



IMPROVEMENT OF ROAD PAVEMENT MAINTENANCE MODELS AND TECHNOLOGIES

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Abstract. The roads as main national assets maintenance costs increase dramatically but budgets stays as it is or even decrease over the years. However, at the same time, it is required to maintain road pavements condition at high level. These trends make asset owners and administrators to search for new ways and methods for more efficient roads maintenance management. As the new road is build or old one reconstructed performance indicators should be identified for whole life cycle as it is defined by design. Pavement condition evaluation by indicating present performance indicators level should be done timely and accurate at road level and whole network level. Ongoing support of pavement condition under network level, with a long-term strategy, allows to prolong the life of the pavement, improve traffic safety and meet public expectations. The comprehensive analysis of road maintenance and management systems recommendations for their improvement and application are presented in the article.

Keywords: deterioration, maintenance, pavement, Pavement Condition Index (PCI), Pavement Quality Index (PQI), Present Serviceability Index (PSI).

1. Introduction

Mobility and safe transport is one of the most important modern human and society's needs. In most of the countries, roads are the most valuable state property. Roads significantly contribute to economic growth and bring some social benefit. Under estimates of World Road Association PIARC in 2014, road transport in separate countries generates from 10% to 20% of GDP. In order to maintain the quality, all road elements need to be supervised: pavements, bridges, tunnels, signs, lights, information system, and other. During operation, as the roads and buildings are degrading, their need for care increases, they become more sensitive to the growing traffic volume, growing freight volumes, and climate change. Without regular road maintenance, roads and streets' asphalt pavement quickly deteriorate. Improperly maintained roads limit vehicle mobility, significantly increase vehicle operating costs, the number of accidents and related human and property costs. The postponement of the execution of road maintenance increases the direct and indirect costs. If road distresses are corrected immediately, the cost is generally low. If defects and distresses are long-standing and large, then

the reconstruction needs to be carried out, and its price request even larger expenses up to three times than the regular technical maintenance. By World Bank initiative, the study, carried out in the South African Road Agency SANRAL in 2004, showed that costs increase by 6 times without the necessary road maintenance and repair in 3 years than the funds that would be given. The costs increase by 18 times without doing road maintenance for 5 years. In order not to increase the costs, it is recommended to use the financial resources in the following sequence: road maintenance, reconstruction, new construction. Studies in Scotland (National Roads Maintenance Review by Transport Scotland in 2011) have shown that after reduction of the cost in road maintenance, the signs of the negative effect for road users and the environment are visible. It is estimated that in 10 years the Scottish society would lose 1,2 € (1,053 £) billion as funds, allocated for road maintenance, are reduced by 40%. 1,14 € (1 £) weaker investment of several periodic maintenance forms the 1,71 € (1,5 £) even higher costs to society and the economy. It has also been noted that the amount of money, allocated for road maintenance every year, cannot be the

same, because the economy is influenced by inflation and a few years later the same money, invested in road maintenance, is insufficient. At present, many countries in the road transport sector are facing a difficult situation, when road maintenance and repair budgets are reduced every year (or at least not increased, though property maintenance costs are rising), but at the same time it is required to maintain at least equivalent to the current road condition and, in some cases, even better.

2. Pavement Management System and Maintenance models

In order to pave or reconstruct the road and select the maintenance, it is necessary to assess and evaluate many options and alternatives. Their amount is determined by natural conditions, road design and construction standards, existing building and maintenance materials, technologies and their price, requirements for cars and other road users in the traffic organization, road maintenance standards, other normative and legal documents, and various other factors. Road construction, reconstruction or repair price depend on the choice of alternatives. The price of a car operation, delay and the risk of accidents are dependent on the selected road. It also depends on how much cost the road maintenance and repairs, and how often they will be carried out. Thus, the decision impact is felt all the way of functioning period. In order to control the processes, the co-ordinating system is needed. The term “Pavement Management System” (PMS) was introduced in 1969 in order to describe the different types of operational decision-making and pavement maintenance (OECD 1987). Activities related to pavement design and construction, maintenance, research and evaluation in PMS were expanded by Haas and Hudson (1978). In terms of pavement condition management, road maintenance and Strategic Planning of Road Works system, the most widely used system of Highway Development and Management is usually presented. It consists of two main components: the impact model for road users and pavement deterioration model. Costs and quantified benefits of each analysed project are calculated using these models. Road Deterioration and Work Effects models (RDWE) are divided into Road Deterioration Model (RDM), which predicts the road surface condition and road pavement maintenance and repair model that the above-mentioned effects of the works pavement deterioration and road users. Individual countries have also started to apply PMS gradually to integrate the entire road network, not just its sections, predicting road surface condition (Tighe *et al.* 2002). RDM are used for this purpose, which are integrated into the complex computing systems. It is argued that the higher class of road is designed than the traffic volume requires, affected by environmental factors. The unperformed pavement reconstruction, repair and maintenance work, very quickly change the condition of the road and almost instantly lose their property value (Falls *et al.* 1994). Over the years, it evolved and improved road pavement interaction with their aging, but the problem remained relevant. The

