



ASSESSMENT MODEL OF LEVELS FOR WINTER ROAD MAINTENANCE

Tomas Ratkevičius¹✉, Alfredas Laurinavičius²

¹Road Research Institute, Vilnius Gediminas Technical University, Linkmenų g. 28, Vilnius, LT-08217, Lithuania

²Dept of Roads, Vilnius Gediminas Technical University, Saulėtekio al. 11, Vilnius, LT-10223, Lithuania

E-mail: ¹tomas.ratkevicius@vgtu.lt; ²alfredas.laurinavicius@vgtu.lt

Abstract. The limited funding for the road industry leads to economizing in the planning of road network maintenance, to identifying the appropriate priorities of the activities with the greatest benefit for the society. The level of maintenance is the direct assessment of the road operation and maintenance service provided to the road users; it directly affects the road maintenance and for road users costs the better is road maintenance, the road users incur the fewer expenses and vice versa. Insufficient road maintenance in the winter time causes not only the danger of traffic accidents but also worsens the driving conditions, increases the fuel consumption, vehicle depreciation, transportation becomes more expensive. Many results of studies showed that the current choice of maintenance levels in the winter time taking into account only the road category and traffic volume does not ensure the indicators of the most advanced world countries and road functional purpose. The principle of the minimal expenses for the society should be the main criterion in identifying the optimal levels of winter road maintenance. The experience of Lithuania and foreign countries helped in creating the model of assessment of winter maintenance levels for Lithuanian roads of national significance, which can be applied in the other foreign countries as well. This model could be an effective tool for the selection of the optimal maintenance levels, which would economically substantiate the winter road maintenance strategy, that best corresponds to the needs of the society.

Keywords: cost-benefit analysis, level of maintenance, slipperiness reducing materials, winter road maintenance.

1. Introduction

The effective road transport system encourages economic growth, however, it also inevitably affects the environment both during construction and modernization as well as during road maintenance. The major part of the road maintenance funds is devoted to supporting the winter maintenance. Thus, it is of crucial importance to distribute them in the most rational way. To optimize the selection of the road maintenance levels in the winter time, it is necessary to regard not only the economic calculations, but also the environmental and social benefits and costs.

The significant economic effect is achieved as a result of road funding and maintenance planning calculations which assist in solving the following problems:

- how to organize and distribute funding for road maintenance;
- which road maintenance levels should be applied and on which roads;
- what economic benefit for the society stems from the winter road maintenance;
- what amounts of funds are necessary currently and will be needed in the future to achieve and

continuously maintain the established optimal road network maintenance level in the winter time.

Many results of studies showed road maintenance great effect on road safety (Andrey *et al.* 2001; Fu *et al.* 2006; Hanbali, Kuemmel 1992, 1993; Hermans *et al.* 2006; Nixon, Qiu 2008; Norrman *et al.* 2000; Qin *et al.* 2007; Shankar *et al.* 1995). On road with snow the accident risk is two times bigger than on bare, dry road but from ten to thirty times more if bad road condition (snow or ice) occurs unexpectedly, without warning and if the winter condition seldom occurs (Andrey *et al.* 2001; Eisenberg, Warner 2005; Knapp *et al.* 2002; Nixon, Qiu 2008; Velavan 2006). The five-year analysis of accident rate data on the national significance roads established that during the warm season the representative road accident amount was reduced by 36 %. However, during the cold season of the same period, the situation did not have improvement tendencies. Therefore, it is necessary to evaluate the quality of the performed winter road maintenance as well as to optimize the winter road maintenance selection methods.

The analysis of the experience of developed countries in the world in the area of winter road maintenance

(WRM) has shown that most of them apply at least three WRM levels (I – high level, II – average level, III – low level). Each maintenance level is meant for a different road maintenance type, mostly based on traffic intensity and road category. Lithuanian national road maintenance in the winter time is currently selected without taking into consideration all the factors that determine the need for the society. Winter road maintenance level application while taking into account only the road category and traffic volume does not ensure the indicators of the most advanced world countries and road functional purpose.

In Lithuania the quality of the WRM results from the limited funding, the WRM levels are being selected without taking into consideration all the factors that determine the need for the society. Thus, it is appropriate to create a WRM quality assessment system, which would assist in establishing economic feasibility of the need for funds and would optimize the application of the WRM levels.

