Table 1. Quality of roads – years 2018 and 2017.^a

Country	2018		2017	
	Overall ranking	Score	Overall ranking	Score
Netherland	1	6.18	1	6.14
Germany	9	5.46	5	5.51
Poland	21	4.14	22	4.10
Slovakia	22	3.96	23	3.99
Czech republic	23	3.95	24	3.95
Hungary	24	3.89	21	4.15
Malta	27	3.24	26	3.23
Romania	28	2.96	28	2.70
EU		4.78		4.76

^aSource: World Economic Forum Global Competitiveness Report. Rating based on a survey by the World Economic Forum, using a scale from 1 (extremely poor, among the worst in the world) to 7 (extremely good, among the best in the world). EU value is calculated as a simple average.

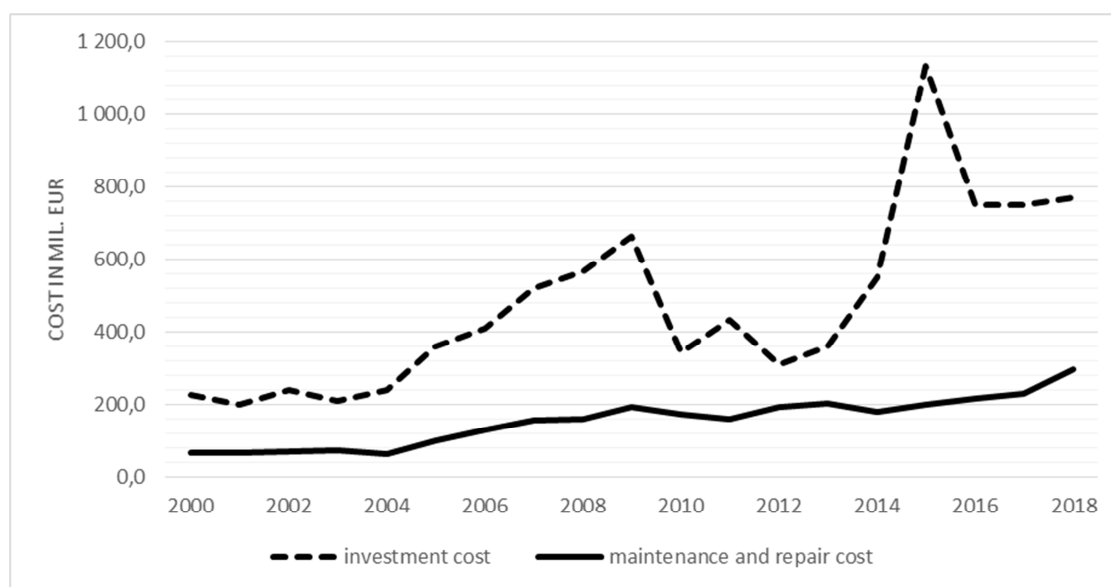


Figure 1. Investments and maintenance cost on road infrastructure in Slovak Republic (Source: own research from Statistical Office of the Slovak Republic data).

Table 2. Expenditures on road infrastructure maintenance (mil. EUR), current prices.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Cost per 1km (2008 -2017) EUR
CZ	611.3	578.3	669.8	569.7	570.7	513.1	587.1	684.4	767.3	721.3	11262.12
HU	444.2	454.0	328.6	256.5	295.8	370.2	272.8	282.2	292.6	369.4	10599.18
SR	161.2	192.4	174.7	159.6	192.6	203.6	181.2	201.0	215.0	229.5	10580.87

^aSource: own research from Statistical Office of the Slovak Republic and Eurostat data

2. Strategic overview about road sustainability and winter road maintenance

Models of road infrastructure sustainability are based on complexity. Strategies must think of all the elements that are present throughout the life cycle of the journey. The approach must be systematic, with the exception of the section on maintenance sustainability. Decision-making is carried out at the strategic, network and detailed project level. At the same time, louder tools are constantly emerging on the need to increase the rate and scope of innovation in individual parts of the model and its planning, decision-making and implementation processes. This is possible exclusively by incorporating new procedures and tools that emerge as suggestions from road users or road managers. However, it is not possible to forget about global demand either. These are mainly external factors, such as climate change or a changed approach to the value of money spent on the various phases of the communication life cycle. The common goal is to create an environment for transport that can be presented in the context of new platforms such as "Smart Cities", "Intelligent transport systems" or "Circular Economy". The space must have quite advanced technological elements that bring adaptive responses to changing climatic conditions. High emphasis must be placed on new, more environmentally friendly materials. Modern roads must include new infrastructural parts of the road, which e.g. they can actively redistribute traffic modes according to current needs (eg fast change of route for vehicles on a bicycle road).

