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Current and future winter road weather condition forecasting in Lithuania

SUMMARY OF DOCTORAL DISSERTATION

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This dissertation was written between 2014 and 2019 in Vilnius university.

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SUMMARY

1. INTRODUCTION

The ongoing climate changes are undeniably caused by human activity (IPCC, 2014), and one of largest impactors is the transportation system. Therefore, most of research topics in this context are usually connected to mitigation of climate change: lowering the emissions of vehicle-produced greenhouse gasses and carbon footprint, using more of renewable energy sources in the transportation modes, encouraging the use of public transport, etc. However, an especially important topic – adaptation to climate change – is mostly untouched in this field. Keeping that in mind, this thesis focuses on climate change impact to road maintenance and traffic safety, aims to describe the influence more precisely, and forecast prevailing tendencies until the end of 21st century in Lithuania.

Changing climate obliges us to purposefully forecast road weather instead of just collecting and analysing the data. Short term forecasts (24–76h ahead) enables specialists to act accordingly, while long term (climate projections) forecasts allow for creation of focused strategies, ensuring good road conditions and safe traffic flow. Short term forecasts were first applied to operational work in 2018 in Lithuania (Stažytė, 2018), while long term projections were never calculated.

International experience showed (Ye et al., 2009; Vaisala, 2010; Kociánová, 2015; Pilli-Sihvola et al., 2015; Nefzi et al., 2016; NCAR UCAR, 2020) that the best tool for short and long term planning of road maintenance activities is road Maintenance Decision Support System (MDSS). Every organization or country usually have their own unique MDSS with one part or module that unites them all – road weather forecasting. Therefore, this thesis suggests an MDSS concept that could be implemented in Lithuania and would help to adapt to climate change more easily. Moreover, an evaluation of suggested road weather forecast module is presented in order to ensure a focused technology advancement in winter road maintenance in Lithuania and future development of Lithuanian MDSS.

Nevertheless, creation of MDSS is a very time and resource demanding process. Lithuanian traffic information system (TIS) project was launched in 2012 Q4 and is meant to collect, archive, analyse and manage road weather and traffic condition data. The system also incorporates traffic restrictions, jams, and multiple other traffic data sources, and is meant to be the main source of information for national road users and road maintenance workers in Lithuania (Lietuvos automobilių kelių..., 2012). Since then there were no significant improvements or changes to TIS. Nevertheless, the advancements in road meteorology and research has not stagnated in Lithuania: there have been multiple analyses and studies in the field (Ratkevičius et al., 2014; Laurinavičius et al., 2015; Šidlauskaitė et al., 2017), and an updated winter road maintenance manual has been released (Lietuvos automobilių kelių..., 2015). All this knowledge and information can be applied directly by expanding TIS, and creating a sophisticated MDSS in Lithuania.

A successful MDSS brings various benefits. According to data by Lithuanian statistics department (Lietuvos statistikos departamentas, 2019-06-01), 97.7% of passengers (about 372 million) and 53.9% of freight (about 89 million tonnes) were transported via roads in Lithuania in 2018. Thus, even a small disruption of traffic flow or any other part of transportation system can have a significant impact on economy of the country, and reduced road conditions may cost human lives.

Traffic conditions and safety in roads depend on multiple different meteorological factors. Intense shower rains, storms, fogs, and other extreme meteorological phenomena in summer can influence road conditions significantly. However, the real challenges for road maintenance workers come with winters, when there is a high chance for freezing rain, snow or black ice to form. During these phenomena the road gets extremely slippery and dangerous (Norrman et al., 2000).

A good example of a situation when sudden weather changes were inevitable but foreseeable, and could have been prepared for, happened on 17th of March in 2005 (also called "the black day") in Helsinki, Finland (Juga et al., 2012). During a very heavy snowfall 3 people have died, and more than 60 were injured in traffic accidents of more than 300 vehicles. The visibility was very poor, friction was very low, and drivers were driving too fast. The study showed (Juga et al., 2012) that even after an early warning was issued a day before, people did not choose their driving speed and distance between cars reasonably. The study also notes the importance of accurate meteorological information (weather radar data and forecasts).

Such examples are the reason for an extensive research effort on meteorological phenomena on roads. However, the effects of climate change on traffic systems started to get into scope of such research relatively recently. The link between climate change and transportation is usually described by analysing greenhouse gas emissions (Chapman, 2007). Nonetheless, the interest in changes of transportation system, road maintenance or traffic safety due to climate change has recently increased (Koetse & Rietveld, 2009; Gelete & Gokcekus, 2018). Even though not all opportunities and dangers for the transportation system are distinguished and fully evaluated, the general consensus of this research states that significant changes are inevitable, and they will be significant all around the world (Rowland et al., 2007; Andersson & Chapman, 2011; Chapman & Hooper, 2012; Hambly et al., 2013).

