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DEPENDENCY OF PAVEMENT ROUGHNESS LEVEL ON THE TYPE OF ROAD WORKS

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Abstract. Managing the condition of the road network is essential to ensure sustainable and efficient road maintenance and development. The term *asset management* is broad, it describes the actions of infrastructure management – the activities associated with structure maintenance and operation, asset improvement, and development. The article analyzes the impact of the road works on the reduction of Road Roughness Index (IRI) depending on the road type and the type of repair. The annual change in IRI is estimated taking into account certain conditions - pavement structure class, road type, heavy traffic flow, repair type. The research analyzes the data of control assurance protocols of road sections repaired in 2008–2016 and the data of routine pavement performance surveys of the Lithuanian road network conducted in 2019. The results of the research are of considerable practical significance, it is recommended to include them in the repair selection module used by the Lithuanian pavement management system.

Keywords: IRI, pavement condition survey, pavement management system, road works, road roughness index.

Introduction

The importance of Lithuania's road infrastructure is reflected in the fact that more than a half (54%) of all goods are transported by road,

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the road sector also makes a significant contribution to gross domestic product (road transport generates about 6% of GDP, transport system – 12%) (Lietuvos automobilių kelių direkcija (LAKD), 2020a).

Road infrastructure should be efficiently managed to ensure that the required destination is reached optimally quickly and safely using high-quality roads. Thus, the roads need to be constantly maintained and repairs should be carried out on time.

Road infrastructure managers face serious challenges and take on important responsibilities – to take care of the public sector assets entrusted to them, as well as the roads and structures attached to them. Their task is to find a proper balance between customer requirements for road quality at affordable prices and road owners' need to get a decent return on the invested money.

Nowadays, planning road network repairs and ensuring road quality with modern methods requires using asset management systems, or pavement management systems (PMS). These tools are used by road maintenance and managing organizations in order to receive objective information and conduct analysis of the current road condition. Application of these tools enables them to make consistent, cost-effective decisions on maintaining and improving the condition of the road network. PMS can be considered a clearly defined and transparent road network planning and maintenance process aimed at minimizing budgetary costs and environmental impact while maximizing pavement life and consumer safety (Zofka et al., 2014). In order to run an efficient pavement management system, it is essential to have access to the reliable input data and use models of changes in the condition of the pavement, action selection algorithms, etc. established by long-term observations and research-based methods.

It should be noted that PMS can be implemented and structured in a variety of ways. It usually depends on the owner of the road and usually includes inventory data of the road along with the relevant information on its current and historical performance, traffic loads, construction, and maintenance history (Zofka et al., 2014).

There are three pavement performance indicators commonly used in running the PMS process at the network level: pavement roughness, deflections, and distresses (Zofka et al., 2014).

The International Roughness Index (IRI) was developed by the World Bank in the 1980s to uniformly evaluate the infrastructure of developing countries; it has become the most widely used parameter in the assessment and management of road systems worldwide. Technically, IRI is a scale of reactions (measured in m/km) of a car (called the "Golden Car") to road surface irregularities. IRI is calculated using a quarter car model moving at 80 km/h, the response of which is accumulated to obtain the values of the roughness index. As this method is mathematical, it is not affected by either the measurement procedure or the vehicle on which the road profile measurements are made (Mathew et al., 2018) and is a computer-based "virtual response-type system" (Sayers & Karamihas, 1998). The survey that allows determining IRI with laser-based systems is called road surface profiling.

In the beginning, roughness was measured with a profilograph, but later such survey equipment as response-type inertial profilometers employing simplified measurement procedures became more popular. The American Society for Testing and Materials (ASTM) has developed standards for a method that continuously measures the pavement surface profile in the longitudinal direction. This method is called the Accelerometer Established Inertial Profiling Reference, it enabled researchers to do large network surveys and analyze data fast (Beckley, 2016). Road surface profiling is the most common method used for quality control of road works and monitoring of the rutting and distress propagation over time (Edeskär et al., 2017).

Minimization of the prediction error of the pavement roughness allows for budget savings through timely intervention and accurate planning significant (Georgiou, Plati, & Loizos, 2018). After applying treatment scenario in the PMS analysis, the higher accuracy of deterioration model can ensure budged savings.

This study examined the values of the International Roughness Index (IRI), which is one of the key parameters describing pavement condition, having an impact on driving quality, fuel consumption and driving safety. The International Roughness Index has been widely used to assess the surface roughness of a pavement. Increased pavement roughness increases fuel consumption, frequency of vehicle maintenance, repair costs, and greenhouse gas emissions, as well as reduces vehicle efficiency (Abdelaziz et al., 2020; Robbins & Tran, 2016; Stankevičiūtė, 2010). At the same time, according to experts from Lithuania and other countries, road roughness has a small impact on traffic safety compared to such factors as drunk driving, speeding, fatigue, etc. (Vaitkus et al., 2016). It should be noted though that this is the only parameter to describe pavement performance quality. Other associated factors describe weather related conditions or inadequate road geometry parameters.

Unfortunately, the IRI value by itself does not describe what type of distress may be occurring in a pavement surface that increases pavement roughness, but it does provide the agency with the estimate of the riding quality experienced by road users. At the same time, it is a universal parameter and many road agencies can use the same technology and compare results (Zofka et al., 2014).

