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INNOVATION IN THE WINTER ROAD MAINTENANCE AND ITS ECONOMIC JUSTIFICATION

Summary. In general, it can be presented that winter road maintenance costs are rising due to increasing mobility, rising of salaries, and technological needs. For this reason, it is necessary to bring innovations into these processes. The greatest space is in the area of weather forecasting, which is a trigger for maintenance activities in the form of reducing black ice or snow removal. Road administrators use predictive services as a standard to obtain critical atmospheric temperature and weather data in advance. From the point of view of transport safety, the need to obtain predictive temperature data on the road surface is also important. These must also be obtained largely by knowing the temperature trends inside the road structure. The article presents the direction of our own research activities, whereas it focuses on the philosophy of research, justification of the idea, the introduction of research procedures, and the presentation of partial results.

1. INTRODUCTION

The wide application of technological innovation is no longer the exclusive issue of the manufacturing industry and the ICT sector. Trends in their regular deployment are already present in everyday processes within the society, including the sectors of mobility and transport of goods and services. In particular, the application of advanced technical and technological tools in the transport infrastructure environment has its own innovative dimension. In general, a quality transport network is one of the basic preconditions for regional development and the accessibility of regions. It directly affects the possibilities of product mobility (goods and services) and develops or limits the socio-economic development of the territory. This means that there is a need to constantly bring new solutions. However, the question is whether these new solutions are really beneficial. Whether the costs associated with their development, testing, installation, and operation can be lower than the benefits they bring. However, it is more important to answer the question whether it is advisable to realize this comparison if we are not able to quantify the benefit, correspondingly using comparable qualitative indicators.

However, we also need to answer the questions of what specific benefit the technological innovation in the field of mobility brings us. Respectively, whether it is possible to describe this innovation in a way that is fast, simple, and understandable for investors as well as the general public. It is therefore appropriate to grasp the whole evaluation process comprehensively. It is necessary to define the reasons for introducing innovation, to understand its philosophy, and to apply it in a research or real environment. At the same time, it is necessary to consider the possibilities of determining its economic efficiency, if possible.

2. LITERATURE REVIEW AND RESEARCH PHILOSOPHY

Transportation systems are the enabler for economic benefits, social well-being, and environmental positives to societies over their life cycle. As an emerging area of research and development, advancing industry practices and asset management strategies have set off opportunities ranging from developing new efficient ways for manufacture, design, construction, basic and advanced operation, inspection, maintenance, and renewal or disposal. More recently, the field has expanded to incorporate many inventions and applications of new sustainable materials, robotic automation, and "smarter" systems that hold great promise for the future [1]. It can be expected that the priorities for further development will be the issues of improving the quality and safety of means of transport, transport infrastructure, and transport processes. Secondary will be the generation of tools designed to increase economic savings (energy and material) in the construction and operation of the transport network and accelerate the deployment of innovative services for road users and administrators. It is important to realize that innovations in transport and transport infrastructure are not just about introducing advanced systems of intelligent transport systems, intelligent parking-related applications, charging technologies, or overall traffic management but also about innovations designed for purposes that are not directly in contact with users but are intended for organizations responsible for transport infrastructure management. Examples include the use of new or recycled materials with improved characteristics to withstand increased loads [2], new approaches being used for evaluation of road surface and degrees of permanent deformation [3, 4], or the application of new prefabricated bridge joint constructions [5]. Further examples of process innovations are also mentioned in Danisovic and Remek [6], where new methods of inspection of transport infrastructure, namely road tunnels, are being used by using improved inspection procedures and audits.

A very interesting type of process innovations on the part of road administrators can also be a combination of the performance of special training of road tunnel operators through a simulator and the evaluation of accidents in tunnels using special software tools designed to predict emergencies in road tunnels [7]. The actual theme in innovation is elements of Internet of Things (IoT), which present large opportunities for both the greatest and the worst of the intelligent transportation and transit systems. At present, aging infrastructure systems possess additional emerging risks by their inability to provide early warnings to operational management, so that critical components can be prioritized and managed in a timely manner [1].

A specific area within transport processes and transport infrastructure is the topic of winter pavement maintenance. Road and highway maintenance performance is necessary for the safety of users and for enabling emergency and security services to perform their basic functions. Accumulation of snow and (or) black ice on the pavement surface during wintertime substantially increases the risk of road crashes and can have a negative effect on the economy of the region [8]. Considering the sensitive feelings of society in the quality of winter maintenance performance, it is advisable to draw the attention of researchers to the development of new innovative solutions for this area. Of course, in the context of R&D, innovation itself does not mean increasing the quality of technical maintenance of winter maintenance through new maintenance vehicles, increasing the use of more environmentally friendly and efficient sprays, or permanently improving the human capacity responsible for supervising and performing winter service processes. It means the primary development and subsequent application of technical and technological solutions that will increase user safety and increase the efficiency of traffic infrastructure administrator intervention.