The climate change forecasts predict, that weather extremes will be more common, global and local mean air temperature in Lithuania will rise, and precipitation will increase, thus, new challenges are rising in relation to climate change (IPCC, 2014; Keršytė et al., 2015). However, these forecasts are very general and widely applied, therefore, they limit the ability to evaluate the effects for certain fields, like transportation system, and road condition. Such evaluation is necessary for certain actions to be planned out, performed, and for the system to adapt to the changing climate successfully. In order to drastically reduce increasing economic costs (Gelete & Gokcekus, 2018), and ensure safe traffic conditions, (Chapman & Hooper, 2012), the impact of climate change to transportation system or a part of it must be kept as low as possible.

Lithuania is not an exception for ongoing changes. It is situated in mid-latitude temperate climate zone and has a shoreline with the Baltic sea. Therefore, west side of the country has oceanic climate and going further from the sea to east-southeast direction it gradually changes to continental (Galvonaitė et al., 2013). Such climate ensures variable winter season weather conditions for road maintenance: westerlies keep it relatively warm and around 0 °C, while rain is often replaced by freezing rain or snow. Nevertheless, a sudden influx of dry and cold air from north can suddenly change the whole weather pattern, making it difficult for winter road maintenance services to work efficiently.

Currently there are road weather stations that automatically collect weather data and generate automated alarms in Lithuania, however, there's no road weather forecasting (LAKD, 2019-03-11). Without such forecasts there is no efficient way to plan winter road maintenance tasks and employ sophisticated methods, and specialists mostly must rely on their long-term experience. Thus, no sufficient MDSS is available in Lithuania in order to help in economic planning of winter road maintenance for both short and long term, while imperative in the near future.

1.1. Object, aims and goals of this work

The objects of this work were current and future winter road weather conditions of Lithuanian roads.

Aims of the work were:

1. to evaluate current and future changes of winter road weather conditions in the 21st. century.

2. to evaluate the importance and accuracy of a proposed winter road maintenance decision support system concept.

Goals of the work were:

1. to create indices that represent Lithuanian winter road weather conditions and evaluate their spatial distribution and variation.
2. to produce a forecast of indices that represent Lithuanian winter road weather conditions and evaluate their changes in the 21st century.
3. to create a concept of winter road maintenance decision support system (MDSS).
4. to evaluate the applicability of road temperature and condition model METRo to Lithuanian roads.
5. to evaluate the applicability of thermal mapping results to road parameter forecasting to Lithuanian roads.
6. to provide recommendations for creation of road maintenance MDSS and the integration of its parts into existing systems.

1.2. Novelty, relevance, and applicability of this work

Novelty

Road meteorology in Lithuania is a relatively new field of science since it only appeared when the first RWIS stations were installed (in 1999–2000). Thus, there is a limited amount of research that has been done. Moreover, this branch of meteorology is evolving rapidly and relatively recently used methods can quickly become obsolete.

Transportation and climate as one context have not ever truly been analysed in Lithuania. To add to that, most of the research was focused on the impact of pollutants from transportation to the environment and climate, not vice versa. This thesis presents a first evaluation of climate change impact to transportation and provides first road climate forecasts in Lithuania.

Furthermore, this work combines all of the road weather measurement and forecasting knowledge that was collected during the last 20 years in Lithuania and provides recommendations for its adaptation to practice in the future. This work contains analysis of thermal mapping data, verification of road condition forecasting model METRo, and a concept for Lithuanian winter maintenance decision support system, that could integrate both methods.

Relevance

The latest report by Intergovernmental Panel on Climate Change in 2014 emphasized the mitigation and adaptation alongside the physical processes involved in climate change. Lithuania is part of European Union, which has a general aim of adaptation: to make Europe less susceptible to impacts of climate change. Two of the main goals – to increase the knowledgebase based on which the decisions are made, and to perform actions of adaptation to climate change (Europos komisija, 2013). This thesis aims to evaluate the impacts of climate variability to transportation system in Lithuania. Thus, it provides the required information for choosing future development strategies.

One of the priorities of such strategies is to ensure the high resistance of Europe's transportation infrastructure. A dynamic winter road maintenance is a faster and more reliable service. However, it demands for a sophisticated maintenance decision support system with road weather forecasting module as its integral part.

Up until 2018 there was no road condition forecasting performed on an operational basis in Lithuania. Thus, the only national road maintainer in Lithuania – AB "Kelių priežiūra" – started integrating the Road status information system, that provides accurate and continuous winter road weather forecasts. Such system could become a part of a modern maintenance decision support system. However, it still requires constant upkeep and improvements in order to receive positive results.