A number of road managing agencies around the world consider the initial IRI value (IRI obtained immediately after construction) as a quality assurance criterion, and the IRI value is determined during periodic measurements as an indicator pointing at the necessary pavement maintenance actions or reconstruction needs (Abdelaziz et al., 2020). Road roughness can be objectively determined and can be subjectively determined by assigning a value to pavement condition (Psalmen Hasibuan & Sejahtera Surbakti, 2019); roughness measurement is required to determine total vehicle operating costs, overall ride quality, or general surface condition (Sayers & Karamihas, 1998).

Researchers from Vilnius Gediminas Technical University in Lithuania analyzed experimental pavement structures. Analyzing these structures after five-year operation, they concluded that the differences in the IRI are related to construction and are not influenced by the type of the pavement structure. Data analysis showed that road roughness decreased after five years (Vaitkus et al., 2012). At the beginning of the pavement service life, the longitudinal unevenness is very low, demonstrating slow deterioration rate except when failures occur during the construction process, such as compaction, etc. (de Lurdes Antunes et al., 2016).

A project carried out by Chen et al. in 2014 concluded that initial IRI, transport intensity, and environmental factors are important factors that may affect the long-term IRI of the network (Chen & Bai, 2019). In the same study the recommendation to use developed IRI models in NCDOT treatment decision-making process and decision trees, triggers for treatment selection (Chen et al., 2014).

In 2014, Abdelaziz et al. found that asphalt overlay was the most effective road maintenance activity that resulted in a significant reduction of IRI value. Repairs or road maintenance, such as crack sealing, surface grinding, manual premix patch, full-depth patch, skin patching, strip patching, and other similar technologies did not contribute to the reduction of IRI (Abdelaziz et al., 2020).

In the 2014 NCDOT research, it was concluded that smooth pavements with smaller initial IRI values deteriorated at a slower rate and had long service life (Chen et al., 2014).

In the study conducted in 2016, Gong et al. found that the initial surface condition was a significant factor in a long-term roughness and rutting change. The researchers compared road sections with surface treatments on both poor and good or fair sections and concluded that surface treatment on poor road sections was more likely to cause higher rutting and roughness propagation in the long term (Gong et al., 2016).

In 1996, FEHRL initiated the PARIS (Performance Analysis of Road Infrastructure) project, which aimed to develop a coherent set of pavement deterioration models for use in pavement management systems. In this study, the dependences of the deterioration curves of various pavement performance indicators and the corresponding forms of the deterioration curves were determined. A linear dependence with time (pavement age) was determined for the pavement roughness deterioration curve. No direct relationships between the yearly deterioration and other cluster variables were determined (EU, 1999).

The results of this study may be used as the input in the development of the Lithuanian pavement management system, since they will allow determining IRI reset values after a certain road work type has been carried out. This may affect the results of road network condition modeling when the road work type is selected for a PMS. It is important to mention the uncertainty of deterioration curves – in the case of this study, it was attempted to determine the speed of the pavement roughness dependence in time after the road works carried out to understand the value of road works. The influence of other parameters was not assessed.

1. Requirements towards road roughness

The Technical Regulation for Roads defines three types of road construction (further – road works): new construction, reconstruction, and repair of a new road. The last type is divided into two sub-types: major repair and simple repair (Lietuvos Respublikos aplinkos ministerija, 2008).

The Lithuanian road design rules specify three procedures to upgrade pavement structures (Lietuvos automobilių kelių direkcija (LAKD), 2019):

- Renovation by completely changing the existing pavement structure;
- Renovation by replacing part of the existing pavement;
- Renovation by applying new layers on the existing pavement structure.

Analyzing the information stored in the Lithuanian Road Information System LAKIS about the repaired sections of the state road network, five types of repairs can be detected:

- Surface treatment;
- Renewal of the asphalt wearing layer;
- Renewal of bearing capacity (in sectors);
- Major repair;
- Reconstruction.

Surface treatment is considered a simple repair. In this study, however, this type will be delineated from simple repair; comprehensive information on the applicable types of repairs in the state road network will be provided. Unfortunately, no detailed information is stored in LAKIS about repair works, just the common name (type) of repair and date.

Description of the road works implemented on the analyzed road sections:

- Surface treatment is the installation of a thin protective wearing layer. It is carried out on the surface of the asphalt pavement by spraying the binder and spreading natural or binder-treated stones. There are three types of surface treatment: 1) single surface treatment, 2) single surface treatment with double stone spreading, and 3) double surface treatment. Surface treatment is intended to protect the pavement from the deterioration effects of the atmosphere and traffic. Using this method, it is necessary to pre-align the profile in both the transverse and longitudinal directions.
- Renewal of the asphalt wearing layer – road works implemented to repair the pavement and/or improve its surface properties. The volume of the repair work usually does not exceed 4 cm of the structure thickness. It implies application of thin layers of asphalt or the slurry seal, hot regeneration of the road, replacement of the top layer. Microsurfacing is not used in Lithuania.
- Renewal of the bearing capacity (in sectors) is an intermediate option between simple and major repairs, in this case, the road surface is thickened to increase its bearing capacity. The solution was applied to roads whose bearing capacity could not ensure the design axial loads of 11.5 tons. This method was applied until 2011, and milling was used only to level the profile and apply additional layers of asphalt.
- A major repair is improvement of the entire or part of the pavement structure, but not less than the top layer. This can be done by laying down new layers on the existing pavement, replacing the old layers with the new ones, or using a combination of these methods.
- Road reconstruction is a type of road works implying the reconstruction of the existing road following the requirements established by the Regulations. Road reconstruction may include treatment of all or some of the structural elements of the road; structures and equipment belonging to the road complex; more than 30% of the road when changing the road route, increasing the radius of the horizontal curves of the road (in the plan) or

performing road straightening works on an additional allocated plot of land.