most commonly applied empirical models of deterioration. Less often applied are mechanistic (analytical) -empirical. They are usually designed under pavement studies collected data on various parameters of pavement deterioration and distress development and trends in the statistical analysis of the results (empirical models), but sometimes they are based on basic principles, or use some of the fundamental dependencies (mechanistic-empirical models). These model types are distinguished: linear regression, probability, networks (Markov), probabilistic-regression, neural networks, and others.

The era of Road Condition Management System and Strategic Planning of Road Works System model consist of a number of smaller models, covering different aspects of the analysis. Countries depending on the road network density, the financial capacity of natural conditions, road design and construction standards (designed for different pavement cycle or period), the existing building and maintenance materials, the technology used, the requirements of traffic operation, road maintenance standards and a variety of other factors, apply different PMS and maintenance models such as:

- **Slovenia.** Road maintenance budget is selected achieving to determine the condition of the road network level and the budget modelling for the period of 15 years. The Modified Swiss Index (MSI) is being used for this. Repair strategy, scenarios for road network or an individual object are selected following road condition network. The used basis of Deighton's Total Infrastructure Management System (dTIMS®) is the detailed information about the road surface condition and the individual construction layers (Leben 2008).
- **Denmark.** PMS “Belman“ is used for three main functions: the road network diagnostics (inspection), road maintenance budget optimization, forecasting and the list of pavement repair contracts (Knudsen, Sand Kirk 1999).
- **Great Britain.** Guided by three main criteria: first criterion – road network and building condition assessment; second criterion – the road condition data statistical analysis and monitoring – development of bidding, conclusion of repair sections; third criterion – pavement condition forecast. While preparing the original PMS system, the main objectives were identified: better economic maintenance management; improved normative documents in accordance with the priorities and investment levels; better quality maintenance works, improved maintenance, design, and material usage monitoring (Wallis 2007).
- **Austria.** The basic principles are: indicators of pavement condition, algorithm composition of homogeneous sections, application of forecasting models, and preparation of long-term costs strategies (Sjögren *et al.* 2013).
- **Germany.** Pavement condition is assessed by the overall index of condition, which is composed of individual indicators. Germany also operates data

system of road surface condition. “IT-ZEB“ data system of road surface condition also operates in Germany, where annual results of pavement condition are placed.

- **Canada.** Cost-effective road network maintenance and repair management system is created and continually improved. The objectives of a system are: to develop and implement a multi-annual budget planning, considering the certain budget restrictions, to prepare practical alternatives of pavement maintenance, repair and other alternatives (Hicks 1977).

It is ideal as pavement care is preventive, roads are always in perfect condition, there are no signs of fatigue, and well-planned maintenance program in conjunction with the PMS allows achieving maximum efficiency, ensuring the possibility carry out the necessary repairs in time. Good planning and efficient maintenance system help to deal with unforeseen circumstances and to maintain the structural integrity of the system. This means that a comprehensive pavement maintenance philosophy is not only prevention or repair; this includes both concepts. Summing up, the management of road network and supervisory practices in different countries, it may be noted that even though applied systems of individual countries, models and procedures differ for its detail, complexity and specific adaptation of the country’s road network aspects. However, in general terms, the objective is the same to ensure long-term, cost-effective, social and

environmental needs of the satisfactory operation of the road network.