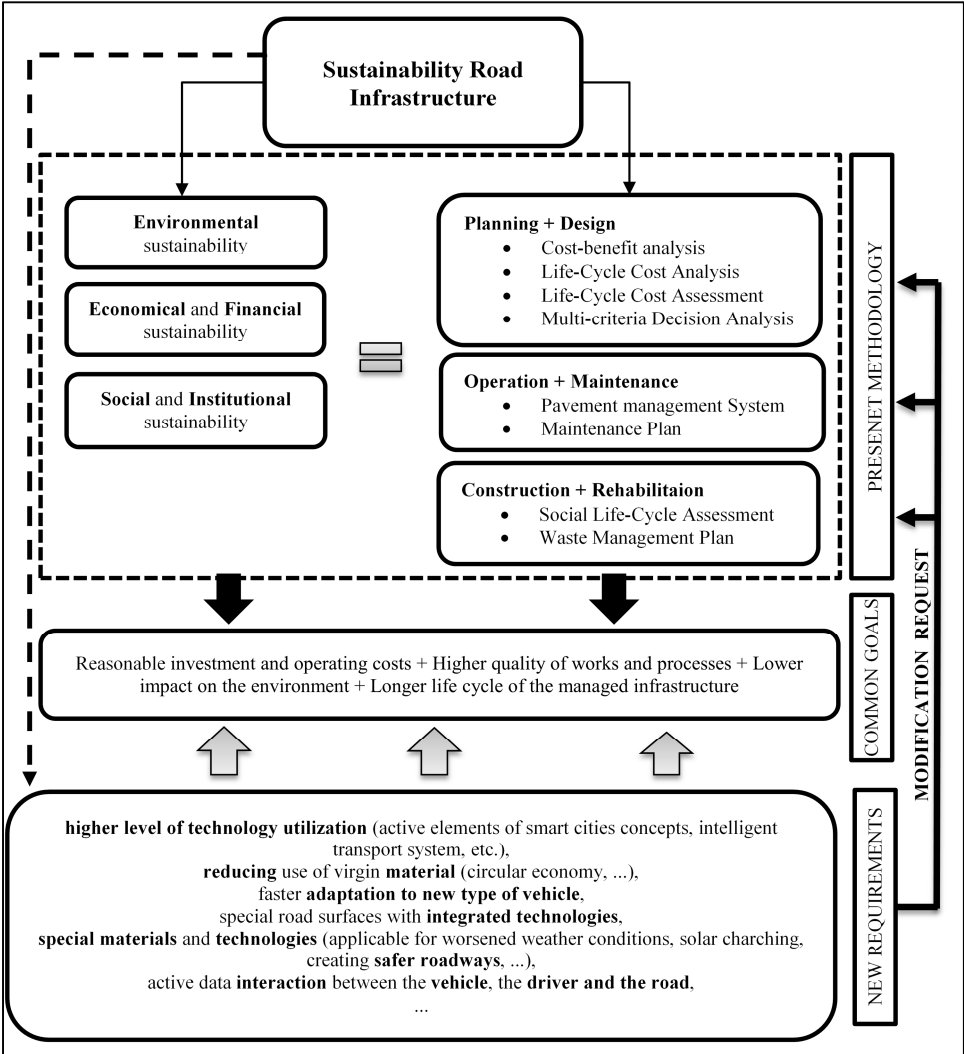


Figure 2. Simplified model of road management elements at context of sustainability (Source: own research).

Winter road maintenance (WRM) also has a place in sustainability models. Its quality, the way it is performed, is influenced by a considerable number of other factors within the sustainability model. The performance of winter road maintenance directly affects the technical condition of the road and the resulting service life, user satisfaction or the overall financial condition of administrators. In the next step, it is possible to present that the method of performing winter maintenance directly affects, of course, the costs associated with routine maintenance (road repairs). If winter maintenance is performed incorrectly, it can be expected that the quality of roads will decrease and investments in their repairs will increase in the short term.