In 2018, the requirements towards IRI after road works were tightened (Lietuvos automobilių kelių direkcija (LAKD), 2018). Now IRI must not exceed the following limit values at the time of acceptance of the works (since 2018):

- 1.0 m/km for motorways and express roads (such exclusion was not applied previously);
- 1.5 m/km for other main roads (1.5 m/km was applied to all main roads);
- 2.0 m/km for the national roads (2.5 m/km was applied);
- 3.0 m/km for the regional roads (3.5 m/km was applied).

At present, such requirements are important when designing new pavement, the top layer of the pavement must be selected so that the need to replace it with a new layer shall arise not earlier than in 12–18 years of use (Lietuvos automobilių kelių direkcija (LAKD), 2019).

2. Experiment

Regarding the construction regulations in Lithuania, the main road network is divided into motorways (speed roads) and other main roads; motorways have higher requirements for IRI. For this reason, motorways are analyzed as a separate network in this study. Four classes of the road network include:

- Regional road network;
- National road network;
- Main road network;
- Motorways.

This study aims at pursuing two different objectives:

- to determine the expected IRI value after implementing road works (RW) and to find out what level of IRI can be achieved by implementing the specific RW;
- to determine the annual increase of IRI after implementing specific road works.

These objectives are achieved by analyzing road sections repaired between 2008–2016 in the state road network of Lithuania.

Road roughness surveys have been carrying out with the laser RST28 during control measurements in 2008–2016. In 2019, surveys were conducted using RST63 laser survey vehicles produced by Ramboll Sverige AB. Both laser profilometers are equipped with Class 1 lasers and meet the requirements of ASTM E950-98 and EN 13036-6. IRI was calculated according to ASTM E1296.

3. Effects of road works

In order to reach the first objective, the IRI values were analyzed, which were collected in routine pavement performance surveys of the Lithuanian state road network performed at a set time interval taking advantage of quality inspection protocols performed after road works.

Five types of repair works were analyzed in this study: renewal of the asphalt wearing layer, surface treatment, renewal of the bearing capacity (in sectors); major repair and reconstruction.

All used data about road sections and their pavement performance were divided into separate groups – data clusters, according to the type of road and type of road works. In order to determine the expected IRI value after implementing road works (RW) and the level of IRI to be achieved by applying the specific RW, all road sections were divided into sixteen clusters (see Table 1).

Table 1. Cluster groups used to evaluate road works effects

No.	Road type	Repair method	Name of the cluster group	Quantity of the objects
1	Motorways	Renewal of asphalt wearing layer	H_Renewal of asphalt wearing layer	1
2	Motorways	Renewal of bearing capacity (in sectors)	H_Renewal of bearing capacity (in sectors)	28
3	Motorways	Reconstruction	H_Reconstruction	10
4	Main roads	Renewal of asphalt wearing layer	M_Renewal of asphalt wearing layer	1
5	Main roads	Renewal of bearing capacity (in sectors)	M_Renewal of bearing capacity (in sectors)	7
6	Main roads	Major repair	M_Major repair	4
7	Main roads	Surface treatment	M_Surface treatment	1
8	Main roads	Reconstruction	M_Reconstruction	14
9	National roads	Renewal of asphalt wearing layer	N_Renewal of asphalt wearing layer	10
10	National roads	Renewal of bearing capacity (in sectors)	N_Renewal of bearing capacity (in sectors)	16
11	National roads	Major repair	N_Major repair	21
12	National roads	Surface treatment	N_Surface treatment	6
13	National roads	Reconstruction	N_Reconstruction	15
14	Regional roads	Renewal of asphalt wearing layer	R_Renewal of asphalt wearing layer	3
15	Regional roads	Major repair	R_Major repair	5
16	Regional roads	Reconstruction	R_Reconstruction	9

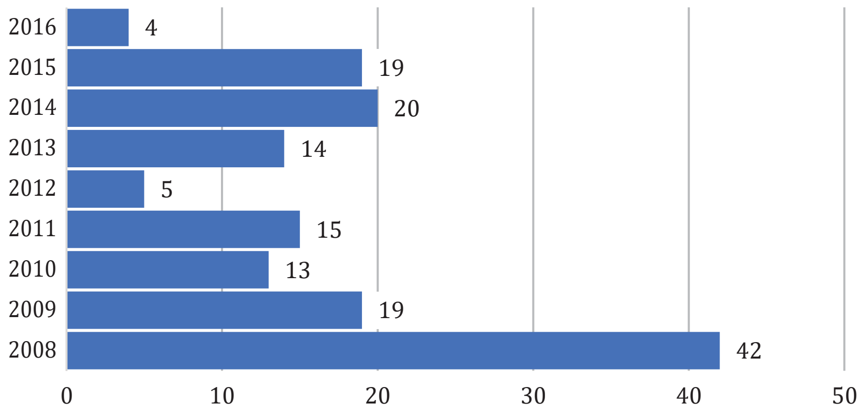

Figure 1. The number of the analyzed repaired road sections each year

The study was performed determining the historic IRI value for each object before RW (source: Lithuanian road information system LAKIS) and considering IRI measurement protocols (measurements carried out immediately after construction works, when IRI measurements are mandatory to determine whether the IRI level does not exceed the regulated values) after RW. Within this experiment, the data on 151 repaired road sections were analyzed. The IRI measurements were taken not only after the repair but also before the repair (IRI measurements of the state road network started in 2007–2008 season).