Winter road condition forecasting provides everyday information about constantly changing weather. To add to that, it expands the possibilities for adaptation to climate change: maintenance professionals can act expeditiously to weather events and be more prepared for upcoming climate changes. Thus, this thesis offers a solution for winter road maintenance decision support system in Lithuania, that would not require extensive amounts of resources and investment to accomplish.

Applicability

All of the information and recommendations presented in this work can be directly applied to road maintenance task optimisation for both everyday activities and long-term future planning. For example, the suggested winter road maintenance decision support system concept could be inexpensively adapted as a part of already existing systems.

Moreover, the results that were achieved during the making of this work outlined the importance of road weather forecast in everyday winter road maintenance. The national Lithuanian road maintainer AB „Kelių priežiūra“ has used the results of this study for long term decision making: in order to ensure good road conditions during winter, economic optimisation of winter road maintenance tasks will be prioritised, with aim to eliminate “human factor” in maintenance activities as much as possible.

Methods used and results achieved during the making of this work can be applied to other branches of transportation system too, such as railroad maintenance and task optimisation. The climate forecasts could be easily adapted and applied to other areas of study also, e.g. the forecast of number of days per year when there’s snow (till 2100) provides relevant information for traffic safety and even agricultural task planning.

Analysis of impact of climate change to road and traffic conditions could be used for determining the appropriate strategy for adaptation to climate change and motivate the creation of action plans. As of writing this thesis, there are no transportation sector adaptation goals in Lithuania.

Moreover, the results and methods presented in this thesis can be used for future research in road meteorology, e.g. evaluating future summer road weather conditions, continuing analysis and verification of road weather forecasting methods, etc.

1.3. Defending arguments

1. Winter road weather conditions will become lighter; however, the danger of extreme and unexpected events will remain.
2. A comprehensive winter road maintenance decision support system ensures that professionals are effectively kept up to date on changing weather conditions.
3. Numerical road weather microclimate modelling is a sufficient way to provide road weather forecasts in Lithuania.
4. Good quality and trustworthy thermal mapping results are harder to obtain in flat lowlands that have constant advection of various air masses.

2. STRUCTURE OF THIS THESIS

This thesis is divided into several different parts:

1. The evaluation of climate conditions in Lithuanian roads in 21st century. Here the impact of climate change to roads and their microclimate is being addressed. This part describes current and future climate conditions that outline the importance of a modern MDSS.
2. The description of concept for MDSS. The suggested version of the system would include the methods that have been successfully applied to Lithuanian roads already (thermal mapping and numerical road weather forecasting). This solution would be less investment heavy and easier to implement.
3. The applicability study of a numerical road weather forecasting model. Verification results of the model are presented here alongside the evaluation of its applicability to Lithuanian roads.
4. Results of thermal mapping and the problem of data quality certainty. The latter is described by interpreting thermal mapping results and comparing them to other dataset, collected in another country.
5. This work includes recommendations for the creation and integration of MDSS or several of its parts. These recommendations were made in consideration with the acquired information and results of this thesis.

3. DATA AND RESULTS

Firstly, it was important to evaluate current and future climate conditions in Lithuanian roads. To achieve this, road climate predictions had to be made. Data that was used in this study was as follows:

- For the evaluation of current conditions, 18 meteorological stations in Lithuania for 20-year period (1985–2005) were used: daily mean, maximum and minimum temperatures, precipitation amount, and maximum wind speed (gusts). Data acquired from Lithuanian Hydrometeorological Service under the Ministry of Environment (LHMS).
- For predictions of future climate, 3 global circulation models (GCMs) were used: GFDL-CM3 (Donner et al., 2011), NorESM1-M (Bentsen et al., 2013) and HadGEM2-ES (Martin et al., 2011). Data was acquired from the fifth phase of the Coupled Model Intercomparison Project (CMIP5) output (Taylor et al., 2011): daily mean, maximum and minimum temperatures, precipitation and snow fluxes, and maximum windspeed near the surface. NorESM1-M model did not have windspeed data, thus it was not used for one of the parameters (AD – days with adverse driving conditions, see below).

GCMs daily values were classified by time: reference period (1986-2005), near-term (2016-2035) and long-term (2081-2100) projections. The period 1986-2005 was used as a reference since it was recommended in the latest IPCC AR5 assessment (IPCC, 2014). Near- and long-term projections were made using 4 Representative Concentration Pathways (RCPs; Moss et al., 2010; van Vuuren et al., 2011): RCP2.6, RCP4.5, RCP6.0, and RCP8.5.