Basically, it is possible to distinguish 4 main directions of WRM sustainability. They are technical, environmental, economic and procedural. It is appropriate if the individual directions go forward in parallel and in particular the trends are not preferred over the others. This is a prerequisite for ensuring the highest possible degree of sustainability in this area. The need to take economic sustainability into account is based primarily on two fundamental needs. The first is the cost-effectiveness of WRM performance. The second is the reduction of economic losses caused by the reduction of the road traffic (loss of travel time) and the reduction of the consequences of accidents caused by accidents in winter.

The performance of winter maintenance in Slovak conditions is demanding due to diverse geographical and climatic conditions. Similarly, it is possible to look at the economic side of the whole process. The table below shows the conditions from one of the Slovak self-governing regions. It shows the dependencies between the manifestations of the winter period and the performance in winter maintenance, including the financial expression.

Table 3. Costs and weather conditions one of the Slovak self-governing regions WRM^a.

Parameter	Year	19/20	18/19	17/18	16/17	15/16	14/15	13/14	12.13
Weather	number of ice days	17	26	23	52	21	13	16	16
	number of frost days	106	126	118	130	97	10	90	134
	number of precipitation days	106	96	110	102	99	89	79	133
	number of snow days	44	63	69	54	49	61	36	88
	number of maintenance service days	111	115	151	122	103	114	97	145
Maintenance volumes	plowing in km	20 111	47 952	84 185	47 836	35 929	30 079	19 989	99 524
	spreading in km	66 709	102 391	108 428	94 922	75 521	65 481	48 965	113 532
Costs	Total in mil. Eur	5	4	6	5	4	3	3	5
	cost per 1 km of maintained roads in Eur	2 386	2 279	2 903	2 549	2 006	1 816	1 479	2 494
	costs for 1 day of maintenance during the WRM period in Eur	30 039	28 964	36 928	32 639	25 470	23 061	18 784	31 167

^aSource: own research from Zilina Slovak self-governing regions data

Financing of the development and maintenance of road infrastructure is not only long-term insufficient in Slovak conditions. Underfunded maintenance costs lead to negative impacts on the overall state of the infrastructure in the future and at the same time generally worsen the users' view of the activities of the communications manager. It is similar in the context of winter road maintenance. It can also be seen from the example above that the economic complexity of the WRM process is a relatively difficult thing to predict and therefore it often reaches a critical level. Inadequate road maintenance in the winter not only results in increased accident rates, but also increases fuel consumption, devalues the value of the vehicle and makes transport more expensive [2]. For this reason, the overall context of winter maintenance is currently receiving new impetus associated with several development trends [3]. This is despite the fact that the expected costs of climate change will fall [1]. These are the most important factors highlighting the need for innovation. Climate change is causing significant year-on-year fluctuations in the economic demands of winter maintenance. The combination of climate change, winter road maintenance processes and the context of economic impacts is becoming increasingly intense. As also stated [5] in his study, when a temperature increase of 1 °C in the studied locality also has a very significant impact on the costs associated with WRM. He further estimates that if the long-term atmospheric temperature rises by 2.5 °C, winter maintenance will not be necessary at all. Warming is expected to reduce the number of frost days in the long term, which could not only reduce road maintenance costs but also reduce accidents by up to 50% [11]. Several studies, such as [8, 10] draw attention to the fact that it will gradually be necessary to actively adapt the performance of winter maintenance to the specific manifestations of climate change. Another important factor that supports changes in approach is the policy of a low-carbon future. Different approaches within the WRM (driver behavior, scope and type of maintenance, ...) also affect fuel consumption and emission load [12, 13]. It is safe to say that winter maintenance can absorb a large number of new approaches and solutions. These can not only directly improve the condition of the road in terms of accessibility, environmental protection, improving the economic efficiency of expenditure, but also bring effects to ensure a longer life of the road structure. From this point of view, it is mainly the need for more gentle winter maintenance in the context of its geographical addressability and the adequacy of the intervention. Modern approaches include advanced interconnections of standard logistics maintenance processes with decision algorithms and simulations [4]. Another innovative direction is the application of new chemical mixtures based on agro-materials [6], which are not only more environmentally friendly, but also have financial competitiveness compared to traditional materials. Great attention is also paid to such advanced influences as the dependence between the type of asphalt, the type of salt used and the nature of the weather [7]. Relatively new research directions include investigating the effects of WRM on the life of bridges [9], [17]. These contexts can then be translated into economic expressions within the total cost of road infrastructure maintenance.