The role of the administrator is to ensure the highest possible safe operation and mobility level during winter service. As stated by Andreescu and Frost [9], snow was seen to be the leading variable, as the number of accidents increased sharply with increased snowfalls. The dangers of accidents, owing to bad weather, thereby reduce the operability of the road serviceability mentioned in other works [10 - 12]. As stated in the work of Jiang et al [13], technology for snow and black ice control, as well as correct maintenance operations are key factors to swiftly, comfortably, safe traffic and development of local and national economy.

One of the key conditions for optimizing decisions on how to perform pavement maintenance is to obtain and use accurate weather information and prediction tools. Weather information can be divided into two categories: observations that reflect current conditions and forecasts that predict future conditions [14]. Self-intervention during winter service is largely initiated by meteorological forecasts for the relevant area. These can be improved by different predictive systems that determine the approximate time when road slip is reduced, i.e. such as ice formation, snowfall, and freezing rain. Intervention efficiency is one of the biggest options for generating savings [15]. It is clear that administrators need to have relevant and current data about the weather situation and road surface conditions, while we can be obtained with multiple options and from various sources. The most important source of real-time meteorological and pavement data is road weather stations (RWS) ensuring automatic data collection, their evaluation, and transmission to customers. Currently, a wide range of technologies of road weather stations are commercially available, and some solutions can be purchased as finished products. Some are manufactured to specific customer requirements. They are a necessary tool for remote monitoring of weather conditions on the roads and in its close environment. They are equipped with special road sensors, which are connected to the station for measuring of road conditions and they are included with variable set of sensors for measuring usually also. Road surface conditions are influenced by more physical and technical parameters. They can produce vast temperature variations across the road section, and we can include here for example numerous and meteorological conditions or geographical and road construction parameters [16]. The most important can be included, among other factors, air temperature, humidity, precipitation amount, wind, radiation fluxes, topography, properties of the road materials, and traffic condition [17, 18]. Their influence on the road conditions and operability is presented in detail in other literature studies [19 - 21].

Road weather stations and technologies built on them are essential components of advanced systems known as the road weather information systems (RWIS). In a subsequent step, it is possible to produce from RWIS a maintenance decision support systems (MDSS). RWIS is a complex software tool that collects all relevant data that are possible to use by dispatchers (operations managers) to support decision making in winter road maintenance process.

The RWIS integrates all available data satellites, public road weather stations and meteorological radars, traffic cameras, and other data from the National Hydrometeorological Institutes (NHI) or National Weather Service (NWS). The RWIS ensure collection of current conditions in selected areas and territories, but the RWIS can include forecasting module in case of interest.

This technological system can generate a point forecast of important parameters in response to the measured data and general weather forecast. In addition, there are high-specialized computational models for road surface forecast. The specialized road weather forecast model is an important part of operations manager information matrix in maintenance decision support system (MDSS). MDSS as a part of RWIS is focused on special linear weather and road surface status forecast and recommendations on winter maintenance [22].

Currently various models are developed for road administrators for predicting meteorological conditions (e.g. METRo [23], RoadSurf [24], etc.). Based on future information about the road surface conditions (they are obtained be these models), the operational manager can determine which action to take associated with ensuring the operability of the transport infrastructure. With development and improvement of transport infrastructure regarding snow and ice control operations, it was necessary to change it recently. Winter operations traditionally relied on the operation managers' knowledge, experience, and best practices to interpret a weather forecast into a snow and ice control plan for each type of risk in the weather. The meteorological forecast concentrated on the upper layers of the atmosphere and did not consider the influence of the temperature at the roadway surface and just below. However, with growth in mobility, whose quality is under the scrutiny of society, it was necessary collaborated to develop and implement more and more process and technological improvements in winter maintenance. These efforts have resulted in more efficient and effective snow and ice control operations that provide drivers safer road conditions, improved and more reliable mobility than economic development instrument, and increasing environmental protection near the road [25]. Generating innovative tools in this area is quite challenging, because the physical process that produces ice on roads is complex and involves the interaction of weather with road surface conditions [26]. Own research presented in this paper is based on the basic assumption that tools for measuring the temperature of the environment are approaching high precision, and that new solutions are needed to assess the temperature within the pavement structure. By doing so, we can make progress in developing processes that can predict temperature development on the road surface. Just these is important to start or hold up the performance of winter maintenance.