During data analysis, two IRI values for each analyzed section were considered: before and after RW and the difference between them (RW effect). For each data cluster given in Table 1, the weighted averages for IRI before RW and IRI after RW and the difference between them for every road section were estimated.

4. IRI increase after road works

To reach the second objective, the IRI values collected during quality inspections performed after road work (in the period from 2008 to 2016) and presented in respective inspection reports, as well as the IRI values collected in 2019 during routine pavement performance surveys of the Lithuanian state road network were analyzed.

Altogether 386 road sections with 5 types of repair works were analyzed: renewal of the asphalt wearing layer, surface treatment, renewal of the bearing capacity (in sectors), major repair, and reconstruction. The distribution of RW types is given in Figure 2.

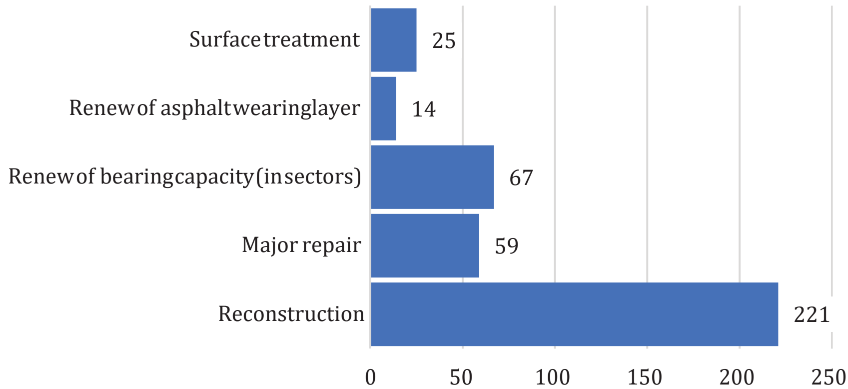

Figure 2. The number of repaired objects in each road work group

In this section of the research, four areas were analyzed and four data clusters were compiled:

- Road type;
- Pavement structure class;
- Heavy Loaded Vehicle Traffic;
- Type of road work and road type.

Road type

All data were grouped into four data clusters: motorways; main roads; national roads; regional roads. Increase of IRI was calculated for every section by:

- determining the difference of IRI for each road section between 2019 and the year when road works were implemented and calculating the average increase per year for this section.
- calculating the average increase for all clusters for all road types.

Road construction class

Road construction class (RCC) was assessed for each road section following the KPT SDK 19 and using heavy loaded vehicle annual average daily traffic. The tested sections cover all types of RCC specified in the regulatory documents (see Table 2).

All data were grouped into eight data clusters as described in Table 2. Increase of IRI was calculated for every section by:

- determining the difference of IRI for each road section between 2019 and the year when road works were implemented and calculating the average increase per year for this section;
- calculating the average increase for all clusters for all pavement structure classes.

Table 2. Road construction class and range of ESALs

No.	Road construction class	Design load A (ESALs), mln.
1.	DK 100	More than 32.0 (to 100.0)
2.	DK 32	from 10.0 to 32.0
3.	DK 10	from 3.0 to 10.0
4.	DK 3	from 2.0 to 3.0
5.	DK 2	from 1.0 to 2.0
6.	DK 1	from 0.3 to 1.0
7.	DK 0.3	from 0.1 to 0.3
8.	DK 0.1	to 0.1

Heavy Loaded Vehicle Traffic

Heavy Loaded Vehicle Traffic groups were assessed for each road section following the Methodology for Assessment and Prioritization of Road Sections of State Roads for Reconstruction and Major Repair (Lietuvos automobilių kelių direkcija (LAKD), 2020b) and using heavy loaded vehicle annual average daily traffic. Table 3 features cluster groups depending on the volume of Heavy Vehicle Traffic.

All data were grouped into sixteen data clusters (none of the sections match HHSV3 and HHSV5 cluster requirements), as described in Table 3. Increase of IRI was calculated for every section by:

– determining the difference of IRI for each road section between 2019 and the year when road works were implemented and calculating the average increase per year for this section.

Table 3. Ranges of annual average daily heavy vehicle traffic

No.	Name	Motorways	Name	Main roads	Name	National roads	Name	Regional roads
1.	HHV1	0 – 1349 veh./day	MHV1	0 – 399 veh./day	NHV1	0 – 79 veh./day	RHV1	0 – 25 veh./day
2.	HHV2	1350 – 2399 veh./day	MHV2	400 – 549 veh./day	NHV2	80 – 129 veh./day	RHV2	26 – 55 veh./day
3.	HHV3	2400 – 2649 veh./day	MHV3	550 – 799 veh./day	NHV3	130 – 179 veh./day	RHV3	More than 56 veh./day
4.	HHV4	2650 – 4199 veh./day	MHV4	800 – 1299 veh./day	NHV4	180 – 339 veh./day		
5.	HHV5	More than 4200 veh./day	MHV5	More than 1300 veh./day	NHV5	More than 340 veh./day		

– calculating the average increase for all clusters for all heavy loaded vehicle traffic groups.

Type of road work and road type

The type of road work and road type were selected as the main attributes to select road sections into data clusters. All tested sections cover eighteen cluster groups (see Table 4).

All data were divided into eighteen data clusters as described in Table 4. Increase of IRI was calculated for every section by:

– determining the difference of IRI for each road section between 2019 and the year when road works were implemented and calculating the average increase per year for this section;
– calculating the average increase for all clusters for all cluster groups by road type and type of road work.