3. Selected solutions supporting increasing the quality of winter maintenance performance

The strategic goal of the research activities at the University of Zilina is to bring innovative elements to the road infrastructure environment with its own partial activities. The area of winter road maintenance is no exception. The aim is to make it possible to increase the quality of winter maintenance and at the same time to contribute to a more efficient performance of road management assets based on less wear and tear of the road body structure due to the action of chemical mixtures. The research team focuses primarily on solutions that are applicable in the context of the future thinking of users and communication administrators. This means that the emphasis is on solutions based on smart cities (local application for specific problems, connection to complex technological systems for urban zone management) and the context of intelligent infrastructure. The aim of the research is to bring new ways that would help increase the effectiveness of the communication manager's intervention. Specifically, it is the geographical addressability of the intervention (perform maintenance only where necessary), optimize the time horizon of the intervention (reduce the volume

of preventive interventions) and eliminate risks in the most critical places by automating the intervention (maintenance of communication without intervention).

3.1 New sensors for road temperature detection and monitoring

Effective weather forecast in the context of ice forecasting is not possible without measuring the temperature of the road structure. These data then enter into the prepared prediction models associated with the estimation of the time of ice formation on the road. It is the verification of the degree of reliability of this method of temperature measurement that is the basic step for future activities associated with the construction of quality road meteorological systems. These consist in the creation of a unique prediction system, the task of which will be to predict the need for winter maintenance at a specific point in the road network.

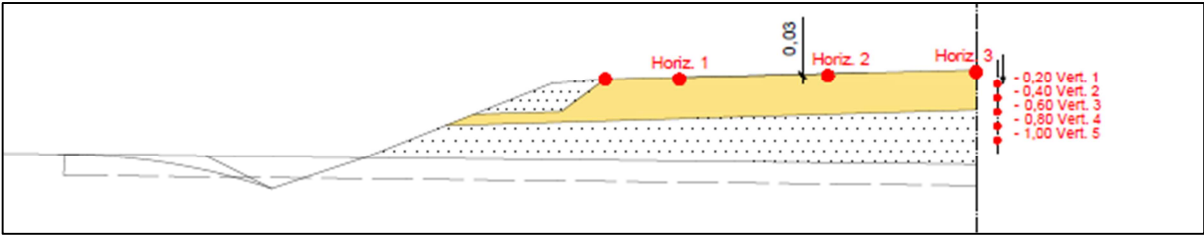


Figure 3. Scheme of installation of onw temperature sensors for weather prediction systems
^aSource: own graphics of construction solution.

It is a system of vertical and horizontal temperature sensors that are installed at different depths and distances within the road. Temperature sensors are designed to withstand not only the installation process, but also to be resistant to common right-hand pressures for a long time. Sensors are not installed in the context of measurements, which should monitor the development and behavior of the road structure in order to monitor the thermal mode of the road. They are installed in the context of the need to very sensitively monitor the development of that part of the road structure that directly affects the state of the road temperature on its surface. For this reason, the sensors used are also optimized for high temperature resolution up to 0.001 degrees Celsius.