The direct side of these technical problems is the financial framework. To better understand the purpose of making progress in winter maintenance processes, it is necessary to give a general insight into the economic aspect of the issue. The starting point for any activity is the fact that the cost of winter maintenance is increasing, especially as a result of increasing mobility in society. In doing so, administrators are indirectly forced to look for improvements in existing or new solutions that can meet the needs of society, but at the same time maintain the economic side of winter maintenance operations at the desired level. At first sight, it can be assumed that any winter maintenance performance brings its effects, primarily from the point of view of achieving an acceptable level of security and the demanded level of user mobility. From a strategic point of view, this view is true, but with a more comprehensive view of these effects, the statement in question has gaps. These are mainly present in the context of the achieved economic efficiency of spending financial resources for winter maintenance. Doubts are due to objective factors.

These are based on the fact that users and administrators themselves have certain expectations of winter service performance. These can be presented as a function of multiple preference factors that the administrator must reflect on. The most important are safety, mobility, environmental considerations, and adequate cost-effectiveness. Naturally, safety is the most watched feature associated with the winter season. It is directly linked to the mobility factor. Users require roadworthiness, despite higher costs for road managers. When assessing environmental effects, attention is focused on the need to apply organic products in selected protected areas. In this case, the primary environmental effects of their application are monitored, which is in many contrasts with their higher price level. However, in the context of the use of these mixtures, it is important to mention that there is becoming balance between the benefits of using more expensive organic blends with the benefits of conventional spreading chemical materials. Ecological-based grit materials (e.g. magnesium chloride) are gradually improving their properties, with products that outweigh the qualities of conventional blends (better efficiency at extra low temperatures, lower levels of corrosion when contacted with metal structures, more effective prevention of ice formation, or need to use less material on the same surface). The last monitored factor is the amount of spent winter maintenance costs, which of course vary from year to year, which makes it difficult to achieve economic efficiency for subsequent periods. These mainly include cost service of maintenance vehicles, grit material costs, and human resources costs. A regional aspect is added to the aforementioned factors. Each managed region is characterized by individual road infrastructure characteristics, different climatic conditions, and technical equipment. At the same time, infrastructure managers have only limited funds available. Thus, they must sensitively evaluate through their management decisions which processes they prefer and in which parts of the infrastructure it will be. For this reason, activities related to the optimization of winter maintenance performance are approached, including an economic expression of costs and benefits, in order to get as close as possible to the set values of indicators in the context of "value for money". Even though ordinary users of the transport network are largely not interested about this information.

Several standard ways to quantify winter maintenance benefits are currently available. Selected features are included in the works of Blumm and Lindemann [27] and Xianming, S. and Liping [28]. At the same time, it states that the most appropriate way to do this is through a modified cost-benefit analysis, tracking the cost-benefit ratios associated with winter maintenance. For this approach, the benefits need to be quantified as much as possible. In cases when it comes to specific social factors, there is a need to qualified them. Selected quantifiable benefits include, for example, savings in the amount of material used to modify the pavement or the number of trips (machine and crew costs). Qualitative indicators include, for example, improving mobility rates (time savings - this can also be quantified), higher customer satisfaction, effect on the country's economy and the region, and reducing negative environmental effects.

As part of the exact naming of the effectiveness of winter maintenance processes, it would be appropriate to transfer all the qualitative benefits to financial statements and then compare them with costs. Owing to this demanding act, we often encounter verbal evaluation of winter maintenance processes and thus the allocation of a selected quality indicator on an imaginary scale of quality.

An interesting method of calculation is also mentioned in the study by Ye et al [29], which also states that it is better not to count on indirect costs (societal) as it is difficult to quantify them. Here is another interesting method of calculating benefits [29]:

$$\mathrm{WMC}_k = f(\mathrm{LM}_k, \mathrm{LOS}_k, \mathrm{WSI}_k, \mathrm{WI}_k, \mathrm{AI}_k) \quad (1)$$

where WMC_k = cost of winter maintenance for the maintenance unit per winter season; LM_k = road lanes maintained by the road maintenance administrators; LOS_k = level of the roadways-maintained service by the road maintenance administrators, often characterized by the quality of pavement condition; WSI_k = winter maintenance difficulty index; WI_k = index of use of weather information (especially accuracy and density of data); and AI_k = level of anti-icing used by the road maintenance administrators.

On the basis of the aforementioned overview of information and knowledge, it is possible to see that it is interesting if not necessary to deal with the economic aspect of winter maintenance. There are factors that influence benefits and costs to a greater or lesser extent. It is up to the pavement administrator to decide how he/she will improve economic efficiency values. The simplest steps include the exchange of technology designed for pavement, the optimization of human capacity, and the planning of journeys. The first two arrangements can be done quite simply and can be categorized as modernization processes or lower-level innovation processes. Setting the values associated with planned vehicle exits may appear problematic. These actions are based on a number of indicators, but the primary situation is the status and prediction of weather conditions in the managed region.