3 indices were created in order to describe road surface and driving conditions. Firstly, there's *days around 0°C (T±0)* – number of days

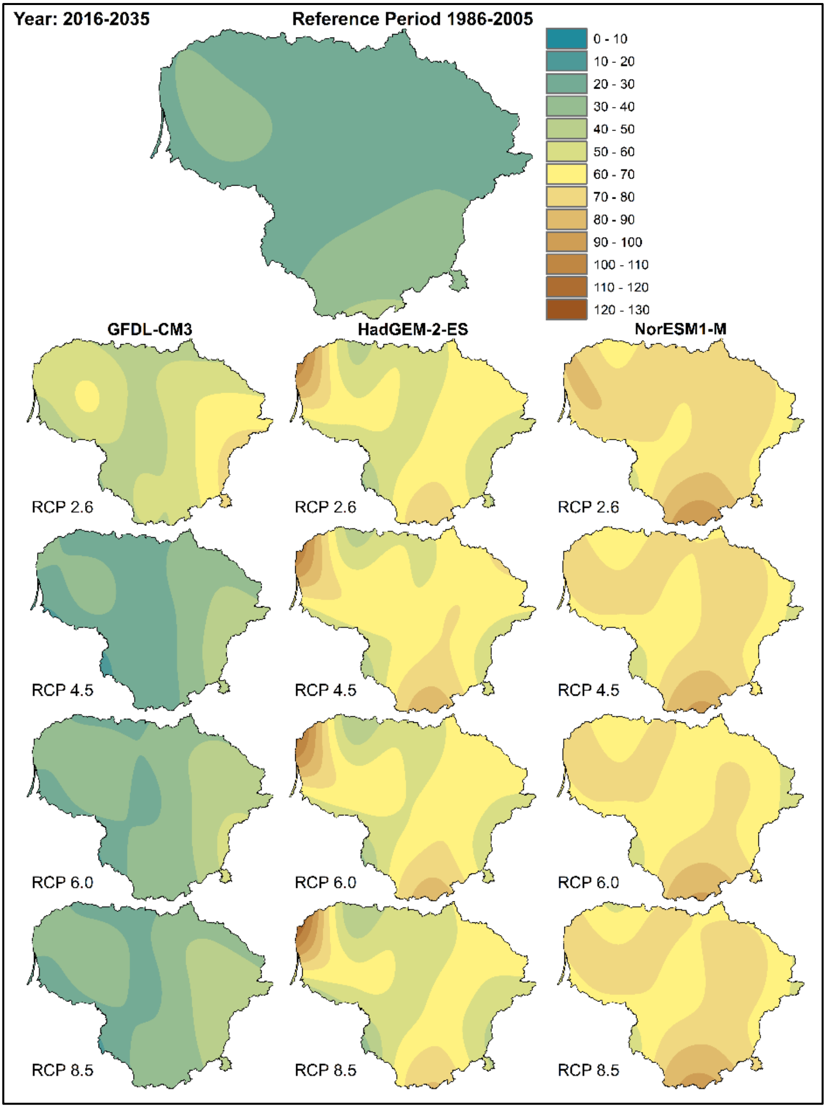

Figure 1 Number of days when daily air temperature fluctuates around 0°C (T ± 0) per year in Lithuania: reference period (top) and near-term (2016–2035) projections under different RCPs and GCMs.

per year when daily air temperature fluctuates around 0°C (maximum temperature is positive, and minimum is negative). This parameter or a concept of it is often used in winter severity estimations for road maintenance. Secondly, *days with snow (SD)* – number of days per year when snow flux is ≥0.2 mm. Precipitation, especially in the form of snow, is another parameter commonly used in winter severity estimations. And thirdly, d*ays with adverse driving conditions (AD)* – number of days when snow flux is ≥0.2 mm, maximum wind speed is ≥10 m/s and mean air temperature is <0°C per year (no AD index calculations were made for NorESM1-M in relation to its outputs lacking maximum wind speed parameter). This parameter was meant to describe days that have inclement weather conditions for driving and road maintenance in general, e.g. blizzards.

ESRI software (ArcGIS desktop, version 10.6, with Spatial Analyst extension) was used for interpolation of values between meteorological stations using spline interpolation method, and for creation of climate condition maps for the reference period, near- and long-term future projections. An example of such maps is given in Figure 1.

Reference period showed that there are around 20–40 days per year in Lithuania when temperature fluctuates around 0°C (Figure 1). To add to that, there is around 20–35 days when it's snowing, and around 1–15 days with adverse driving conditions. This sums up Lithuanian winters as stressful periods for winter road maintenance professionals: on average, every other day requires maintenance tasks being performed due to snowfall or ice formation on road with some blizzards and extreme conditions from time to time.

However, the structure of Lithuanian winter will change drastically by the end of 21st century. The long-term predictions display a radical increase of T±0 days, a decrease of SD days with as little as no snowfall at all in some regions, and AD days will remain of a significant amount only in areas with higher winds, e.g. the Baltic coastline.

Such changes will require road maintenance professionals to adapt quickly and rely even more on sophisticated technologies to predict everyday weather patterns. One of such technologies can be a winter maintenance decision support system (MDSS). Thus, a concept for MDSS in Lithuania is presented (Figure 2).