Having performed the analysis of the WRM practice, it was determined that selection of economically feasible WRM levels would require the assessment of the functional purpose of the roads. The principle of the minimal expenses for the society is the main criterion for identifying the optimal levels of WRM.

Swedish National Road and Transport Research Institute (VTI) in collaboration with the Swedish Road Administration developed a different Winter Model which is a unique tool allowing to create an economically-based winter maintenance strategy while selecting the road maintenance levels leading to the most significant economic benefit to the society. Figure 1 shows 60 % of the total expenses incurred by the society consist of costs related to travel time. Almost 15 % are made up by road accident losses, the costs of the remaining social and economic factors do not reach 10 %, while the expenses of the WRM represent only up to 0.5 %. These results can lead us to a conclusion that currently, the most important social and economic factors are travel time and road accidents, which jointly stand for more than 75 % of all the expenses incurred by the society in Sweden (Berglund 2008; Wallman 2004).

In summarizing the practices of the road infrastructure asset management and road maintenance in different countries as well as the quality improvement possibilities it

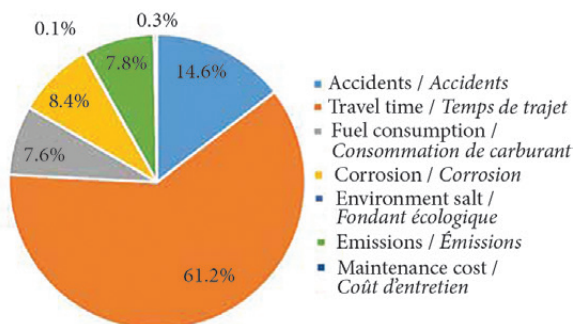


Fig. 1. Setting social and economic factors identified in the Swedish winter road maintenance model (Wallman 2004)

is worth noting that despite the differences of details, complexity and application for specific country's road network aspects in the systems, models, and procedures applied for road infrastructure management and road maintenance of different countries, the general view of the goal to be achieved is the same, i. e. to ensure road infrastructure functioning, which would be the long-term, economically efficient and meet the social and environmental needs.

As the social and ecological road infrastructure requirements become more evident, while the road maintenance funding is extremely limited, it is important to assess the social and economic aspects in selecting the road maintenance levels. The performed analysis of the scientific works on WRM can lead us to a statement that the condition of the surfaced portion of the roadway in the winter influences the greatest economic benefit. The technologies and materials used for the maintenance of this particular portion of the road as well as the set requirements (optimal selection of the maintenance levels in the road network) have the most significant impact on the potential maintenance quality improvement. Since the technologies used in Lithuania are similar to those used abroad, it would be more sensible to research the efficiency and appropriateness of the alternative materials under the conditions specific to Lithuania (comparing them with the traditional salts). However, the main task is to create a tool, which could assess the quality of the applied maintenance (surface cleaning and salting) means as well as the provided economic benefit for the road users.

The purpose of this paper is to suggest a model of assessment of winter road maintenance levels that would economically justify the need of funds, and could be an effective tool for the selection of the optimal maintenance levels, taking into account the factors having the most significant impact on the direct expenses of the road users.

2. Winter road maintenance experimental research and analysis of the results

The market continually offers different new materials for salting or sanding the roads with seemingly greater effectiveness and lower negative impact on the environment. However, their price in comparison with the traditional chloride salts is dozens of times higher, while their declared effectiveness does not always prove itself in practice. Therefore, it is necessary to carry out experimental research to evaluate the efficiency of the alternative materials and to compare it with the currently used materials as well as to offer recommendations for the application of the materials on the national roads in Lithuania.

The analysis of the experience of Lithuania and foreign countries lead to suggesting a research methodology of efficiency of chemical slipperiness reducing materials (SRMs), which would allow to make objective assessment of the chemical materials alternative to traditional chloride salts under meteorological and traffic conditions in Lithuania (Cuelho, Harwood 2012; Chen *et al.* 2009; Flintsch *et al.* 2009; ; Malmivuo 2011; Nakatasuji *et al.* 2005; Rezaei, Masad 2013; Wang *et al.* 2004; Xu, Tan 2012).