As stated in Losurdo et al [30], the provision of decisions based on reliable data and knowledge on current and expected weather conditions contributes to the provision of traffic flow, and thus, the improvement of the road safety level. For this reason, it is also subject to its own activities of solvers to develop technologies to measure and predict the selected temperature indicators road construction. Just this pavement parameter (temperature and its trends) that is currently very interesting from the viewpoint of road administrators. It can make a significant contribution to improving models designed to optimize maintenance performance, such as preventive intervention. This is obviously much more desirable than removing snow fall or black ice.

Such benefits in partial form can be relatively easily transformed into inputs into various mathematical and economic simulation and calculation procedures. Despite the impression that it will be a simple ratio of costs incurred e.g. to buy technology and benefits on the other hand, the opposite is true. Valuation is a fairly demanding matter requiring relatively large asset management knowledge consisting of cost and benefit economics, as well as in the management of transport processes and the efficiency of transport systems and technologies.

The assessment of economic benefits is often associated with the assessment of the situation before and after the implementation of innovations. An interesting example of the economic expression of the benefits of innovations in winter maintenance can be included in the approach outlined in Schneider et al [31], using the example of deploying new technology.

$$\mathit{Capacity}_{Innovative}\ x\ \mathit{OverallUR}_{Innovative}\ x\ \mathit{Efficiency}_{Innovative} = \mathit{Capacity}_{Traditional}\ x\ \mathit{OverallUR}_{Traditional}\ x\ \mathit{Efficiency}_{Traditional}\ x\ \theta \quad (2)$$

where $\mathrm{Capacity}_{\mathrm{Innovative}}$ = number of lanes the innovative equipment may treat in a single pass; $\mathrm{Capacity}_{\mathrm{Traditional}}$ = number of lanes the traditional equipment may treat in a single pass; Overall

$UR_{Innovative}$ = overall utilization rate of the innovative equipment over the winter season; Overall $UR_{Traditional}$ = overall utilization rate of the traditional equipment over the winter season; $Efficiency_{Innovative}$ = efficiency of the innovative equipment in treating the roadway; $Efficiency_{Traditional}$ = efficiency of the traditional equipment in treating roadway, and θ = number of traditional equipment needed to equal the abilities of a single innovative equipment.

This calculation can be modified according to the type of innovation. The problem with the application of this calculation is that the implemented innovation does not replace the existing part of the already operating technology or the implemented process. Another possible approach, designed to assess the economic efficiency of innovation, is an approach based on the experimental application of the subject of innovation in the real environment and the re-evaluation of its benefits. This procedure is in high risk. At the same time, it is partially unsuitable for calculating the economic efficiency of winter maintenance. Problems are differences arising between the winter seasons, mainly owing to the trends of the winter season and different traffic conditions.

3. METHOD OF RESEARCH AND RESULTS

The University of Zilina has focused on road administration themes for a long time, including a winter road maintenance processes, not only from the point of view of its performance but also from the viewpoint of optimizing the economic costs associated with its implementation. For this reason, the research center of the university, in collaboration with the own Faculty of Civil Engineering, partners from Slovak University of Technology in Bratislava and private R&D company, has carried out comprehensive research over a longer period of time. It started by definition of main winter road maintenance problems and continued with the design of a technological solution, in our case, is it predictive pavement temperature systems. In the end, the economic efficiency of this innovation will be comprehensively assessed. This research will run for several years and will provide demanded answers, especially to road managers, on whether investments are being made effectively.

The whole process is already at an advanced stage. Problems are defined and solutions are presented. Research team has carried out the development and experimental installation of new temperature systems. This part of project is continuous, as we strive to achieve the highest quality and reliability of this. The parallel part is an assessment of whether the innovations in question can generate economic benefits, respectively, whether a relevant answer can be given to this question at all.

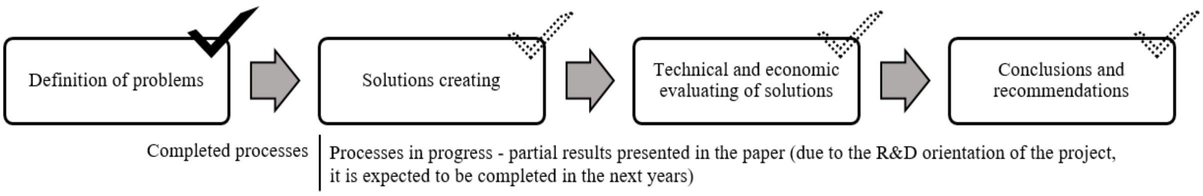

Fig. 1. Scheme of the state of project processes

The following sections present the current progress in solving the project. The research team monitors the feedback by gradually re-announcing the achieved results. Based on it, it can improve future processes and also eliminate errors that may occur. The presented knowledge does not go into a detailed specification, as it is not necessary for the reader. They present important solution steps and principles that are used.