A two-dimensional road weather forecast could be achieved using thermal mapping road fingerprints in combination with a road weather forecast model output. The resulting forecast then could be displayed in Lithuanian traffic information system (TIS) and used as a tool by maintenance professionals. However, both of MDSS parts (thermal mapping and road weather forecast model) need to be assessed in order to determine their applicability to Lithuanian roads.

The Model of the Environment and Temperature of Roads (METRo) model was chosen for the road weather forecasting. This

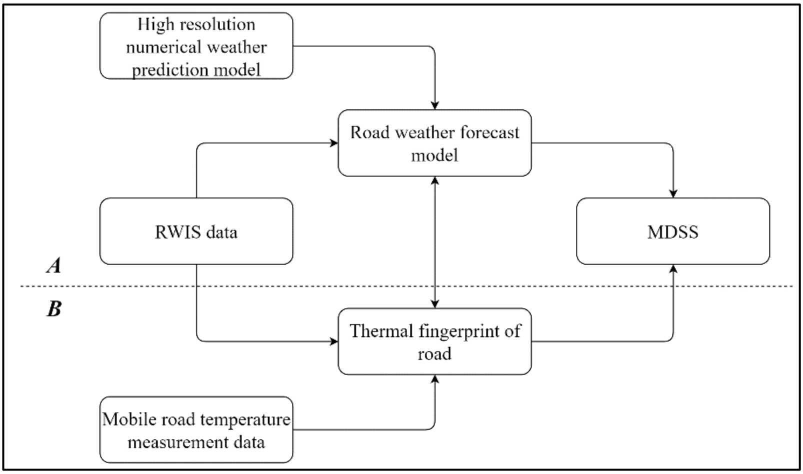

Figure 2 MDSS concept in Lithuania, that could incorporate thermal mapping and road weather prediction data. A – shows one-dimensional road weather forecast at RWIS location, B – two-dimensional forecast, that could be achieved using thermal mapping road fingerprints.

model was created in 1999 by Environment Canada scientists. It is available for free under GNU General Public License (Free Software Foundation..., 2007) and is being constantly developed to this day. METRo is a one-dimensional energy balance model, that requires input from high resolution numerical weather prediction model, RWIS sensors, and road bank layers (static information).

For the METRo verification study, the following data was used:

- RWIS sensor data from stations on "Via Baltica" (European route E67 or A1, A5, A8 and A17) and Vilnius–Panevėžys (A2) roads: Maišiagala, Saločiai, Šėta, Šilai, Skriaudžiai. Time period: from 2016-11-14 till 2017-01-04 (51 days in total).
- Numerical weather prediction model data from LHMS: High Resolution Limited Area Model (HIRLAM). Data was renewed every 6h and forecast was available for +24h for every 1h.
- Road bank layer information from Lithuanian road administration (LRA) under the Ministry of Transportation.

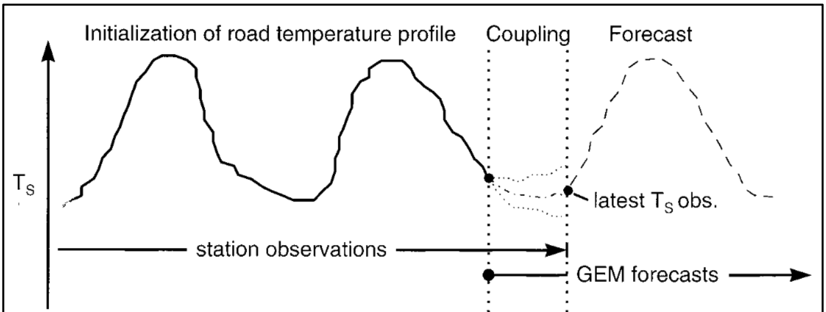

Figure 3 The three stages of METRo forecast process: road surface temperature profile T_s from RWIS, a coupling stage, and the forecast. During the coupling stage, both station observations and meteorological Global Environment Model (GEM) forecasts are used to determine a correction coefficient for radiative fluxes (Crevier & Delage, 2001).

METRo requires a “coupling” stage – when there’s an overlay of RWIS and weather prediction model datasets. Thus, 36h of RWIS data with 24h HIRLAM forecast was used, with 12h overlap. See Figure 3 for explanation of the coupling stage.

METRo model verification results provided some insight into possible problems for model implementation: the resulting forecast depends greatly on input data quality, and model forecasting skill depends on numerical weather prediction model skill. The largest biases were observed in those stations where there was the largest amount of missing data. Moreover, model performed worse during days when the weather was influenced by a larger atmospheric circulation phenomenon, e.g. atmospheric front. Nevertheless, METRo model performed well for the tests and showed good potential for application in Lithuanian roads.