3. Theoretical model for pavement condition evaluation at network and road levels

Recently, there is a tendency how the road network infrastructure management model is changing from the traditional Condition-Based Model to Service-Based Model. Service-Based Model is based on Performance Indicators: reliability, availability, continuity, traffic safety, security, health, environment, economy, and politics. Pavement Distress Index (PDI), used in many countries, is assigned to condition-based parameters (Haas *et al.* 1994; Loizos *et al.* 2002) as well as Distress Manifestation Index (DMI) (Chan *et al.* 2014; Kazmierowski, Ninguan 2002). The service-based is assigned to the most widely used Present Serviceability Index (PSI), Ride Comfort Index (RCI) (Chan *et al.* 2014; Kazmierowski, Ninguan 2002). Determining the pavement PSI, the main indicator is the surface roughness. It should be noted that in foreign countries the road infrastructure management and maintenance are often carried out under a performance-based concept, where the road owner pay to the contractor not only for quantities of performed work, but also under qualitative terms. Performance-based concept in most cases up to now applied in the typical qualitative several parameters: International Roughness Index (IRI), pits, cracks, track, wheel grip, road signs and horizontal marking, drainage systems and other (Figs 1–2), but lately, more and more attention is paid to the social, environmental, integrity and availability requirements. According to surveys, carried out in different countries, the World Road Association (PIARC), Pavement Technical Committee, has grouped parameters, which are applied by countries to describe the state of the road: the pavement surface distress, friction, roughness, rutting, macrotexture, load capacity, crumbling of pavement edges, and noise. Individual countries, such as Sweden, Poland, France, Germany applies four, Estonia three, Lithuania two pavement condition parameters (Baril *et al.* 2013, Lang, Mladenovic 2013). It is very important accurately predict pavement deterioration (structural and functional) in the pavement condition management and strategic planning of investments. Road ranking method, based on pavement condition, is the easiest way to identify the priority of strategic planning of road work needs. The condition of the road elements need to be taken into account while assessing the road network.

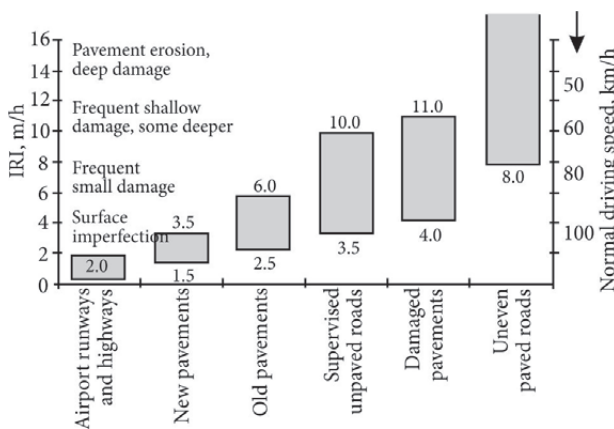


Fig. 1. IRI values for different road pavements (Sayers *et al.* 1986)

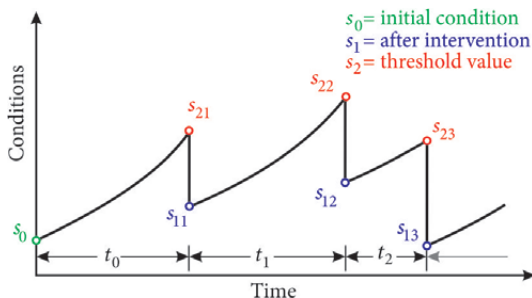


Fig. 2. Pavement condition is assessed determining IRI (Cirilovic *et al.* 2014)

The distribution of pavement roughness in main roads of Lithuania is shown in Fig. 3, distribution of rut depth – in Fig. 4, and distribution of pavement defects – in Fig. 5. Without the surface and pavement condition assessment, another road network and road building criteria of quality are significant to decisions. Countries, such as Canada, the USA and China use 0–100 points rating system for description of road condition. These evaluation indicators of pavement condition are found in separate

methodologies: PSI; Safety Index (SI), PCI and others (Fig. 6). These evaluations, or ratings are summed up and pavement structural-functional state is assessed. It is considered that the different sets of parameters can evaluate the minimum price of road maintenance, road maintenance and drivers' costs. Complex parameter introduction and application in PMS is an essential effective management of road infrastructure aspects (Zietlow 2004). Using the experience of other countries and taking into account today's realities, the increased needs of the public and road maintenance funding, Lithuania should apply more modern road network maintenance and management system that enables efficient evaluation of the technical condition of the road network and site level. One of such systems is shown in Fig. 6. It is expressed the need to maintain the state of pavement within the range of 7–10 of scale and to repair in the range of 6–7.5 of the scale.