The proposed system presented in this chapter solves the problem of measuring the temperature path profile and the boundary conditions of using the predictive model to determine the future trend of temperature development within the road structure. The monitored values are obtained by direct method, it means the temperature sensors are installed directly inside the pavement and the searched values are not calculated from the ambient temperature (air). An important part of the design is a prediction model that, based on sensor inputs and historical measurements, can with some probability predict temperature trends at the measurement site. The goal of our research was to develop our own technology tools that have high reliability and can be part of the predictive modelling of temperature development. For the verification of model described in the next section, the research team created more experimental installations with two groups temperature sensors buried in the road surface. First group consists of vertical installed sensors, which are arranged with a pitch of 20 cm, to the depth of 1 meter. In the second group is a horizontal layer of sensors (across the entire width of the road) located in the road surface. All temperature sensors were made based its own technology. They are placed in a special enclosure that can protect them against potential mechanical damage (present during installation) and use in road traffic.

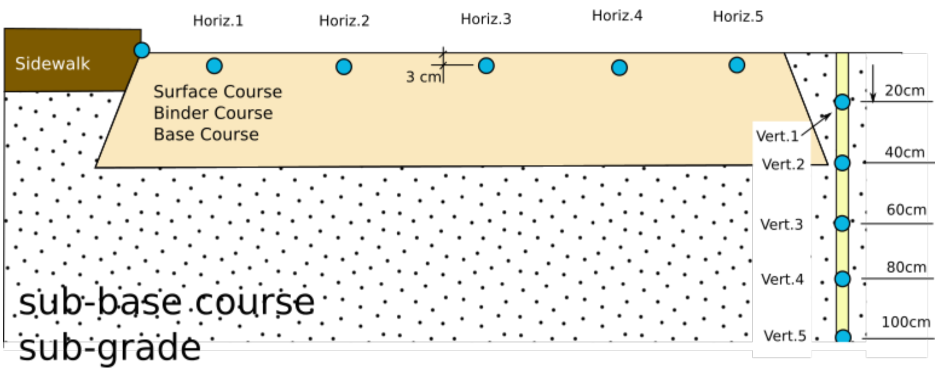

Fig. 2. Scheme of sensors system design

The installation of the sensor system was conditioned by the provision of sensors that resist high temperatures and pressure when laying asphalt. Furthermore, it was necessary to minimize the cables with 1-wire bus system (due to the least possible cut into the road) and provide a temperature measurement range from to -50°C to 120°C. An essential part of the system is application software. It was realized in the form of its own development. It serves on autonomous data collection and consists of server and application parts. The system is designed so that, it will be possible through the web interface data access, processing, and visualization of measurement data continuously.

Data processing design comes from the physical rules based on derivation of Fourier equation of heat conduction.

For heat transfer are valid general equations:

$$(Q_1 - Q_2) = (q_1 - q_2)S\Delta t = -\Delta q S\Delta t \quad (3)$$

$$(Q_1 - Q_2) = mc(T_1 - T_2) = \rho S\Delta x c\Delta T \quad (4)$$

Fig. 3. Installation of temperature sensors in asphalt roads

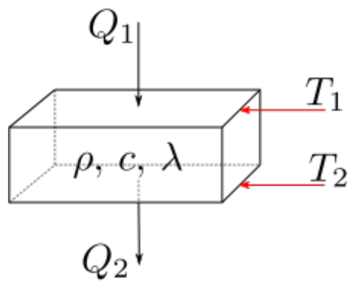

Fig. 4. Heat transfer diagram in physical environment

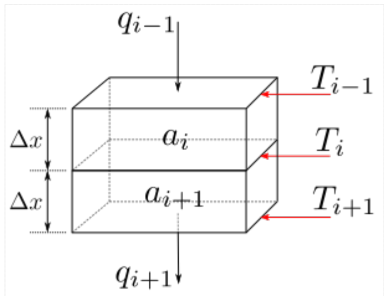

Fig. 5. Heat transfer in the segment of non-linear environment

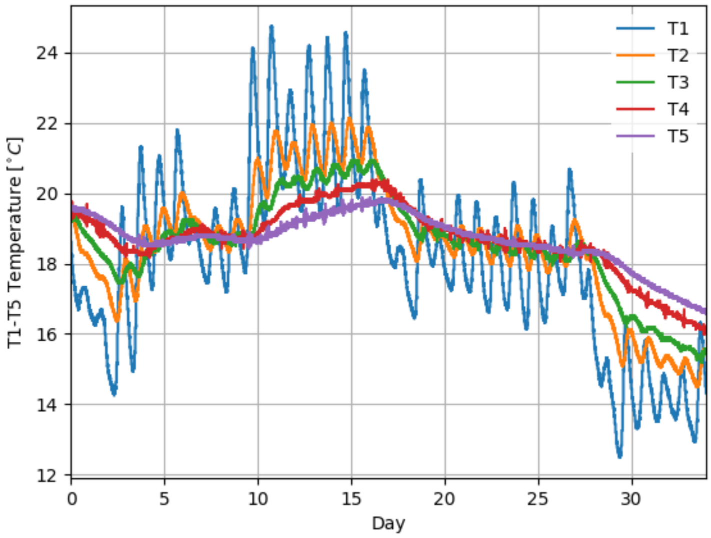

Fig. 6. Temperatures chart for autumn

The data obtained in this way enter the prepared prediction systems, which determine the behavior of the road and its surface owing to changes in weather conditions. Subsequently, this information will enter our information systems in the form of alarms needed for communication managers. Based on these systems, they will be able to manage their interventions more effectively during the winter. In parallel to these activities, the research team also deals with defining ways that will determine whether these specific innovations bring benefits, and, of course, whether these benefits are higher than the costs invested. Below are the basic hypotheses that have been developed. These are currently undergoing detailed analysis, and we are trying to modify the wording so that it is possible to create the simplest possible calculation formulas for calculating benefits in financial terms.

As mentioned, the road administrator has limited financial resources and has the responsibility to efficiently spend financial resources in managing his/her assets. Investment in upgrading infrastructure for better winter road maintenance needs to be judged sensitively and implement thoughtfully. The administrator should present 2 basic features of the innovations that he/she plans to apply to the transport network:

- innovation is characterized as more efficient than the original equipment or process and
- declare that the funds spent on innovation will bring at least the same amount of benefits in financial terms (after deducting investment and operating costs), or qualitative indicators.

Both of the aforementioned characteristics are quite challenging to express. The research team is therefore trying to find the right way to define the economic benefits, specifically in the context of using its own predictive temperature system. The presented technology can bring in particular one major benefit. To improve the prediction of the possibility of black ice on the pavement surface. This benefit alone cannot be quantified, as is the idea of an investor who finances innovation. It is therefore necessary to look for subsequent effects. These are mainly the following:

- optimizing the trip of the technical vehicle responsible for the maintenance of the section (i.e., increasing the efficiency of the journeys with the effect of reducing the cost of managing the route in the form of fuel, spreading material, vehicle, and human resources costs)
- reduction of negative effects on the environment (optimal spreading frequency),
- improving regional accessibility, as well as increasing safety and mobility, and
- other benefits not directly related to winter road maintenance.

Other benefits include follow-up benefits for other areas such as its primary application. In the case of a device for monitoring the temperature development of a road structure in a vertical and horizontal profile, secondary benefits arise. These are for example in the form of monitoring the behavior of materials used for road construction in different periods from the point of view of development of deformations from traffic for individual temperature moments. These benefits, where users are for example research and development organizations, are very difficult to quantify and are often expressed in verbal terms.

Based on the assessment of multiple approaches that make it possible to evaluate the benefits of innovation in winter maintenance, one of the following approaches is appropriate:

1. an approach based on comparing the estimated quality of selected processes before and after installing the innovation. In our case, we would monitor the quality of the road surface temperature development prediction. It would be a simplified verbal assessment. An additional quantity within this functional dependency would be to estimate the quality of the entire winter maintenance process before and after the installation of the mentioned technology, which could be in proportion to the quality of the selected process (measurement and temperature prediction),
2. application of approaches based on method cost-benefit analysis. This would have to be modified to the specific needs of the technology in question. For example, in the case of the own innovation presented above, in addition to the investment costs, the costs of increasing the costs of operating and maintaining the innovation would have to be included. On the benefits side, we would have to quantify set of benefits, including social (time saving and accident reduction),
3. approach based on comparing the situation before and after the real implementation of innovation. In this case, we can quantify the economic benefits and also qualify. Investment costs are immaterial in this case owing to the fact that their administrator has these already invested.
4. an approach based on applying innovation to the transport network through societal interests, and we would not intentionally follow the cost side. This means that in the case of our technology for predicting temperature development, focus on providing a higher standard for users, regardless of benefits,
5. apply advanced mathematical calculations and simulations to focus on quantity WIk (formula 1. WI indicates the extent to which the maintenance administrators process can use weather information. WI has for winter maintenance activities two main meanings. First is usage intensity of weather information data (observations, quality and speed of processing and predictions). Second meaning is accuracy of weather information, so WI can be a vector indicating usage intensity and accuracy; and
6. the combination of the aforementioned approaches and their expansion.

In the next period, the research team will face several important tasks. Work on improving one's own technological system predicting the temperature state of the road surface. In parallel, they must work on a detailed calculation of the possible benefits resulting from installation in real operation. Based on this, the backward correlation will determine the innovation factor. This will represent a certain coefficient, which will tell us what is the size of the financial benefit per 1 euro invested in a given innovation. All these activities are directly related to the current state of the project solution described in this paper.