Taking into consideration road maintenance specialists, their habits and psychology, they would most likely rely on only one parameter while making decisions – road condition. It is difficult to verify the road condition forecasts due to lack of observational data and the frequency of false measurements by the sensors. However, both available datasets (observations and forecast) were converted into binary format: the condition either requires road maintenance or not. These new datasets were compared against each other and it was found that 55% of forecast events were correct. Therefore it is recommended for road maintenance specialists to always evaluate the information in all it’s complexity rather than simply make decisions based on one parameter.

METRo model provides forecast for one point in space – RWIS station location. In order to get forecasts for the whole road stretch, it must be extended by combining it with Thermal mapping data. Thermal mapping study was performed using TM data from 2015, when “Via Baltica” (European route E67 or A1, A5, A8 and A17) and Vilnius–Panevėžys (A2) roads were mapped (Figure 4).

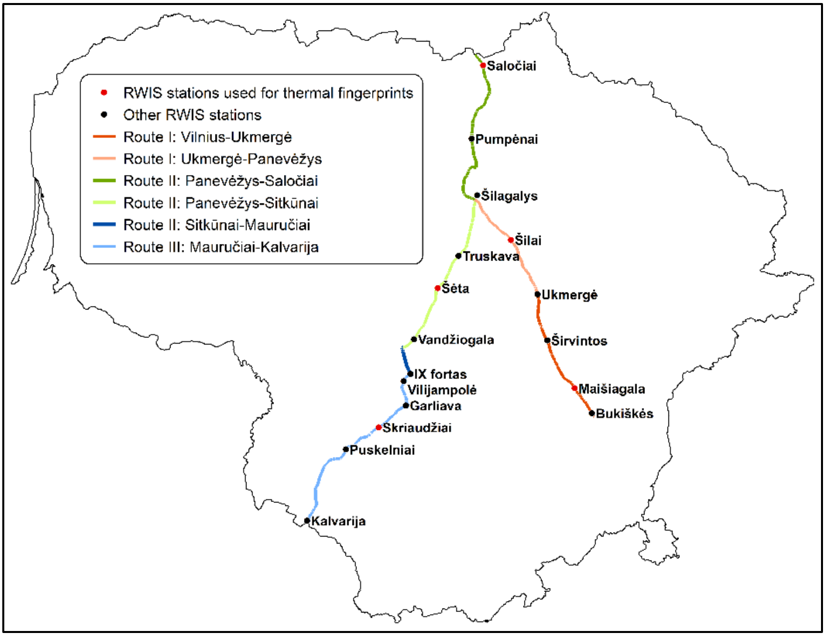

Figure 4 Thermal mapping routes (I, II and III), road sections (marked with different colours) that were mapped in 2015, and RWIS stations that were used in the study.

The TM data evaluation study showed that most of road surface temperature deviations are relatively small (±0,5°C). This is consistent with previously performed TM in 2000–2001: the reported variation amplitude was only 1.1–2.3°C (Bukantis, 2000, 2001). However, the "cold spots" of the road, where slipperiness was most probable during clear nights, were still distinguished.

It was decided to compare these results with another TM dataset, preferably a more hilly or mountainous region. Raw TM data is usually hard to acquire because it is mostly unavailable anymore after the initial analysis is performed. However, data from TM of Czechian roads of the same year (2015) was acquired and used for further study.

Dataset included a section in motorway No. 18 (from Olbramovice to Příbram), and a section in motorway No. 19 (from Tabor to Lety).

The comparison of datasets has shown that the connection between terrain and road surface temperature was weaker in lowlands than in the more hilly or mountainous regions. Terrain changes in Lithuanian roads are a lot more subtle and gradual, compared to Czechian roads. Therefore, consistent cold spots were discovered only in the more sudden terrain drops in Lithuania, e.g. river valleys, and during extreme or clear nights only. Whereas in Czechian roads most of the analysed routes exhibited similar temperature patters all across the road, which were clearly distinguishable even during damp or overcast conditions.

It was concluded, that in former areas the weather is more often influenced by adverting air masses and general weather patterns and not the local environment and microclimate. Moreover, lowland TM was not as replicable as more mountainous TM.

To sum up, TM application in Lithuania is questionable, unless a great care for data quality is aimed for. Thus, this work was used for creating of 10 recommendations for future MDSS development.