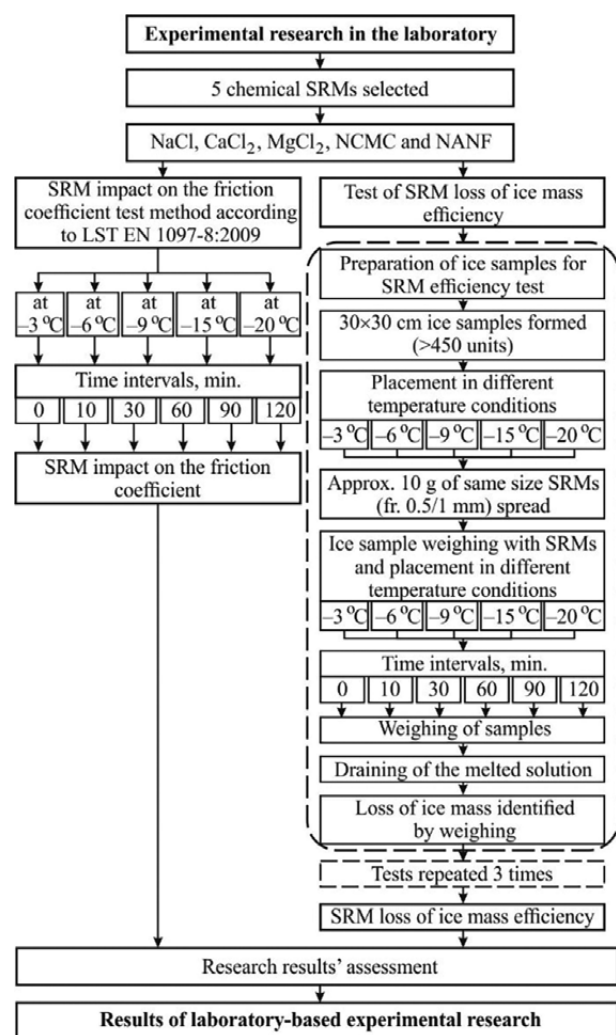


Fig. 2. Laboratory-based experimental research plan (compiled by the author Ratkevičius, T)

To identify the most efficient SRMs under the road weather conditions in Lithuania a preliminary research plan was compiled with two stages:

- experimental research in the laboratory (Fig. 2).
- experimental research on the tested sections (Fig. 3).

Based on the developed research methodology for road SRMs research of five chemical materials was completed, including: sodium chloride (NaCl), calcium chloride (CaCl₂), magnesium chloride (MgCl₂), a mixture of sodium and calcium modified chlorides under the commercial name of *Icemelt* (NCMC), and a mixture of sodium acetate and sodium formate under the commercial name of *Nordway* (NANF) (Fig. 2).

The assessment of the laboratory-based research results the three most effective SRMs was selected (NaCl, CaCl₂, NANF), which were tested under the real-life weather and traffic conditions on the national significance road sections (Fig. 3).

The summarized experimental laboratory-based and field research results are presented in Table 1, in which the resulting materials' efficiency in each research is distributed into four categories (starting from high efficiency marked by "+" to no efficiency marked by "-").