CONCLUSION

The paper deals with the partial outputs of the project, which focuses on the design of innovations associated with winter maintenance and the effort to evaluate the possibility of calculating economic benefits resulting from their use in real operation. The individual chapters gradually inform about the need for innovations in transport processes by fulfilling the demanded factors of modern use of the pavement. They are represented by users and administrators, and are presented in the form of security requirements, an appropriate level of mobility, the need to increase environmental protection and ultimately by increasing the cost-effectiveness of the "value for money" approach. The paper presents own design of a sensor system for monitoring and predicting the development of the road structure, even with a short technical summary. The reason for its development was the fact that there are relatively reliable prediction tools in the prediction of atmospheric temperature development. However, in systems installed directly in the road, there is currently considerable room for innovation and solutions to improve forecasts. The research team believes that by applying new solutions, it is possible to achieve higher accuracy and reliability of weather monitoring and predicting systems. Increased weather forecasting accuracy and road temperatures could reduce maintenance costs, improve winter maintenance performance, and improve transport processes overall.

What remains questionable is the determination of the way in which the economic effects of such conceived innovations can be accurately expressed. Although there are some ways presented in the paper, there is room for generating unambiguous approaches. This will give the pavement administrator the information he/she asks when assessing whether or not to initiate the innovation process. In conclusion, deploying this innovation can also generate benefits for other science areas. Among others, e.g. also for research aimed at monitoring deformations of individual roadway layers in different temperature developments.

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References

1. Kaewunruen, S. & Sussman, J.M. & Matsumoto, A. Grand challenges in transportation and transit systems. *Frontiers in Built Environment.* Publisher: Frontiers Media S.A. 2006. Vol. 2. ISSN: 2297-3362.
2. Sramek, J. Complex modulus and fatigue of recycled asphalt mixtures. In: *Advances and Trends in Engineering Sciences and Technologies. Proceedings of the International Conference on Engineering Sciences and Technologies.* ESaT 20152016. High Tatras Mountains, Slovakia. Publisher: CRC Press/Balkema. 2015. P. 207-212. ISBN: 978-113802907-1.
3. Decky, M. & Kovac, M. & Muzik, J. & Micechova, L. & Duris, L. Objectification of public bus stop's pavement surface morphology. *Civil and Environmental Engineering*. Publisher: Sciendo. 2018. Vol. 14. No. 1. P. 44-53. ISSN: 1336-5835.
4. Decky, M. & Pitonak, M. & Sramek, J. & Hajek, M. & Schenk, P. Effect of load plate size on results of static load test. In: *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM.* Publisher: International Multidisciplinary Scientific Geoconference. Albena; Bulgaria. 2018. Vol. 18. No. 1.2. P. 239-245. ISSN: 1314-2704.