Table 4. Cluster groups by road type and type of road works

Road type	Type of road works	Name of the cluster group
Motorways	Renewal of asphalt wearing layer	H_Renewal of asphalt wearing layer
Motorways	Renewal of bearing capacity (in sectors)	H_Renewal of bearing capacity (in sectors)
Motorways	Reconstruction	H_Reconstruction
Main roads	Renewal of asphalt wearing layer	M_Renewal of asphalt wearing layer
Main roads	Renewal of bearing capacity (in sectors)	M_Renewal of bearing capacity (in sectors)
Main roads	Major repair	M_Major repair
Main roads	Surface treatment	M_Surface treatment
Main roads	Reconstruction	M_Reconstruction
National roads	Renewal of asphalt wearing layer	N_Renewal of asphalt wearing layer
National roads	Renewal of bearing capacity (in sectors)	N_Renewal of bearing capacity (in sectors)
National roads	Major repair	N_Major repair
National roads	Surface treatment	N_Surface treatment
National roads	Reconstruction	N_Reconstruction
Regional roads	Renewal of asphalt wearing layer	R_Renewal of asphalt wearing layer
Regional roads	Renewal of bearing capacity (in sectors)	R_Renewal of bearing capacity (in sectors)
Regional roads	Major repair	R_Major repair
Regional roads	Surface treatment	R_Surface treatment
Regional roads	Reconstruction	R_Reconstruction

5. Results for effect on road works

The results for five different road work technologies and the effect they have had on road performance by decreasing the value of IRI are presented below.

Renewal of the asphalt wearing layer

Before renewal of the asphalt wearing layer on the motorways, the average value of IRI before road works was 1.25 m/km. A reduction of IRI value by 0.52 m/km was achieved (see Figure 3). Thus, the average value of IRI after road works on the road the surface was 0.73 m/km during a simple repair of the asphalt pavement on the motorway roads.

Before renewal of the asphalt wearing layer on the roads with the status of the main road, the average value of IRI before road works was 2.49 m/km (see Figure 3). The reduction of 1.7 m/km was achieved and after the renewal of asphalt wearing layer the on main roads, the average achieved IRI value was 0.79 m/km.

Before renewal of the asphalt wearing layer on the roads with the status of the national road, the average value of IRI before road works was 4.4 m/km (see Figure 3). A reduction of IRI value by 2.96 m/km was achieved and after the renewal of the asphalt wearing layer on the national road network, the average achieved value of IRI was 1.44 m/km.

Before renewal of the asphalt wearing layer on the regional roads, the average value of IRI before road works was 3.65 m/km (see Figure 3). A reduction of IRI value by 1.95 m/km was achieved. Thus, after the renewal of the asphalt wearing layer on the district roads, the average achieved IRI value was 1.71 m/km.

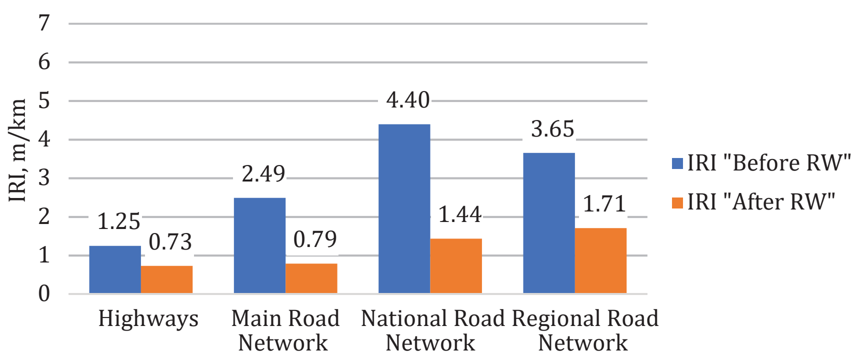

Figure 3. Change in IRI after renewal of the asphalt wearing layer

Renewal of the bearing capacity (in sectors)

Before renewal of the bearing capacity (in sectors) on the motorway road network, the average value of IRI before road works was 1.76 m/km (see Figure 4). A reduction of IRI value by 1.02 m/km was achieved; the average achieved value of IRI after road works was 0.74 m/km after repairs aimed at renewal of the bearing capacity (in sectors) on the main roads with the status of a motorway.

Before renewal of the bearing capacity (in sectors) on the main roads, the average value of IRI before road works was 2.83 m/km (see Figure 4). A reduction of IRI value by 2.1 m/km was achieved. Thus, after the repair of the asphalt pavement and renewal of the bearing capacity (in sectors) on the main roads, the average achieved IRI value was 0.73 m/km.

When renewal of the bearing capacity (in sectors) on the national road network was initiated, the average value of IRI before road works was 3.69 m/km (see Figure 4). A reduction of IRI value by 2.61 m/km was achieved; the average achieved value of IRI after road works was 1.08 m/km. It was reached by implementing the type of works aimed at the renewal of the bearing capacity of asphalt (in sectors).

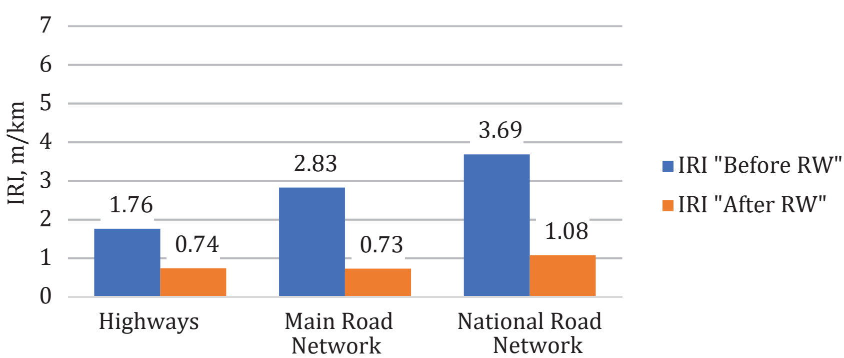

Figure 4. Change in IRI after renewal of the bearing capacity (in sectors)

Surface treatment

Before implementing the surface treatment technology on the main road network, the average value of IRI before road works was 2.7 m/km (see Figure 5). A reduction of IRI value by 1.84 m/km was achieved. After the repair on the main roads, the average achieved value of IRI was 0.86 m/km.