4. RECOMMENDATIONS

1. It is recommended to further develop both RWIS and TIS systems in Lithuania, and to integrate them both into a modern MDSS. The results presented in this thesis showed that road weather conditions will change in the 21st century. In some areas the changes will make road maintenance easier, but in others – it will not. Therefore, a modern MDSS can help to ensure climate change resistant transportation system.
2. This work proposes a version of MDSS, that would contain two integral parts (methods) that were already applied to Lithuanian roads – thermal mapping and numerical road weather forecasting. In combination, both methods can provide two dimensional weather forecast (for road sections). It is particularly important to calculate forecasts expeditiously: forecasts should be run at least every 4 hours, best – every 1 hour. The research has showed, that model accuracy decreases significantly over time.
3. When using METRo model for other studies and research, it is recommended to evaluate and include additional data if available. Road bank layer configuration was tested in one of the studies. The data was collected from latest reconstruction plans of the roads. However, it showed that by changing the parameters artificially the model performance could be improved.
4. Hardware condition, calibration, and data quality are of the highest importance. It was found that even the smallest errors can cause inaccurate results. Moreover, the more data interruptions there are, the lesser the results of METRo will be.
5. When making a winter maintenance decision it is recommended to take into consideration multiple parameters, rather than just one, e.g. road condition. It is important to evaluate all available meteorological information and make a multifaceted decision.

Moreover, it is advised to consider the time of day, because the model has the highest accuracy during hours when there's the highest chance for slipperiness to occur, e.g. 06:00–10:00.

6. In order to ensure accurate thermal fingerprints while thermal mapping, it is advised to closely follow recommendations of the methodology. For example, make sure to take measurements 2h after sunset and 2h before sunrise, or perform thermal mapping during accurately determined weather type. If there are any doubts about the quality of the measurements it is recommended to perform additional measurements and reduce the probability of error.
7. Thermal mapping should be repeated on the same road every 2–3 years or once a reconstruction has been done. Even if the road was not changed during the last few years, the objects around the road that affect it's thermal properties are constantly changing. For example, a nearby forest might regrow or expand.
8. It is very important to ensure good state and proper maintenance of mobile sensors used in thermal mapping. Research has shown, that road surface temperature deviation variation is minor in Lithuania, therefore, errors made by unaccurate sensors could affect the results.
9. RWIS sensor maintenance and data quality is of high importance too, because this station data will be the reference point for forecasts. Road surface temperature should be the same for mobile and stationary measurements (a minor bias of ±0,1℃ is allowed).
10. The calculated forecast should be presented for users in TIS (or MDSS) in an easy and understandable way. Tools for visual data manipulation should be intuitive and should not overburden the screen. The best way to visualize a 2D road condition forecast is by using a vector map (GIS) layer, where different colours would represent different road conditions.

5. CONCLUSIONS

1. To summarize the results of road climate forecasts, the driving conditions should improve and less winter road maintenance actions will be needed by the end of 21st century. However, the changes will not be same for different phenomena: days with temperature variation around 0°C will increase, there will be less snow and it will happen less often, moreover, days with adverse weather conditions (e.g. blizzards) will decrease, except for the coastal area, where it will most likely increase.
2. According to global circulation model (GCM) projections it is very likely that number of days with temperature fluctuations around 0°C will drastically increase by the end of the 21st century: about +20 days per year in lowlands and +80 days per year in the coastal areas (on average 50–100% more than currently). The increase of the number of such days will put a strain on winter road maintenance, because there will be more days with slippery road conditions, and there will be a higher chance of traffic accidents.
3. Days with snowfall will greatly decrease by the end of the 21st century. For example, the GCM predictions showed that there can be –15% decrease with RCP4.5 pathway, and as much as –100% decrease with RCP8.5 pathway. Moreover, it is expected that in some areas there might not be any snowfall at all, especially during warmer winters. Since there will be less snowfall, driving conditions should improve, and road maintenance should be less challenging and resourceful (less de-icing materials and task performance time needed).
4. It is very likely, that days with adverse driving conditions (e.g. blizzard) will increase in the near future, because of increased winds in some areas in Lithuania. However, the conditions should improve by the end of the 21st century: on average the number of days will decrease from 1–15 days per year currently,

to 0–10 days per year by 2100. The number of days with adverse driving conditions will remain higher around areas with generally higher winds, e.g. Baltic coast.

5. During the verification process of METRo model, it was concluded, that there are no significant differences between different RWIS stations. The least accurate road surface temperature forecasts were produced in Šėta station – mean absolute error (MAE) was 1.28°C, and the most accurate forecasts were in Šilai station – MAE was 1.05 °C. The least accurate road sub-surface temperature forecasts were produced in both Šėta and Saločiai stations – MAE for both was 0.81 °C, and the most accurate – Šilai station again with MAE of 0.67 °C. These differences were mostly influenced by the quality of the initial data and not the model itself. Therefore, in order to ensure high quality METRo forecasts, it is recommended to increase the reliability of the station and not the frequency of data transmission.
6. The largest bias for METRo forecasts was observed during the more intense atmospheric circulation events, e.g. during passing of frontlines. Thus, weather forecast data and the skill of the numerical weather model has the highest influence to METRo forecasting skill. This is the most evident during days, when local weather is more influenced by general synoptic situation rather than local microclimate of the road. During the study of applicability of METRo to Lithuanian roads, all of the events with high bias (e.g. when Maišiagala station road temperature forecast was 1–2°C lower than measured) corresponded to positive temperature advection from South or Southwest.
7. METRo road condition forecast is exceedingly difficult to verify, and a lot of assumptions must be made. It was found that 55% of times METRo forecast mostly fit the measurements (for example, times when the forecast predicts snow on road, but the measurement was ice, were considered as “fit”). Therefore, it is

recommended to always analyse all the parameters before making a decision for winter road maintenance task.