5. Farbak, M. & Bujnak, J. & Jost, J. Short headed fastenings in concrete structures-theoretical and experimental investigation. In: *Procedia Engineering*. *24th Russian-Polish-Slovak Seminar on Theoretical Foundation of Civil Engineering, TFoCE 2015*. Samara; Russian Federation. Publisher: Elsevier Ltd. 2015. Vol. 111. P. 188-193. ISSN: 1877-7058.
6. Danisovic, P. & Remek, P. Joint road safety operations. In: *Advances and Trends in Engineering Sciences and Technologies II - Proceedings of the 2nd International Conference on Engineering Sciences and Technologies.* Vysoke Tatry; Slovakia. 2016. Publisher: CRC Press/Balkema. P. 735-740. ISBN: 978-131539382-7.
7. Jancarikova, E. & Mikolaj, J. & Danisovic, P. Risk and Incidents Assessment in Slovak Road Tunnels. In: *Procedia Engineering*. Publisher: Elsevier Ltd. *12th International Scientific Conference of Young Scientists - On Sustainable, Modern and Safe Transport, TRANSCOM 2017*. High Tatras Grand Hotel Bellevue. Slovakia, 2017. Code 136438. Vol. 192. P. 376-380. ISSN: 1877-7058.
8. Sherif, A. & Hassan, Y. Modelling pavement temperature for winter maintenance operations. In: *Canadian Journal of Civil Engineering*. 2004. Vol. 31. No. 2. P. 369-378. ISSN: 03151468.
9. Andreescu, M.-P. & Frost, D.B. Weather and traffic accidents in Montreal. *Climate Research*. 1998. Volume 9. Issue 3. P. 225-230. ISSN: 0936577X.
10. Andrey, J. Long-term trends in weather-related crash risks. *Journal of Transport Geograph*y. 2010. Volume 18. Issue 2. P. 247-258. ISSN: 09666923.
11. Karpova, G. & Sigova, M. & Kruglova, I. & Kelbakh, S. Conditions and Current Trends for Improving Road Safety in Federal Highways in Russia. In: *Transportation Research Procedia.* Publisher: Elsevier B.V. 2017. Volume 20. P. 272-276. ISSN: 23521457.
12. Datla, S. & Sharma, S.2008. Impact of cold and snow on temporal and spatial variations of highway traffic volumes. *Journal of Transport Geography.* Vol. 16. No. 5. 2008. P. 358-372. ISSN: 0966-6923.
13. Jiang, C. & Zheng, J. & Liu, J. & Wu, L. & Yang, J. Studies review of the technology for snow and ice control for winter road maintenance. In: *Proceedings of the 3rd International Conference on Transportation Engineering. 43rd International Conference on Transportation Engineering, ICTE 2011.* Chengdu, China. 2011. P. 3245-325. ISBN: 978-078441184-166923.
14. Ye, Z. & Strong, C. & Fay, L. & Shi, X. Cost Benefits of Weather Information for Winter Road Maintenance. *Final report Iowa Department of Transportation*. 2009.
15. INCA-CE ROAD SAFETY TEAM. *Transregional strategy for the use of nowcasting information in road safety.* 2012.
16. Dudak, J. & Gaspar, G. & Sedivy, S. & Pepucha, L. & Florkova, Z. 2017. Road structural elements temperature trends diagnostics using sensory system of own design, In: *IOP Conference Series: Materials Science and Engineering.* Building up Efficient and Sustainable Transport Infrastructure 2017. BESTInfra 2017, Prague; Czech Republic. Publisher: Institute of Physics Publishing. 2017. Vol. 236. No. 1. ISSN: 1757-8981.
17. Krsmanc, R. & Šajn, Slak A. & Demšar, J. Statistical approach for forecasting road surface temperature, *Meteorological applications*. 2013. Vol. 20. P. 439-446.
18. Chapman, L. & Thornes, J. E. Small-scale road surface temperature and condition variations across a road profile. In: *Proc. 14th Int. Road Weather Conference SIRWEC Prague*. 2008.
19. White, S. P. & Thornes, J.E. & Chapman, L. A. *Guide to Road Weather Information Systems SIRWEC.* 2006.
20. Perry, A.H. & Symons, L.J. *Highway Meteorology.* London: E & FN Spon. 1991.
21. Kawashima, S. & Ishida, T. & Minomura, M. & Miwa, T. Relations between surface temperature and air temperature on a local scale during winter nights. *Journal of Applied Meteorology.* 2000. Vol. 39. P. 1570-1579.
22. Kocianova, A. The intelligent winter road maintenance management in Slovak conditions. In: *Proc. XXIV R-S-P seminar: Theoretical foundation of civil engineering (Procedia).* 2015.
23. Linden, S.K. & Drobot, S.D. The Evolution of METRo in a Roadway DSS. In: *Proc. 15th Internat. Road Weather Conference* SIRWEC. Quebec. 2010.

24. Kangas, M. & Heikinheimo, M. & Hippi, M. RoadSurf: a modelling system for predicting road weather and road surface conditions. *Meteorological applications.* 2015. Vol. 22. P. 544-553.
25. Smithson, L.D. Optimized and sustainable winter operations in Canada and the United States. In: *TAC Conference and Exhibition - Transportation: Innovations and Opportunities.* Publisher: Transportation Association of Canada (TAC). 2012.
26. Berrocal, V.J. & Raftery, A.E. & Gneiting, T. & Steed, R.S. Probabilistic Weather Forecasting for Winter Road Maintenance. *Journal of the American Statistical Association.* 2010. Vol. 105. No. 490. ISSN: 0162-1459.
27. Blumm, J. & Lindemann, A. Characterization of the thermophysical properties of molten polymers and liquids using the flash technique. *High Temperatures-High Pressures.* 2003. Vol. 35-36. P. 27-32
28. Xianming, S. & Liping, F. *Sustainable Winter Road Operations*. John Wiley & Sons Ltd. 2018. ISBN: 9781-119185147.
29. Ye, Z. & Shi, X. & Strong, C.K. 2009. Evaluation of effects of weather information on winter maintenance costs. *Transportation Research Record.* Greenfield, T.H.b. 2009. No. 2107. P. 104-110. ISSN: 03611981.
30. Losurdo, F. & Dileo, I. & Siergiejczyk, M. & Krzykowska, K. & Krzykowski, M. Innovation in the ICT infrastructure as a key factor in enhancing road safety. A multi-sectoral approach. In: *Proceedings - 25th International Conference on Systems Engineering*, ICSEng 2017. Publisher: Institute of Electrical and Electronics Engineers Inc. 2017. P. 157-162. ISBN: 978-153860610-0.
31. Schneider, W. & Miller, C. & Crow, M. & Holik, W. *Evaluation of the Viking-Cives Tow Plow for Winter Maintenance*. Ohio Department of Transportation, Columbus. 2014.

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