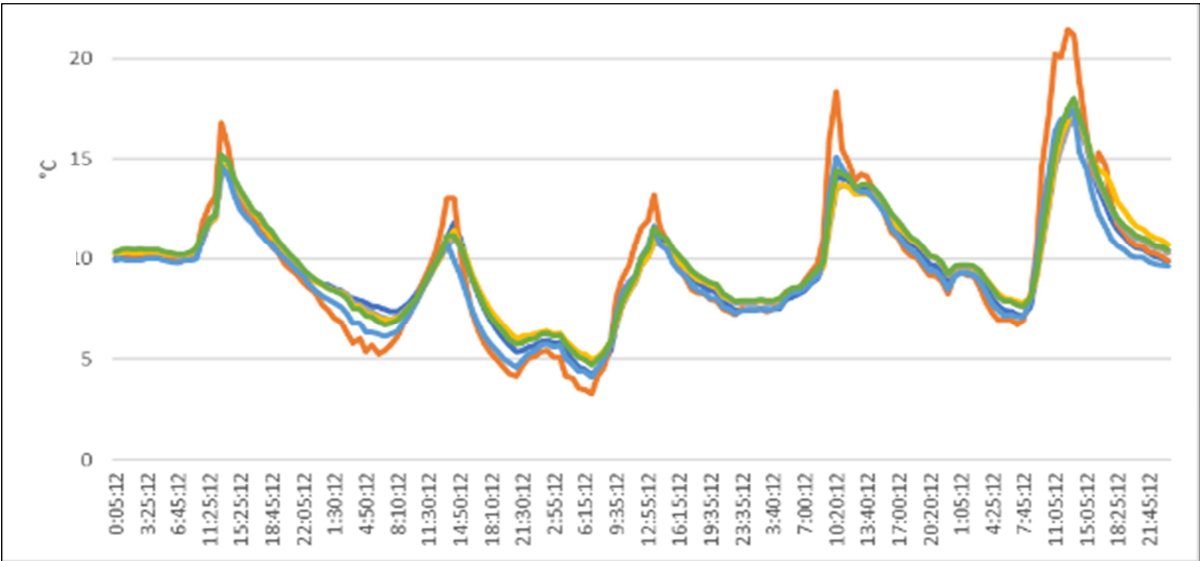


Figure 4. Overview of the sensitivity of sensors installed in the road to weather changes
^aSource: own research from University of Zilina data.

3.2 Autoamtized anti-icing spraying system

It is well known that increased slipperiness increases the risk of accidents. Deciding when and where to protect communication against the ice is based on meteorological measurements and prediction. However, these predictive models have some uncertainties. This undermines the effectiveness of administrators' intervention, which in turn translates into increased costs that may not be spent efficiently [16]. As stated in [14], data from meteorological stations, together with weather forecast models and data from meteorological radars and satellites, are processed, presented and used to predict the condition and temperature of the road surface. The result is information support for the right maintenance decision and for efficient and timely road care in winter. Gradually, however, there is a need to innovate older approaches that integrate not only meteorological conditions, traffic data, road surface condition or temperature [15]. It is necessary to gradually address the symptoms of risks associated with different situations of roads (sections with less sunlight, sections near reservoirs,...). It is also necessary to ask for new meteorological approaches that can be used to predict the occurrence of sudden weather conditions. The University of Zilina is developing a comprehensive system consisting of a new meteorological forecasting model, which will also be connected with a reaction system preventing the occurrence of negative situations on the road. One of these systems is an automated spraying system. These are not completely new in the world. However, they still cannot be considered perfect and must be constantly improved and tested. Their primary task is to prevent and reduce the formation of a layer of ice on the road surface at a critical time interval ending with the arrival of maintenance vehicles. It should be borne in mind that its purpose is not to remove thick layers of ice, to prevent the accumulation of a layer of snow on the road or to keep the road dry. It is understood as a supplement in the process of winter service, resp. winter maintenance in order to respond operatively to the possibility of reducing the operability and safety of a critical section of the road.



Figure 5. Automatized anti-icing spraying systems of University of Zilina. Source: authors' photos

The entire installation also includes a software application that not only informs the road administrator about the status of the road section, but also helps in deciding whether to start interventions or processes. The program allows you to manage a centralized early warning network in front of the ice through its own alert algorithm.