The purpose of this management system of road network condition is to determine the optimal maintenance strategy applied in separate sections of road. This system is divided into two levels: road network and the object. Network level is associated with the planning, budget, and political (safer community, support and development of local economy, increasing of social welfare, environmental protection, poverty reduction, accessibility for all, quality of life) solutions. Decisions are highly dependent on the quality of the information system. It has to be possible selectively accumulate amount of data, expand them and to carry out restructuring depending on possibilities. Important information systems have a unified, unambiguous reverse procedure system, which obeys all the data that allows all network elements correctly identified, as well as to put them. The necessary data for administering the flexible data bank systems, which can accept and each time to renew the existing levels presented and allows the exchange of data with other systems, as well as the opportunity to provide a graphic picture of the results. The data in the information system databank should be entered carrying out the regular and periodic research also making assessment of road condition under the object level. The road condition forecast by road network level should be carried out under a functional, structural, traffic safety, environmental, and financing approach. Functional surfacing work should be seen as a surfacing serves its user. The main characteristic of the pavement is the driving comfort level. The concept of pavement service level and work is used for determination of driving comfort level. Pavement level of service could be expressed in PSI, which is determined by the roughness and distress (cracks, potholes, ruts) measurements performed at regular intervals throughout the service life of the pavement. Special equations need to be composed for PSI calculation, which would justify the results of roads research under the field conditions. The primary PSI should be determined immediately after pavement equipment. The main factors influencing decrease of pavement service level are load, time and the environment. New or restored pavements are normally designed