Before repairing the pavement surface on the national road network using the technology of surface treatment, the average value of IRI before road works was 3.74 m/km (see Figure 5). A reduction of IRI value by 2.34 m/km was achieved. Thus, by applying surface treatment on the regional road network, the average achieved value of IRI after road works was 1.4 m/km.

Major repair

Before conducting the major repair of the pavement on the motorway road network, the average value of IRI before repair works was 3.31 m/km (see Figure 6). A reduction of IRI value by 2.62 m/km was achieved. After the major repair of the asphalt pavement on the motorway road network, the average achieved value of IRI was 0.69 m/km.

Before applying major repair on the main road network, the average value of IRI before road works was 3.64 m/km (see Figure 6). A reduction of IRI value by 2.72 m/km was achieved. Applying major repair of the asphalt pavement on the main road network, the average achieved value of IRI after road works was 0.92 m/km.

Before applying major repair on the roads with the status of the national road, the average value of IRI was 5.83 m/km (see Figure 6) before road works. A reduction of IRI value by 4.36 m/km was achieved. Thus, after the major repair of the asphalt pavement on the national roads, the average IRI value was 1.47 m/km.

Reconstruction

Before the reconstruction of the roads on the motorway road network, the average value of IRI before road works was 2.01 m/km (see Figure 7). A reduction of IRI value by 1.15 m/km was achieved. Thus, after the road reconstruction works on the motorway roads, the average value of IRI of 0.86 m/km was achieved.

Before applying road reconstruction on roads with the status of the main road, the average value of IRI was 3.09 m/km (see Figure 7) before road works. A reduction of IRI value by 2.17 m/km was achieved and after the road reconstruction works on the main road network, the average achieved value of IRI was 0.92 m/km.

Before road reconstruction on the national road network, the average value of IRI before road works was 4.35 m/km (see Figure 7).

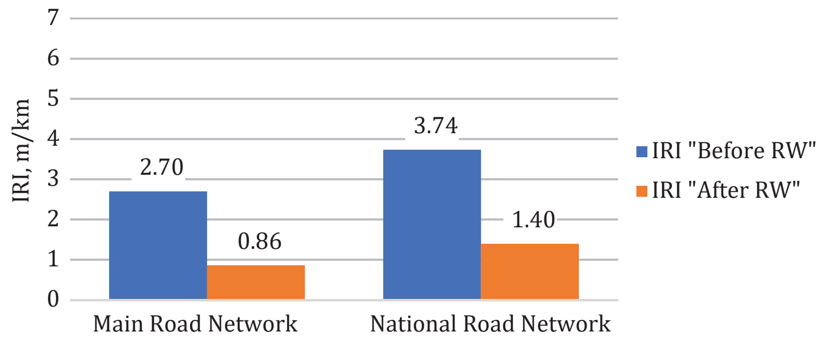

Figure 5. Change in IRI after applying surface treatment

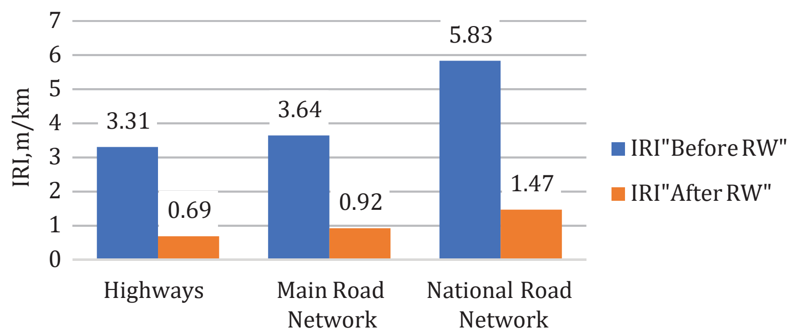

Figure 6. Change in IRI after major repair

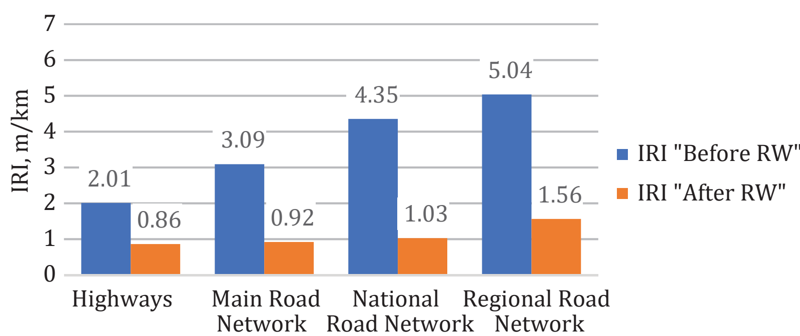

Figure 7. Change in IRI after reconstruction

A reduction of IRI value by 3.33 m/km was achieved. Thus, after the road reconstruction works on the national roads, the average achieved value of IRI was 1.03 m/km.