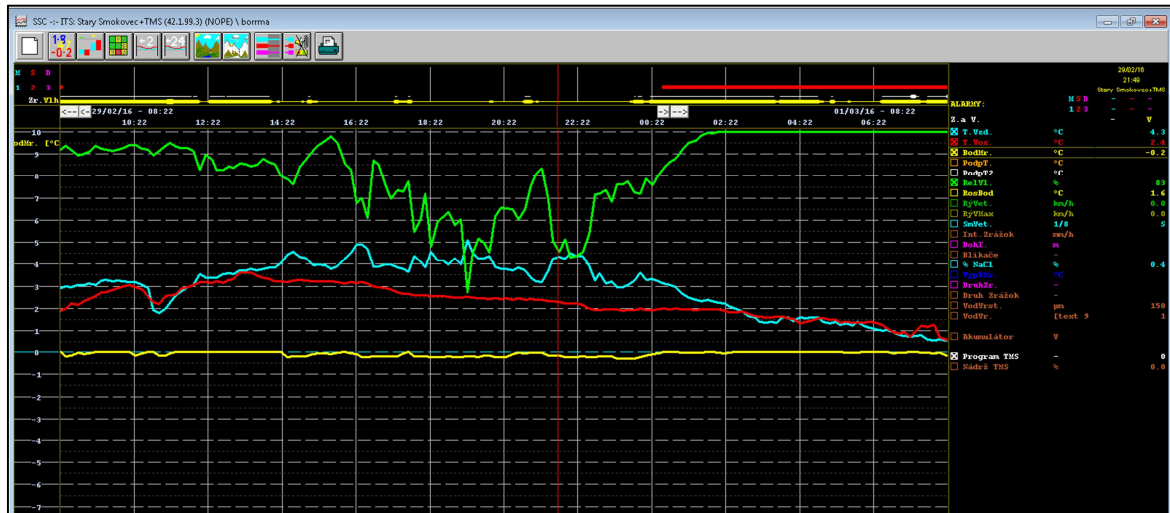


Figure 6. Software application as part of Automatized anti-icing spraying systems
Source: authors' photo

4. Economic benefit of technological innovations on the maintenance process

As mentioned in the introductory chapters, winter maintenance directly affects the overall economic condition of road maintenance. The common goal should be to optimize the technological background and processes in order to achieve the greatest possible economic, social benefits and benefits in the field of environmental protection. At this point, process and technological equipment innovations are needed. However, these not only generate benefits, but are also associated with certain costs. An overall comprehensive assessment of the impact of their implementation is relatively difficult to define. The whole process of winter maintenance creates a relatively large set of costs and benefits. These are also influenced by a wide range of factors. Factors are divided into uncontrollable (climatic soils) and controllable (WRM performance strategies, quality of technological equipment, scope of WRM, type of material used in relation to the environment, etc.). The overall approach to WRM then brings additional benefits. For safety, the environment, user costs and benefits (corrosion, travel time), costs associated with ensuring the quality of communication after winter maintenance.

The basic method can be presented as follows:

$$Q_{WRM} = Q_{WRMold} \cdot x \cdot k + Q_{WRMinn} \cdot x \cdot (1 - k) \quad (1)$$

Q_{WRM} - quality of winter road maintenance

Q_{WRMold} - quality of winter road maintenance - unchanged state

Q_{WRMinn} - quality of winter road maintenance – innovated parts

k - percentage share of original winter road maintenance processes from the total volume of WRM

This method is explicitly conducted in the context of professional estimation, which expresses how innovations (technological, process) affect the resulting quality of WRM. The second method is based on exactness and is based on the methodology of cost-benefit analysis. For our questions, it is possible to present the statement as follows through a modified NPV.

$$NPV_{WRM} = \sum_{i=1}^T \frac{CF_T}{(1+i)^T} - cost_{inn} \quad (2)$$

where

$cost_{inn}$ - innovation cost

T - time

i - discount rate

This method is relatively accurate, but only if the calculation is detailed and includes all the costs and benefits associated with implementing the innovation. The following table shows the impact of the above technological innovations on selected parts of winter road maintenance in simple terms positive/negative/neutral.

Table 4. Effect of technological innovation implementation to Winter Road Maintenance.^a