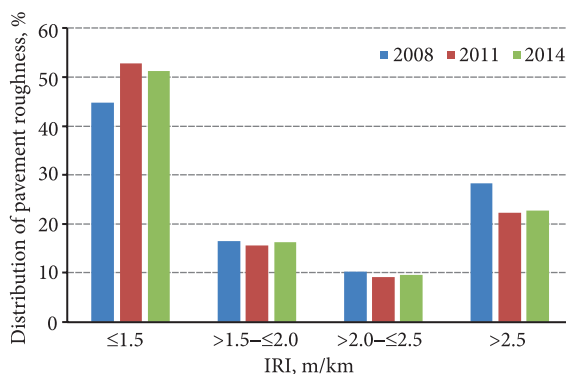


Fig. 3. Distribution of pavement roughness in main roads of Lithuania

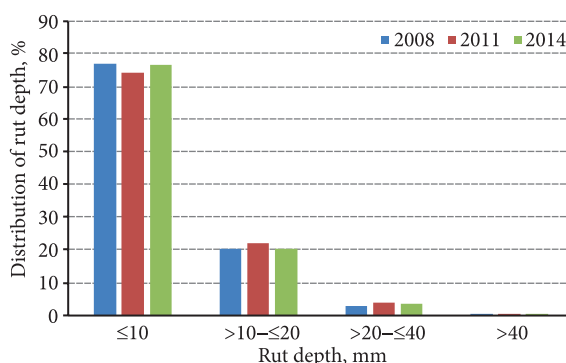


Fig. 4. Distribution of rut depth in main roads of Lithuania

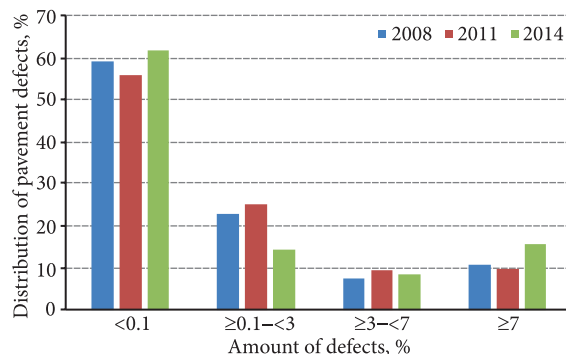


Fig. 5. Distribution of pavement defects in main roads of Lithuania

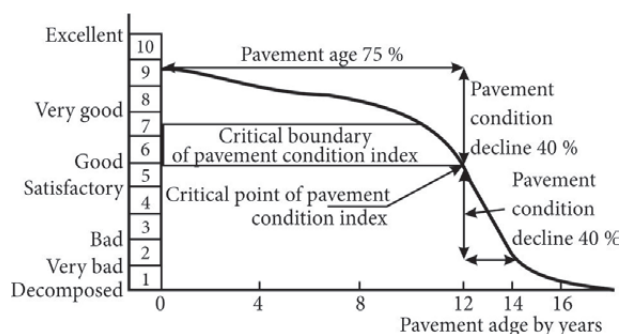


Fig. 6. Pavement maintenance dependence on Pavement Condition Index

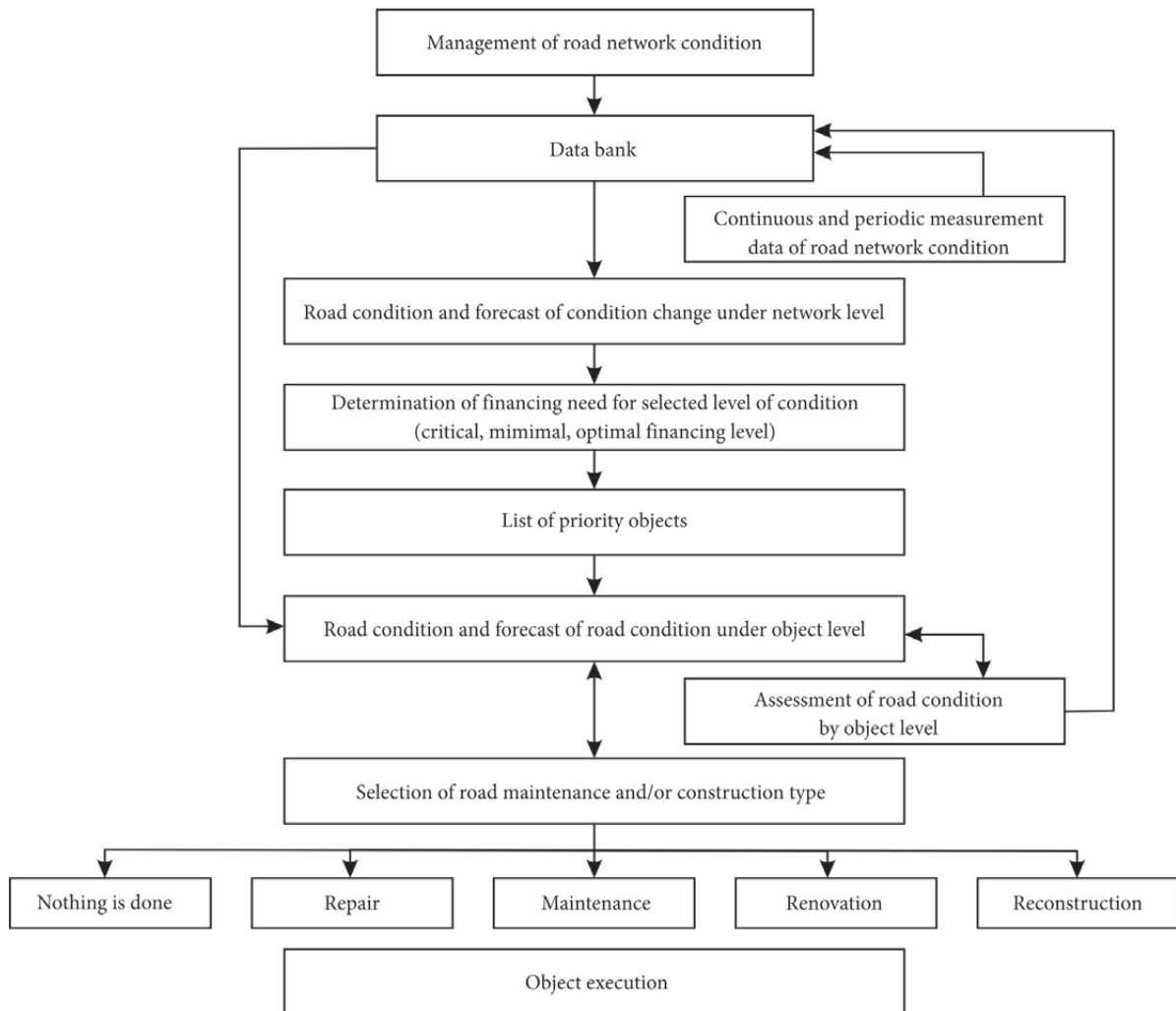


Fig. 7. Management system of road network condition

for 20 years, so the road service life cycle period is necessary to provide prospective traffic, expressed by the ESAL's. Road service life cycle period is defined as the period during which a new or rebuilt pavement structure has to serve until it reaches its final level of service. ESAL's points during the road service life cycle period is expressed as total amount from the traffic opening time when the level of service is reduced to marginal significance. Maximum road service life cycle period for a particular type of surfacing has to rely on the experience and actually meet the pavement service life. Pavement service life is extended, periodically repaving or rebuilding pavement structure. Structured pavement work associated with its physical condition: the appearance of cracks, surface fatigue, erosion and other lesions, negative influencing pavement sustainability. Accurate information, identifying a total of ESAL's, is an important factor in the pavement condition forecast in the network level. Continuous monitoring of selected objects, allows comparing the present traffic volume and designed traffic volume what are a significant conditions. Road pavement is affected by negative temperature in winter and rainfall during year. Thaw/freezing, during the spring pavement failure and others will also be

assessed. While analysing the structural pavement work, drainage coefficients are often used (wet conditions). Pavement residual age is measured. E_0 deformation module is determined by Falling Weight Deflectometer (FWD). State of the road traffic safety is separately considered. The SI, analysed traffic accidents, their causes, the cost of road users in their car operation, delay, the risk of accidents, as well as the vehicle caused a negative impact on the environment are used for this (Table 1).