Before road reconstruction on the regional road network, the average value of IRI value by 5.04 m/km (see Figure 7) before road works. A reduction of IRI value by 3.47 m/km was achieved. Thus, after road reconstruction works on the regional roads, the average achieved value of IRI was 1.56 m/km.

6. Analysis of IRI increase after road works

The results of the expected IRI increase after applying one out of five road works technologies are listed below.

Road type

Results of analysis of IRI increase after road works are displayed in Table 5, the objects are clustered by road type.

Table 5. IRI values after road works by road type

Road type	Subjects per group, pcs	IRI value after RW, m/km	IRI change per year, m/km
Main roads (only motorways)	39	0.8	0.02
Main roads	31	0.82	0.03
National roads	72	0.95	0.05
Regional roads	244	1.54	0.05

As it may be seen from Table 5, the IRI values increase along with the decrease of road category. Irrespective of the technology used, it can be predicted that IRI will increase annually by 0.02 m/km on the motorways, by 0.03 m/km on the main roads, and by 0.05 m/km on the national and regional roads.

Road construction class

Each object was assigned to a cluster according to its road construction class (RCC), which depends on the intensity of heavy traffic. The results obtained are shown in Table 6.

Table 6. IRI values after road works by RCC

RCC	Objects per group, pcs	IRI value after RW, m/km	IRI change per year, m/km
DK 0.1	90	1.66	0.05
DK 0.3	122	1.49	0.06
DK 1	52	1.21	0.06
DK 2	39	0.97	0.03
DK 3	21	0.86	0.03
DK 10	21	0.81	0.03
DK 32	38	0.79	0.02
DK 100	3	0.74	0.02

Table 6 presents the results for each road construction class separately. As it may be noticed, the values of IRI after road works decrease along with the increase of road construction class. Except the lowest road construction classes, all others show a declining increase in IRI over the year. On the roads of a weaker road construction class (DK 0.1 – DK 1), the annual increase in IRI ranges from 0.05 to 0.06 m/km, and on the roads of a higher road construction class (DK 2 – DK 100), the annual increase in IRI ranges from 0.03 to 0.02 m/km.

Heavy loaded vehicle traffic

Each object during analysis was assigned to a cluster according to the prevailing heavy loaded vehicle annual average daily traffic in that section. The results obtained are presented in Table 7.

As it can be seen from Table 7, the results are ambiguous. On the national and regional roads, along with the increase of the heavy traffic group, IRI decreases after road works. However, on the motorways and main roads, IRI does not follow this trend after road works. The annual increase in IRI is also inconsistent with the increase in heavy traffic.

Table 7. IRI values after road work by separate heavy loaded vehicle group

Cluster	Road type	Heavy vehicle group	Objects per group, pcs	IRI value after RW, m/km	IRI change per year, m/km
HHV1	Motorways	V1	9	0.68	0.02
HHV2	Motorways	V2	25	0.85	0.03
HHV3	Motorways	V3	0	n/a	n/a
HHV4	Motorways	V4	5	0.74	0.03
MSV1	Main roads	V1	3	1.02	0.04
MHV2	Main roads	V2	6	0.76	0.08
MSV3	Main roads	V3	7	1.01	0.03
MHV4	Main roads	V4	6	0.77	0.03
MHV5	Main roads	V5	9	0.75	0.02
NHV1	National roads	V1	6	1.31	0.14
NHV2	National roads	V2	10	1.21	0.08
NHV3	National roads	V3	5	1.16	0.12
NHV4	National roads	V4	22	1.06	0.08
NHV5	National roads	V5	29	0.84	0.04
RHV1	Regional roads	V1	125	1.67	0.04
RHV2	Regional roads	V2	78	1.47	0.05
RHV3	Regional roads	V3	41	1.43	0.03

Type of road work and road type

Each object was assigned to a cluster according to the type of repair applied in that section. The results obtained are shown in Table 8.

Table 8 shows the results presented by forming clusters by road type and type of road works. It can be seen that the average achievable IRI after road works on the motorways is the lowest and continues to increase along with the change of road type.

Surface treatment on the main, national, and regional roads can be expected to reach 0.86, 1.39 and 2.61 m/km, respectively. On average, road roughness would increase by 0.05 m/km annually, but on the main roads, it would increase by 0.12 m/km, on the national roads it would increase by 0.05 m/km, and on the regional roads – by 0.04 m/km.

In case of renewal of the asphalt wearing layer on the motorways and main roads, IRI can reach up to 0.8 m/km after road works. During the renewal of the asphalt wearing layer on the national road network, the average value of IRI after road works was 1.44 m/km, and on the regional roads – 1.39 m/km. On average, road surface roughness would increase by 0.04 m/km annually, but on the motorways and main roads it would increase in smaller increments of 0.01 and 0.02 m/km, and on the national roads – by 0.06 m/km and regional roads – by 0.03 m/km annually (see Table 7).

IRI value of up to 0.9 m/km can be achieved (expected) after renewal of the bearing capacity (in sectors) on the motorways, main and national roads. IRI value of up to 1.38 m/km can be achieved after renewal of the bearing capacity (in sectors) on the regional roads. On average, road surface roughness would increase by 0.03 m/km annually on the motorways and main roads, and on the national and regional roads – by 0.04 m/km annually.