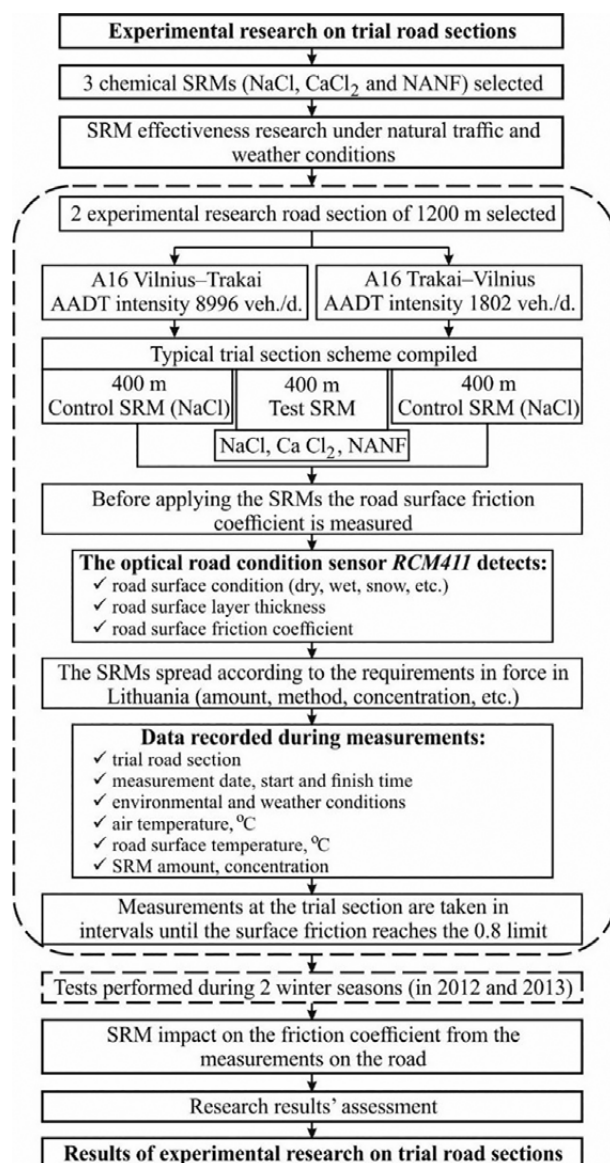


Fig. 3. Plan of experimental research on trial road sections (compiled by the author Ratkevičius, T)

Table 1. The summarised total slipperiness reducing materials effectiveness research results

Slipperiness reducing materials	Ambient temperature, °C				
	-3	-6	-9	-15	-20
NaCl	+++	±±±	±∓ -	---	---
CaCl ₂	±±±	±∓	∓∓∓	∓∓ -	-∓ -
NANF	± + *	± ∓ *	∓ ∓ *	∓ - *	- - *
MgCl ₂	∓ ± *	- ∓ *	- ∓ *	- ∓ *	- ∓ *
NCMC	+++	±±±	±∓∓	∓ - -	---

Note: + high efficiency, ± average efficiency, ∓ low efficiency, - no efficiency, * has not been studied.

In summarizing the experimental research results, similar tendencies of laboratory-based and field-based SRM efficiency research were noticed:

- in case of surface temperature ranging from -2 °C to -6 °C under the effect of NaCl and CaCl₂, the

friction coefficient varies in the same interval from 0.3 to 0.8 and reached the same values after an identical time interval, while in case of surface temperature lower than $-9\text{ }^{\circ}\text{C}$, all the researched materials are insignificantly effective.

- when the surface temperature reaches $-15\text{ }^{\circ}\text{C}$ and fall below the ice can be melted only using CaCl_2 and MgCl_2 salts. However, even their efficiency is considerably low, while all the other researched materials are not efficient at all.

NaCl efficiency compared to NANF is higher up to $-7\text{ }^{\circ}\text{C}$ both in respect of the ice and snow melting speed and in the value of the friction coefficient.

The assessment of the chemical materials for WRM tested in different aspects and the additional evaluation of the effect of these materials on the environment as well as the consideration of their price lead us to a conclusion that the most suitable choice for the highest maintenance level on roads are NaCl and CaCl_2 salts which are currently in use. It is noteworthy that prior to the application of the described and other alternative materials it is necessary to complete a thorough analysis of the requirement of their supply, transportation, storage and use (technical capacity)

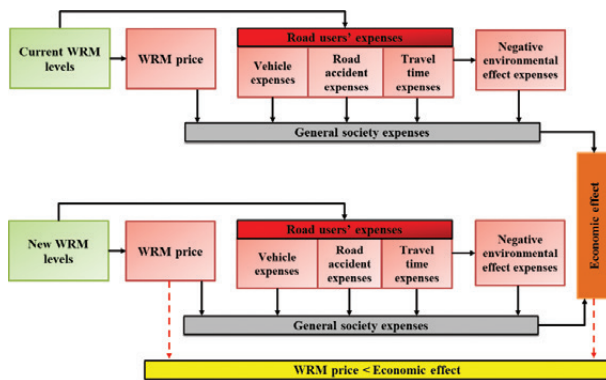


Fig. 4. The theoretical model scheme of winter road maintenance levels assessment (compiled by the author Ratkevičius, T)