Under variety of construction methods and standards, it is recommended to use the more accurate indicators' (Present Serviceability Index (PSI), Pavement Quality Index (PQI), and Pavement Condition Index (PCI)) values. This is because financing need (critical minimum, optimal) is foreseen for predicted level of pavement condition. The priority list of objects is made after carrying out the forecast of road condition and condition change under object level. Condition assessment under object level is performed for forecast specification of road condition change. The information about object place, building year, pavement construction, materials and primers, type of maintenance and performance year, traffic, climate conditions and other detailed pavement data are collected carrying out the

Table 1. Traffic safety indicators and the impact to drivers's behaviour

Factor class	Traffic safety indicator	Impact for driver
Grip or road surface texture	Macrotexture and microtexture characteristics, as International Friction Index (IFI) Skid resistance Types of automobile tires	Little
Road surface smoothness	International Roughness Index (IRI) Dependency of road smoothness and driving speed	High
Pavement distress	Pavement distress frequency and scale	Average
Geometry of road construction	Widths of lanes and curbs, safety, median, footpath, types of curbs Cross slope	Average
Visibility of road surface	Pavement colour and reflection Horizontal and vertical marking	High
Road materials	Pavement type Colour and texture of materials Mineralogy and anti-slip properties	Low
Traffic safety devices	Security warning signs Traffic safety devices	High
Environment and climate conditions	Place and time of traffic accident Roadside barriers Precipitation (fog, rain, snow) and wind	Very high

assessment of road condition. The databank data was used for information collection. The primary research under field conditions is performed. The following information is collected: area of pavement distress, the defects and their causes in road elements; drainage condition; roughness; traffic control and safety information. After that, the assessment of received data and matching to road condition prognosis of object levels is carried out. It is necessary to assess the need for additional data. If this data is not needed, (≥ 100 meters) homogeneous sections are made, and pavement maintenance/repair strategy is selected. If additional information is required, it is necessary to carry out a second study in the field. The studies would include detailed measurement and testing, including drilling cores, material pick-up, roughness, deflections, slip resistance measurements and laboratory tests. The assessment of received data and matching of road condition prognosis of object levels is performed. Collected additional data about the object is stored in a database. Maintenance and/or construction types are selected: a) doing nothing; b) correction; c) repair; d) rehabilitation; e) reconstruction.