Parameters or Specifics	New sensors for road temperature detection and monitoring as part of complex alarm systems	Automatized antiicing spraying systems
Road Administrators' investment costs		
Costs of new technologies	<p>Negative</p> <ul style="list-style-type: none"> • new technologies represent additional investment costs, including cost for new staff • needs to have money for services and repair 	<p>Negative</p> <ul style="list-style-type: none"> • new technologies represent additional investment costs, including cost for new staff • needs to have money for services and repair
Road Administrators' operational costs		
Cost of sanding material and salt	<p>Positive</p> <ul style="list-style-type: none"> • if the Road Administrator does not know the detailed road surface temperature, it is necessary to take precautionary interventions. When using predictive technologies, he sees when and whether maintenance is necessary at all. 	<p>Positive</p> <ul style="list-style-type: none"> • in case of early intervention against the ice, it is possible to use less material. Ice is still very weak or is yet to form. <p>Negative</p> <ul style="list-style-type: none"> • necessary to have sufficient supplies of chemical mixtures at the place of installation of the technology, as well as clean water for cleaning the system
Costs of mechanism maintenance	<p>Positive</p> <ul style="list-style-type: none"> • lower volume of interventions, reduce the cost of maintenance vehicles 	<p>Positive</p> <ul style="list-style-type: none"> • lower volume of interventions, reduce the cost of maintenance vehicles <p>Negative</p> <ul style="list-style-type: none"> • there are costs associated with refilling chemical tanks
Staff costs	<p>Neutral</p> <ul style="list-style-type: none"> • Standard technological innovations bring savings in personnel costs. In this case, however, this does not apply due to the low scope of innovation on the road network. • every technology requires human supervision 	<p>Positive</p> <ul style="list-style-type: none"> • Standard technological innovations bring savings in personnel costs. In this case, however, this does not apply due to the low scope of innovation on the road network. • every technology requires human supervision
Road maintenance costs	<p>Positive</p> <ul style="list-style-type: none"> • Higher quality of winter maintenance combined with adequate salting contributes to lower damage to the structure of the road structure. From this it is possible to predict lower financial needs for repairs or cleaning of ditches from spreading material 	<p>Positive</p> <ul style="list-style-type: none"> • Higher quality of winter maintenance combined with adequate salting contributes to lower damage to the structure of the road structure. From this it is possible to predict lower financial needs for repairs or cleaning of ditches from spreading material

Environment quality		
Contamination of air, surrounding water, soil and vegetation	Positive	Neutral
	<ul style="list-style-type: none"> increasing the efficiency of road administrator interventions within the WRM reduces the volume of produced emissions of maintenance vehicles the reduced volume of chemicals used reduces the negative impact on the environment 	<ul style="list-style-type: none"> Due to the point technology, which solves only very risky sections of the road, the positives are only minimal from this point of view and it is rather possible to classify it as a neutral effect.
Selected user costs		
Travel time saving	Positive	Positive
	<ul style="list-style-type: none"> A road that is maintained according to the expected conditions is more comfortable than a road where maintenance work is only being carried out 	<ul style="list-style-type: none"> if the road administrator eliminates risk places on the road network (eg ascents, shaded places) and there are no delays in these parts
Safety	Positive	Positive
	<ul style="list-style-type: none"> the road manager can have information about the planned change of weather conditions and subsequently the conditions on the road surface - he can perform the intervention in advance and thus increase safety) 	<ul style="list-style-type: none"> the road administrator eliminates risk places on the road network (eg ascents, shaded places)
Corrosion of vehicles	Positive	Positive
	<ul style="list-style-type: none"> (Interventions are targeted and there is no unnecessary performance, the road is less exposed to chemicals, which subsequently degrade vehicles) 	<ul style="list-style-type: none"> (Interventions are targeted and there is no unnecessary performance, the road is less exposed to chemicals, which subsequently degrade vehicles)
Impact on the economy of the country and the region	Positive	Positive
	<ul style="list-style-type: none"> Higher quality of peoples and goods mobility 	<ul style="list-style-type: none"> Higher quality of peoples and goods mobility

^a Source:own research

5. Conclusions and future work

Road sustainability is a complicated model depending on a wide range of factors. At first glance, it may seem that the performance of winter maintenance only slightly affects its quality. However, in the context of climate change and the need for more efficient expenditure on road infrastructure management, it is necessary to consider introducing innovations in this area as well. The economic sustainability of WRM comes to the fore. Innovations that can improve meteorological forecasting models and action technology platforms for reducing road slip are one such tool. They not only have a positive effect on driving safety and the environment, but also contribute to increasing the economic sustainability of the WRM. Future challenges will include bringing exact approaches that can quantify this benefit. This step is necessary to allow administrators to compare the benefits of each innovation.