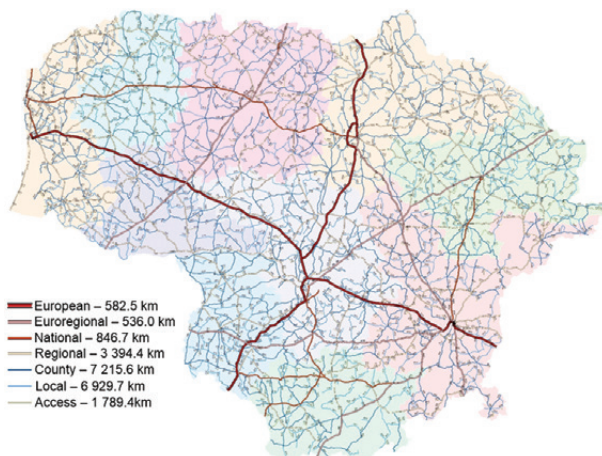


Fig. 5. Road network breakdown into categories according to the functional purpose (VGTU Road Research Institute scientific report *Functional analysis of the road network elements and preparation of the development scheme*)

as well as other specific features, whereas some of them are extremely sensitive to the humidity of the environment and are transported only in sealed vacuum bags, etc. Moreover, while taking into account their considerably high price (adding up all the expenses related to their purchase until application) it is feasible to perform the cost-benefit analysis since the practices of the foreign countries show that the scope of use of these materials is very small.

3. The theoretical model of assessment of winter road maintenance levels

The evaluation of the analysis of literature sources performed in the first chapter leads to a compilation of the theoretical model of assessment of WRM levels (Fig. 4). The theoretical model is made based on the main principles of the Winter Model developed by VTI in collaboration with the Swedish Road Administration. It is impossible to fully adopt the mentioned Swedish winter model as the model is adapted for the Swedish road network in particular.

To identify the economically optimal maintenance levels, it is necessary to calculate certain economic indicators – maintenance prices and road user cost road users' expenses. It was established that the economically optimal maintenance levels could be calculated for only one road element – the surface.

The most significant impact on the road user's expenses in the winter time is made by the condition of the surfaced portion of the roadway. Therefore, the application of the developed theoretical assessment model of WRM levels is dedicated to this particular element of the road. For the sake of the economically feasible assessment of WRM levels, the functional purpose of the Lithuanian national significance roads was taken into consideration. In such case, the quantification of public spending would be limited to the calculation of the average values of all the road functional dependence groups with the account of different maintenance levels. To identify the economically feasible road maintenance levels and to simplify the economic calculations and assessments the distribution of the Lithuanian national significance road network according to the functional purpose presented in the VGTU Road Research Institute scientific research report *Functional Analysis of the Road Network Elements and Preparation of the Development Scheme* were used (Fig. 5).

The important estimate values were identified for the compiled theoretical WRM levels quality assessment model, which make the most significant impact on the direct expenses of the road users related to safe traffic, travel time, vehicle operational costs and environmental ones. Based on the minimal public spending principle to identify the optimal WRM level, it is necessary to:

- calculate the maintenance price or the specific maintenance work type price of the certain road element for different maintenance levels;
- identify the types of road users costs (vehicle operational costs, time, road accident expenses) which are influenced by the road element maintenance or specific maintenance work type;

- calculate the road users costs for different maintenance levels of the certain road element or specific maintenance work type;
- identify the maintenance level for which the aggregate road element maintenance and road users costs would be the lowest; the same maintenance level will be the optimal one for that particular element or maintenance work type. In other words, in the case of maintenance of this particular road element under a certain level, the public spending will be the lowest, whereas in the case of maintenance of the same under a different (even higher) level the society will incur losses.

To get an exact result economically-wise while identifying the factors influencing the societal needs, it is important to know all the factors having an impact on the modelled size. However, while identifying the environmental and vehicle operational costs' estimates, a problem arose of the lack of reliable statistical data on these factors. Moreover, in Lithuania, the assessment of the mentioned factors would currently require immense material and physical resources. Thus, they are not being assessed in this paper.

4. Application of a assessment model of levels for winter road maintenance on Lithuanian national roads

After the analysis of the experimental research results, the evaluation of the national significance road maintenance levels' in the winter time was made by using the developed model. The benefit components of the national significance road maintenance in the winter time were evaluated, i. e. the road accident loss and travel time savings which are directly dependent on some beneficiaries (road users). The higher the volume of the road traffic, the more beneficiaries there are, and, consequently, the higher is the benefit provided by the road as well as the benefit provided by road maintenance.