4. Recommendations for pavement maintenance technologies

It is significant to take into account very important pavement maintenance, repair group while carrying out the analysis of the road pavement functioning, groups of deterioration determinants and their interaction analysis. This is important because the pavement maintenance may refer to a simple cleaning of the pavements and can mean measures for stopping of potholes, cracks, rutting formation, as well as pavement repair. Therefore, approach to road maintenance could vary. All maintenance work is

dedicated to pavement maintenance cycle or extension. Selected pavement maintenance strategy (repair cycles) and properly applied funded routine "summer-winter" road maintenance, help to receive the maximum economic effect. Observations and pavement condition surveys show that most often skipped moment to apply the appropriate repair strategy. Inexpensive preventive pavement maintenance only briefly pauses pavement deterioration, but later pavement repairs require a significant investment. The activity of several different pavement maintenance is defined by: the support of state level, recovery of pavement condition, reconstruction (Fig. 7). It is important to properly identify the operating conditions of the roads and to provide optimal solutions and technologies for repair. After all, most often during periodic maintenance, left the old pavement structures of different deterioration used for various effects are more sensitive road construction materials, applied cheaper technical and technological solutions. This greatly increases the distress and the probability of occurrence of defects. Deteriorated structures have to be carefully evaluated, and new road construction materials have to be qualitatively manufactured, used and laid. Ongoing support of pavement condition by road network level, with a long-term strategy allows the use of an integrated, cost-effective practical measures that prolong the life of the pavement, improve traffic safety and raise public expectations. Pavement reconstruction, when pavement structure is changed or structural improvements are carried out, allows extending the pavement life. Preventive maintenance is considered as one of the most important types of pavement preservation. This is a cost-effective, a planned operating road maintenance system that slows down the deterioration of the pavement

and improves the state of road network. The corrective maintenance is carried out taking into account the disadvantages interfering effective PMS. Current maintenance is usually planned and daily performed works. Canadian experts suggest the pavement sustainability (service life extension) strategy, which includes the preservation of normal technical procedure where the pavement is still in good or satisfactory condition and poor, requiring repairs that are more extensive or reconstruction (Kazmierowski, Ninguan 2002).

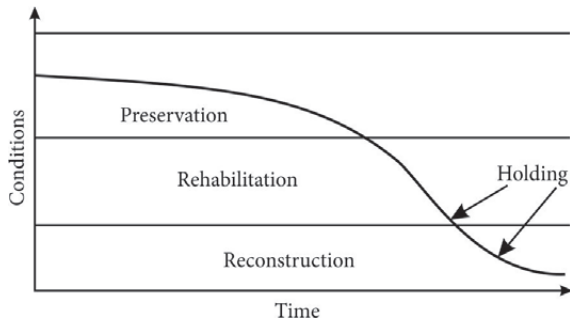


Fig. 8. Types of pavement maintenance strategy

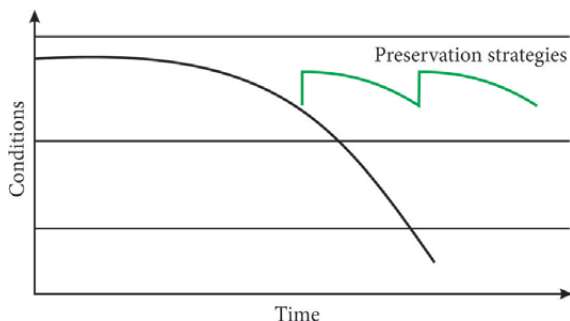


Fig. 9. Preservation strategy of pavement condition

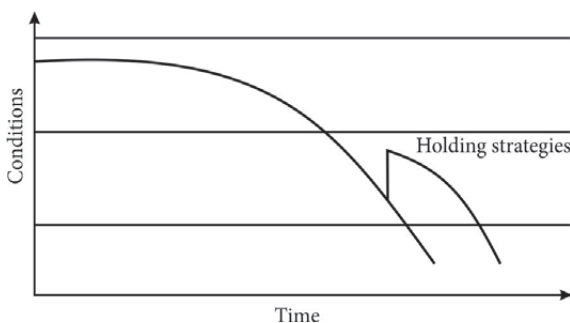


Fig. 10. Strategy of pavement support

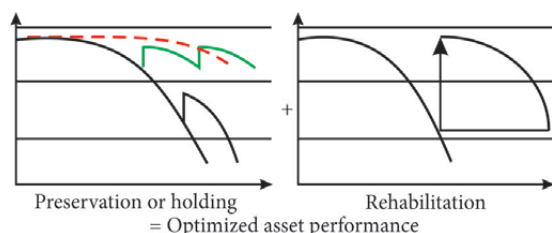


Fig. 11. Coordinated strategies of pavement maintenance

The general understanding of road maintenance options dependent on pavement conditions presented by Kazmierowski (Figs 8–11).