8. Thermal mapping (TM) results have shown that most of the mapped roads have relatively low deviations of road surface temperature (±0,5°C) from RWIS station data. Higher deviations are only observed in certain short road segments that have generally different microclimate (e.g. bridges and overpasses). The road that had the highest deviation was Sitkūnai–Mugučiai: +9°C. The road that had the lowest variation was Panevėžys–Saločiai, where more than 88 % of values were ±0,5°C and only slightly higher deviations were only observed on overpasses (>±1,0°C).
9. Lithuanian TM data was compared to Czechian TM data and it was concluded that the connection between terrain and road surface temperature was weaker in lowlands than in more hilly or mountainous regions. In former areas the weather is more often influenced by adverting air masses and general weather patterns, and not the local environment and microclimate. Moreover, lowland TM was not as replicable as more mountainous TM. Decent results in lowlands were only achieved during clear ("extreme") nights, while most of TM data from mountainous regions had similar tendencies during all weather types.
10. Taking into account all of the results presented in these studies, the suggested MDSS concept and its parts are considered suitable for Lithuanian roads. However, all the data involved in calculations must be of high quality in order to get the best results. Most of biases and inconsistencies presented in this thesis could be explained or even fixed in the future if higher quality of input data would be achieved. For example, best METRo forecast results were achieved in those locations where there was the least amount of missing data from the station.

LIST OF PUBLICATIONS

There are 2 published papers (in English) in referred scientific journals (ISI WoS) containing the results of this thesis:

1. Šidlauskaitė L., Kažys J. 2019. Changing temperate climate conditions for winter roads in the twenty-first century (Lithuanian example). Journal of Theoretical and Applied Climatology. https://doi.org/10.1007/s00704-019-02938-1
2. Šidlauskaitė L., Bogren J. 2019. Thermal mapping in flat lowlands and undulating uplands – a comparison of results. The Baltic Journal of Road and Bridge Engineering. 14(3): 326-340. https://doi.org/10.7250/bjrbe.2019-14.446

There are 3 published conference proceedings:

1. Šidlauskaitė L., Kažys J. 2018. Future climate conditions for winter roads in Lithuania. XVth International winter road congress, 20–23 February 2018, Gdańsk, Poland.
2. Šidlauskaitė L., Bogren J. 2018. "Thermal mapping in flat lowlands and undulating uplands – a comparison of results". SIRWEC2018: 19th internation road weather conference, 29.5.–1.6.2018, Smolenice, Slovakia. Smolenice: SIRWEC, 2018. p. 49–51.
3. Kažys J., Šidlauskaitė L. 2018. "Future climate conditions for summer roads in Lithuania". SIRWEC2018: 19th international road weather conference, 29.5.–1.6.2018, Smolenice, Slovakia. Smolenice: SIRWEC, 2018. p. 73–75.

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SHORT DESCRIPTION ABOUT THE AUTHOR

Lauryna Šidlauskaitė was born in 1988 in Kaunas, Lithuania. She graduated Kaunas Salomėja Nėris secondary school (currently known as Kaunas Gediminas secondary school of sports and health) in 2007 and was accepted into Vilnius university (VU in Vilnius, Lithuania) for a “Hydrology and Meteorology” bachelor degree program. During these years in university she gradually leaned towards road meteorology and defended her bachelor thesis “The evaluation of stations’ representativeness in road weather information systems (RWIS)” in 2011.

After a successful graduation Lauryna was accepted into VU for a “Hydrometeorology” masters degree program and continued her studies in road meteorology. She received The Steponas Kolupaila Student Aid Fund award from Lithuanian Foundation (USA) for her achievements in the meteorology field as a student in 2012. She defended her masters thesis “The modelling of road surface parameters and slipperiness assessment” in 2013.

Shortly after graduating Lauryna was accepted into VU physical geography (06P) doctorate program in 2014. During the years in the program she continued her work in road meteorology in Lithuania by actively taking part in several projects related to her study field. As of the time of defence of this thesis in 2020 she is employed at AB “Kelių priežiūra” which is a government owned road maintenance company. Lauryna is an integral part of technology develompment team in the company and continues to expand her knowledge and experience in road meteorology.

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