It is common practice to compare the activities under analysis, their costs, and consequences with a certain zero type alternative of the absence of activity. This principle is also applied while calculating the benefit of the WRM: the benefit is calculated as the reduction of the vehicle travel time, vehicle operational cost and road accident loss because the WRM is performed. The higher the maintenance level, the lower are the travel expenses (and losses) and the greater are the savings. However, it would be difficult to imagine national significance roads where WRM would not be performed at all – such catastrophic

scenario would hardly be possible on national significance roads. While determining the degree of economic effect made by the road maintenance quality, a cost-benefit analysis was performed according to three WRM scenarios (Fig. 6):

- basic – the applied WRM levels during the winter seasons of 2011–2014;
- minimal – provided that all the national significance roads are being maintained by applying the lowest WRM levels;
- optimal – provided that national significance road maintenance levels in the winter time are applied with consideration of their functional purpose.

The experimental research results' assessment in Chapter 2 established the fact that the traditional chloride salts were the most effective for the Lithuanian weather and traffic conditions (Bulevičius *et al.* 2014; Laurinavicius *et al.* 2016; Ružinskas *et al.* 2016). During the cost-benefit analysis for the compiled three WRM scenarios the WRM technology and used chemical materials' costs applied in Lithuania in 2011–2014 were employed (Table 2).

As a consequence of the comparison of the alternative scenarios of WRM with the applied ones during the 2011–2014 winter seasons the following results were received (Table 3 and Fig. 7):

- according to the minimal WRM scenario, more than 160 representative road accidents would take place, while the total societal losses would reach 122.03 mln. Eur compared to the basic scenario;

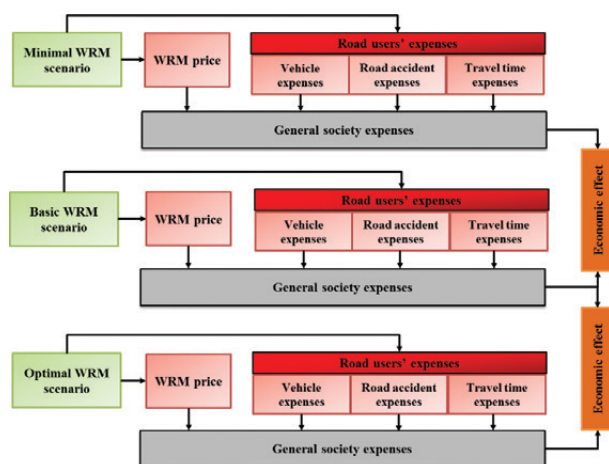


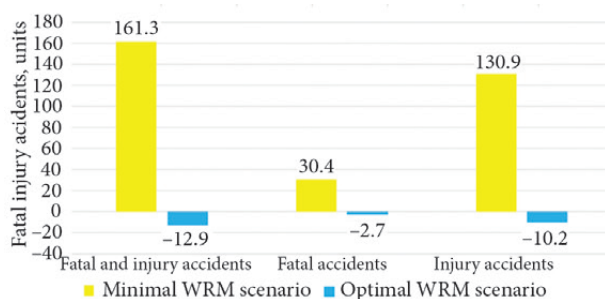
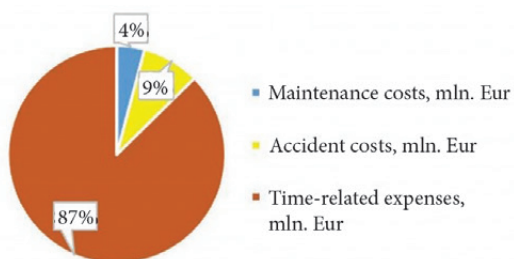
Fig. 6. The scheme of winter road maintenance levels assessment model (compiled by the author Ratkevičius, T)

Table 2. The continuous prices (costs) applied in the model for 1 km of winter road maintenance, Eur per year (season) in 2014 (Lithuanian Road Administration under the Ministry of Transport and Communications of the Republic of Lithuania)

Maintenance levels	Main roads		National roads	Regional roads
	2-lane road	1-lane road		
I – high	13907.0	8530.9	5118.5	1374.5
II – average	8757.0	5371.7	2584.9	983.1
III – low	4172.7	2559.7	1238.1	800.7