Adapting pavement preservation strategy (Fig. 9), the following repair methods are used:

- Thin surfacing. Used for: patching cracks, water and dirt entering the cracks prevention, to improve the adhesion of wheel with the coat, patching of micro cracks and smashed, patching, renewal of pavement edges and pavement surface.
- Crack Sealing is used to prevent water from entering into the cracks of pavement surface.
- Slurry Seal is used for: sealing surface cracks, correcting of small irregularities, friction playback, etc.
- Measures against micro-surfacing. Applied to: polymer-modified cold asphalt, bitumen emulsion spraying technology, mastics, and dense mixtures. Normally the thickness is 12 mm.
- Chip Seals.
- Ultrathin Bonded Friction Course (Nova Chip). Applied to: the use of polymer-modified bitumen emulsion sprayer.
- Fiber Modified Chip Seal (Fiber Mat).
- Hot in-Place Recycling.
- It is appropriate to identify surface defects, determine their causes and only then apply the selected strategy of pavement maintenance and repair:

- the preservation strategy. Applying this strategy the time of pavement service is extended and functional condition of a road system is maintained. The instruments used: milling of 50 mm, 50 mm resurfacing (Recycled Hot Mix); hot regeneration (Hot in-Place Recycling); sealants of breaking and cracks;
- the repair strategy. It recovers the pavement condition until the required structural or operational compliance, extends the validity of elements of road system. The instruments used: milling of 50 mm, 90 mm recycled hot mix; the use of hot in-place recycling and laying 50 mm;
- the reconstruction strategy. Pavement structure is being changed, renewed value of managed property. The instruments used: asphalt pavement and base (chipping) layer thickness change; full surface modification; new pavement installation;
- support strategy. It is planned for some time. The strategy is applied to an acceptable level of functionality and security while covering the restoration, repair or reconstruction work will be completed. The instruments used: insulating material (using hot asphalt); thin surface coating;
- immediate measures. If the road network status assessment and accident analysis shows the relationship between the road condition and accident have to be subject to immediate measures. In addition to the traffic restrictive measures, construction/repair tools can be applied. Larger-scale building measures have to be included into the

maintenance planning of surface state. Concerning the adoption of immediate measures, assessment results of road network can change.

5. Results and conclusions

1. To summarize the state of the road network management and maintenance practices in different countries, it may be noted that systems, models and procedures differ for its complexity of the specific applications by the country. However, in the general point of view, the objective is the same to ensure long-term, cost-effective, social and environmental needs of the satisfactory operation of the road network.

2. The European and North American experience shows that using a pavement management system and the application of effective models, an average savings are from 15% to 30% of maintenance budget. Pavement deterioration prediction and condition monitoring is an indispensable factor for effective road asset management.

3. There is a tendency that the road network infrastructure management model is changing from the Condition-Based Method to Service-Based Method, which is based on performance indicators: reliability, availability, continuity, safety, security, health, environment, economy and politics, but their value and applicability should be estimated.

4. In determining and evaluating the condition of the road network, it is recommended to follow the basic principles: the road network and building condition, data statistical analysis, maintenance/strategic planning of road works proposals, provision of repair road sections, the algorithm of homogeneous sections, forecast of pavement condition and more.

5. The effective management of the road network need to apply the pavement condition multidimensional analysis, priorities and investment levels to improve the normative documents and the technical condition of the road network to assess the Total Condition Index, composed of the epoch, Service-Based methodology reasonable parameter set. When preparing the multi-annual road network maintenance and repair programs, road network analysis sectioning, identifying each object repair or reconstruction of the need to apply the road of sustainability (service life extension) strategies and innovative, timely repair techniques.

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