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References

- [1] Matthews L, Andrey J and Picketts I 2017 Planning for Winter Road Maintenance in the Context of Climate Change *Weather Climate And Society* **9** (3) pp 521-32, DOI: 10.1175/WCAS-D-16-0103.1
- [2] Ratkevicius T and Laurinavicius 2017 Assessment Model Of Levels For Winter Road, Maintenance, *Baltic J.l Of Road And Bridge Eng.* **12** (2) pp 127-34, DOI: 10.3846/bjrbe.2017.15
- [3] Pilli-Sihvola E, Aapaoja A, Leviakangas P, Kinnunen T, Hautala R and Takahashi N 2015 Evolving winter road maintenance ecosystems in Finland and Hokkaido *IET Intelligent Transport Systems* **9** (6) pp 633-38 (Japan) DOI: 10.1049/iet-its.2014.0220
- [4] Tang WJ, Zhang GH Liao MJ 2015 A Framework of Winter Road Maintenance Optimization, *11th Int. Conf. On Natural Computation* pp1057-61
- [5] Lorentzen T 2020 Climate change and winter road maintenance *Climatic Change* **161** (1) DOI: 10.1007/s10584-020-02662-0
- [6] Nazari MH, Shi XM 2019 Developing Renewable Agro-Based Anti-Icers for Sustainable Winter Road Maintenance Operations *J. of Materials in Civil Eng.* **31** (12) DOI: 10.1061/(ASCE)MT.1943-5533.0002963
- [7] Hossain SMK, Fu LP, Hosseini F, Muresan M, Donnelly T and Kabir S 2016 Optimum winter road maintenance: effect of pavement types on snow melting performance of road salts *Canadian J. Of Civil Eng.* **43** (9) pp 802-11, DOI: 10.1139/cjce-2016-0010
- [8] Venalainen A and Kangas M, 2003 Estimation of winter road maintenance costs using climate data *Meteorological Applications* **10** (1) pp 69-73 DOI: 10.1017/S1350482703005073
- [9] Stemberk P, da Silva WRL, Sykorova J and Bartova J 2013 Fuzzy modeling of combined effect of winter road maintenance and cyclic loading on concrete slab bridge *Advances In Eng. Software* **62-63** pp 97-108 DOI: 10.1016/j.advengsoft.2013.04.008,
- [10] Norem H 2009 Selection of Strategies for Winter Maintenance of Roads Based on Climatic Parameters *J of Cold Regions Eng.* **23** (4) pp 113-35, DOI: 10.1061/(ASCE)0887-381X(2009)23:4(113)
- [11] Andersson AK and Chapman L 2011 The impact of climate change on winter road maintenance and traffic accidents in West Midlands UK *Accident Analysis And Prevention* **43** (1) pp 284-9 DOI: 10.1016/j.aap.2010.08.025
- [12] Vignisdottir HR, Ebrahimi B, Booto GK, O'Born R, Brattebo H, Wallbaum H and Bohne RA 2020 Life cycle assessment of winter road Maintenance *Int. J. of Life Cycle Assessment* **25** (3) pp 646-61, DOI: 10.1007/s11367-019-01682-y,
- [13] Vignisdottir HR, Ebrahimi B, Booto GK, O'Born R, Brattebo H, Wallbaum H and Bohne RA 2019, A review of environmental impacts of winter road maintenance *Cold Regions Science and Technology* **158** pp 143-53 DOI: 10.1016/j.coldregions.2018.10.013
- [14] Kocianova A 2015 The intelligent winter road maintenance management in Slovak conditions, *24RSP (TFOCE 2015) Procedia Engineering* **111** pp 410-19 DOI: 10.1016/j.proeng.2015.07.109
- [15] Mahoney WP and Myers WL 2003 Predicting weather and road conditions - Integrated decision-support tool for winter road-maintenance operations *Highway Maintenance Safety, Support And Services: Maintenance*, Book Series: Transportation Research Record Series **1824** pp 98-105
- [16] Riehm M and Nordi L 2012 Optimization of winter road maintenance energy costs in Sweden: a critique of site specific frost warning techniques *Meteorological Applications* **19** (4) pp 443-53 DOI: 10.1002/met.275
- [17] Bujnakova P, Jost J, Farbak M and Kotes P 2019 Experimental study of the modulus of elasticity of concrete at different ambient temperature *IOP Conference Series: Materials Science and Eng.* **549**