Table 3. The total expenses incurred by the society in the winter season in 2011–2014, in mln. Eur

Functional purpose of the road	BASIC		MINIMAL		OPTIMAL	
	Maintenance costs, mln. Eur	Society losses, mln. Eur	Maintenance costs, mln. Eur	Society losses, mln. Eur	Maintenance costs, mln. Eur	Society losses, mln. Eur
European	17.07	804.57	5.96	870.07	19.88	779.43
Euroregional	11.52	351.41	5.49	371.83	11.52	351.41
National	15.70	517.97	7.49	546.02	17.97	514.58
Regional	35.07	835.59	16.80	876.88	33.87	838.29
County	31.85	607.43	25.43	624.24	28.76	619.05
Local	22.19	211.73	22.19	211.73	22.22	211.69
Access	5.73	45.72	5.73	45.72	5.74	45.70
Total	139.13	3374.41	89.09	3546.48	139.96	3360.15

**Fig. 7.** The expected road accident amount identified by the model (the winter road maintenance scenarios applied in 2011–2014 winter seasons)**Fig. 8.** The total losses incurred by the society in 2011–2014 winter seasons

– according to the optimal WRM scenario 13 representative road accidents less would take place, while 13.43 mln Eur compared to the basic scenario would reduce the total societal losses.

Cost-benefit analysis results showed that the road maintenance costs in the winter season of 2011–2014 made up only approximately 4% of the total societal expenses compared to the **expenses** incurred by the society during road accidents and travel time expenses (which constitute 9% and 87% respectively) (Fig. 8).

The obtained modelling results prove that the offered assessment model of winter road maintenance levels makes it possible to determine the economically feasible road maintenance strategy for Lithuania's national significance roads.

6. Conclusions

1. Lithuanian national road maintenance in the winter time are currently selected without taking into consideration all the factors that determine the need for the society. Winter road maintenance level application while taking into account only the road category and traffic intensity does not ensure the indicators of the most advanced world countries and road functional purpose.

2. The analysis of the experience of Lithuania and foreign countries lead to suggesting a research methodology of the efficiency of chemical slipperiness reducing materials, which would allow making an objective assessment of the chemical materials alternative to traditional chloride salts under meteorological and traffic conditions in Lithuania. There were performed field and laboratory-based research of the materials efficiency based on suggested methodology. The research results showed that in case the air temperature is:

- up to -6°C the most effective material is the traditional sodium chloride;
- in case it is lower than -9°C all the tested materials are insignificantly effective.

3. The assessment of the analysed chemical materials for winter road maintenance tested in different aspects, and the consideration of the effect of these materials on the environment as well as the review of their price lead to a conclusion that the most suitable choice for Lithuanian conditions is the sodium and calcium chloride salts.

4. The calculation of the total public expenses during the winter seasons of 2011–2014 determined that the road maintenance costs made up only up to 4% of the total general expenses, while the expenditure related to the road accident losses and travel time costs respectively reach 9% and 87% of the total calculated public costs. The most economically rational way to apply the winter road maintenance levels which would minimize these total public costs. Based on the obtained modelling results the maintenance levels applied according to the optimal scenario during the 2011–2014 period up to 13 representative road accidents would be avoided, and more than 13 mln. Eur

would reduce the total public expenses. In the case of implementation minimal winter road maintenance scenario, more than 160 representative traffic accidents would take place, and the total societal losses would be 122 mln. Eur more compared to the basic scenario.

5. It is important to know all the factors having an impact on the modelled size, to get an exact result economically-wise while identifying the factors influencing the societal needs. However, while performing the environmental and vehicle operational costs' estimations, a problem arose of the lack of reliable statistical data on these factors. Moreover, in Lithuania, the assessment of the mentioned factors would currently require immense material and physical resources. Thus, they are not being assessed in this paper. In the future, it would be appropriate to evaluate these factors, this process requires systematic accumulation and processing of the data related to environmental and vehicle operational cost estimates. These factors is important because of the presence of clear tendencies showing that in the future such areas as environmental protection, climate change, and energy saving will take priority positions and their significance for the economy and the entire society will only increase.

6. The suggested model of assessment of winter road maintenance levels could be an effective tool for the application of the optimal maintenance levels, which would economically substantiate the winter road maintenance strategy, that best corresponds with the needs of the society.

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