Table 8. IRI values after road works by the type of road works and road type

Cluster	Road type	Type of road works	Objects per group, pcs	IRI value after RW, m/km	IRI change per year, m/km
H_Renewal of asphalt wearing layer	Motorways	Renewal of asphalt wearing layer	1	0.8	0.01
H_Renewal of bearing capacity (in sectors)	Motorways	Renewal of bearing capacity (in sectors)	28	0.73	0.03
H_Reconstruction	Motorways	Reconstruction	10	0.74	0.01
M_Renewal of asphalt wearing layer	Main roads	Renewal of asphalt wearing layer	1	0.79	0.02
M_Renewal of bearing capacity (in sectors)	Main roads	Renewal of bearing capacity (in sectors)	9	0.71	0.03
M_Major repair	Main roads	Major repair	4	0.75	0.02
M_Surface treatment	Main roads	Surface treatment	1	0.86	0.12
M_Reconstruction	Main roads	Reconstruction	16	0.86	0.01
N_Renewal of asphalt wearing layer	National roads	Renewal of asphalt wearing layer	11	1.44	0.06
N_Renewal of bearing capacity (in sectors)	National roads	Renewal of bearing capacity (in sectors)	17	0.9	0.04
N_Major repair	National roads	Major repair	22	0.89	0.02
N_Surface treatment	National roads	Surface treatment	7	1.39	0.05
N_Reconstruction	National roads	Reconstruction	15	0.87	0.04
R_Renewal of asphalt wearing layer	Regional roads	Renewal of asphalt wearing layer	12	1.39	0.03
R_Renewal of bearing capacity (in sectors)	Regional roads	Renewal of bearing capacity (in sectors)	13	1.38	0.04
R_Major repair	Regional roads	Major repair	33	1.47	0.04
R_Surface treatment	Regional roads	Surface treatment	6	2.61	0.04
R_Reconstruction	Regional roads	Reconstruction	180	1.55	0.03

After major repairs on the motorways and main roads, IRI was less than 0.9 m/km, and on the regional roads it can reach 1.47 m/km after the major repair. Unfortunately, at the time of the analysis, not a single road belonging to the class of motorways had been repaired by applying the major repair. On average, road roughness would increase by 0.03 m/km annually, but on the main and national roads it would increase by 0.02 m/km, and on the regional roads – by 0.04 m/km.

In case of road reconstruction on the motorways, main and national roads, IRI after road works does not reach 0.9 m/km. On the regional roads, IRI reaches 1.55 m/km after road reconstruction. On average, road roughness would increase by 0.03 m/km per year, but on the motorways and main roads it would increase in smaller increments of 0.01 m/km, and on the national and regional roads – by 0.04 and 0.03 m/km per year, respectively.

Conclusions

1. The analysis has shown that more complex repairs (major repair and reconstruction) have a greater effect increasing the roughness of the road pavement, thus decreasing IRI value. These repair methods also allow ensuring the highest pavement roughness.
2. IRI survey data before and after road works (which took place between 2008 and 2016) have been compared. It has been determined that the average values obtained are significantly lower than those required by the normative documents. On the motorways, national and regional roads, the threshold IRI values are respectively 1.0, 2.0 and 3.0 m/km for newly built roads or roads after road works where at least top (surface) layer was treated. IRI reduced in the range from 0.52 m/km (before RW – 1.25 m/km and after RW – 0.73 m/km) to 2.9 m/km (before RW – 4.40 m/km and after RW – 1.44 m/km) implementing renewal of the asphalt wearing layer. IRI reduced in the range from 1.02 m/km (before RW – 1.76 m/km and after RW – 0.74 m/km) to 2.61 m/km (before RW – 3.69 m/km and after RW – 1.08 m/km) by applying surface reinforcement. IRI reduced in the range from 1.84 m/km (before RW – 2.70 m/km and after – 0.86 m/km) to 2.34 m/km (before RW – 3.74 m/km and after RW – 1.40 m/km) by applying surface treatment. IRI reduced in the range from 2.62 m/km (before RW – 3.31 m/km and after RW – 0.69 m/km) to 4.36 m/km (before RW – 5.83 m/km and after RW – 1.47 m/km) by applying major repair. Finally, IRI reduced in the range from 1.15 m/km (before RW – 2.01 m/km and after RW – 0.86 m/km)

to 3.47 m/km (before RW – 5.04 m/km and after RW – 1.56 m/km) implementing reconstruction.

3. The analysis of the difference between two data sets – the survey after road works and the survey carried out in 2019 – shows that roughness decreases by IRI 0.02 m/km annually on the roads with the status of the motorway, by 0.03 m/km on the main roads and by 0.05 m/km on the national and regional roads after performed road work. It can be stated that design and repair method requirements are more strict for high-class pavement structures, or it may be inferred that the quality of construction works is not so high on the regional roads. This conclusion does not include a detailed analysis of the shape of the roughness (IRI) deterioration curve and is intended to provide only a general picture of the impact of the applied road works on separate road types.
4. It can be stated that the value of roughness is better after repair work on the roads of higher road class. A more pronounced effect is achieved on the roads of higher significance: 0.8 m/km on the motorways and expressways, 0.82 m/km on the main roads, 0.95 m/km on the national roads, and 1.54 m/km on the roads of regional significance. After the repair, the rate of deterioration of IRI was found to be higher on the roads of lower significance.
5. After analyzing the data, it has been proposed to apply the obtained research results from Table 8 in the Lithuanian pavement management system by using the established values of IRI after road works and applied repair scenarios, taking into account the type of road and the applied repair technology in the decision trees. For motorways IRI after road works can be set in the range from 0.73 to 0.8 m/km depending on the selected type of road works; for the main roads IRI after road works can be set from 0.71 to 0.86 m/km depending on the selected type of road works, and for the regional roads IRI after road works can be set from 1.38 to 2.61 m/km depending on the type of the selected road work.

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