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Foresight Study of Road Pavement Technologies

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Abstract

The objectives of this paper are foresight study of the anticipated needs and requirements as well as identification of development directions of materials and technologies for use in road construction in the time perspective of approximately 30 years. In order to address this goal, Delphi forecasting method was utilized in the Polish-nationwide study with 150 invited experts. Paper presents results of research project dealing with development of directions of road pavement technologies with regards to the environmental aspects. As a result of the analyses, it was concluded that binding materials with improved viscoelastic range (often with modifications) would continue to play a leading role. Furthermore, according to the experts, the technologies that enable to monitor the state of road pavement in a continuous manner will be used to a greater range. Introduction of sensors into the pavement network will lead to the construction of "smart" roads while the spread of nanomaterial technologies in road construction will improve the durability and reliability of road pavement construction.

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Keywords: foresight; Delphi method; road; pavement; technology; materials; environment; sustainability

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1. Introduction

Development of road infrastructure is inextricably connected with natural environment. Considering large natural wealth of Poland, there are many conflicts between environment and transport network, which is particularly noticeable in the period of last few years – in an era of a dynamic development of road transport in this part of Europe. It is beyond doubt that the development of road infrastructure is necessary to achieve economic and social benefits but in accordance with the principles of sustainable development and the need to respect the laws of nature. In the Polish case, public authorities are obliged to conduct an environmental impact assessment for linear investments. That enables the reconciliation of interests of road users with the requirements of environmental protection. The aim of the environment protection is not to restrict the development of infrastructure but to mitigate and compensate for its effects on: surface water and groundwater, the land surface – soil, air, wildlife, landscape, vibration and noise. The current process of road network construction in Poland requires technically safe solutions meeting the transport needs of the present without compromising the ability to meet such needs in the future.

The main objective of road construction industry in Poland is to create a network of motorway and expressway links between the main urban centers as well as links with international road system and European metropolitan areas by 2030 as part of the TEN-T framework [1]. Highway ring-roads of major urban areas will be an additional key element. Crucial parts of the complementary network of expressways will include sections providing service of the areas currently not sufficiently accessible, such as Middle Pomerania, Masuria, Eastern Poland, Subcarpathia and Klodzko Valley. The implementation of these tasks will be certainly difficult from the point of view of so-called "extreme" environmentalists. A characteristic feature of road construction is linear nature of works which makes a specific type of impact on natural environment. One must strive to seek a compromise solution between two conflicting discourses, i.e. the provision of human development providing the opportunity to satisfy a variety of needs and the status quo or even expanding natural areas in which humans cannot interfere. So-called “sustainable pavement” is a proposed solution to this conflict.

This paper presents the application of foresight study based on Delphi method to a specific, well-defined issue of road pavement technologies development with regard to the sustainability aspect. The objectives of this paper are: (i) formulation of anticipated needs and requirements as well as identification of development directions of materials and technologies for use in the perspective of approximately 30 years in road construction; (ii) identification of material and technological requirements for road construction in environmentally protected areas in Poland. Selected outcomes of research in the identification of the main areas and theses associated with projected trends in the advancements in new materials, technology and pavements used in road construction in the context of the specific environmental requirements and sustainable development are described in the paper. Results described in this paper were obtained during the research project conducted in 2011-2014 and supported by Polish General Directorate for National Roads and Motorways [2]. The research methodology applied in this project was based on the concept of foresight that enables to anticipate future from a very broad perspective taking into consideration factors influencing predicted phenomena of social, technological, economic, ecological, political, value-based and legal nature. Foresight studies are gaining importance in the complex contemporary world, especially in the context of evidence-based policy. More than two thousand foresight initiatives of supranational, national, regional, sectorial or so-called thematic type may be identified in the existing published works on foresight [3,4].

2. Literature review

The problem of environmental degradation and the effects of unsustainable development gained global significance in the early 70s of the twentieth century. Stockholm Declaration of the United Nations Conference imposed on governments a duty to protect and improve the environment for both present and future generations [5] The situation in the world had led to the conviction that there was no other course of social and economic development as an eco-development, the concept of which was formulated during the third Session of the Governing Board of the United Nations Environment Program (UNEP) [6]. The Lisbon Strategy of 2000 established guidelines of the EU economy development based on competitiveness and knowledge. In 2001 a chapter on environmental protection was added [7]. It emphasized that "economic development, social cohesion and environmental protection must go hand in hand". Among the main threats to sustainable development are: greenhouse gas emissions, loss of biodiversity and regional imbalances.

In the general meaning, "sustainable pavement" should be characterized by low energy requirements, low emissions and environmentally friendly design. This pavement should be safe and meet the transport needs of the present without compromising the ability to meet such needs in the future. A modern pavements should be constructed with materials allowing for traffic noise reduction and improve water drainage parameters [8,9]. Using currently available materials and technology, a significant improvement in substitution of virgin materials with recycled ones is possible [10,11], including both asphalt and cement based technologies [12]. In terms of social costs, long durability periods are required. Such solution is possible by e.g. application of so-called asphalt perpetual technology [13]. Carbon footprint can be reduced together with extending the construction season by application of the warm mix asphalt (WMA) technology [14,15]. Finally, "future" technologies are approaching the present construction market by using of the nano-size materials [16,17] and other technology-based sustainable solutions [18,19].

In general, traditional materials and road technologies as well as modern, innovative solutions may be used for construction of sustainable pavements in Poland. Following technologies should be considered:

- asphalt pavement – road pavement with use of bitumen material for binding;
- cement concrete pavement – road pavement with use of cement for binding;
- pavement with recycled materials – road pavement with demolition waste, material form road re-construction and other post-industrial materials used in structural layers;
- long lasting (so-called perpetual) pavement – special road pavement designed and constructed to achieve at least 50-years of durability;
- intelligent pavement – special road pavement with built-in gauges mainly for the purpose of monitoring road and traffic condition;
- quiet pavement – special road pavement design and constructed to mitigate traffic noise.

It can be observed that – on the national-government level – there is a need to collect the most-up-to-date information regarding development directions of road pavement technologies with regards to the environmental aspects. Once such information is available, necessary regulations and strategies can be accepted and disseminated to the industry.

In the existing published works, the authors have not come across the application of the Delphi method for the formulation of the pavement technologies with the respect to environmental issues.

3. The Delphi Survey technique

The Delphi method is a kind of expert research in which the views of the experts are treated as an eligible contribution in formulation of judgments about the future and solving complex problems in the situation of uncertainty. In the classical approach, this method enables efficient communication of the group of experts who remain anonymous to each other, in order to solve a complex problem. The method is used to predict long-term processes or phenomena, knowledge of which is inadequate or uncertain, i.e. in the situation when no reliable data on them exist or when the external factors have decisive impact on them. Moreover, these problems are not suitable to be subjects of precise analytical techniques of traditional forecasting. Therefore, methods based on experience and intuition that relate to the collective intelligence/collective wisdom can be useful to analyse such problems [20, 21].

In the classical approach, the Delphi study is preceded by formulation of Delphi theses and ancillary questions. Each Delphi thesis refers to the future description of dependencies between issues arising from the specificity of the study, its context and the goal. In the simplest approach, it is a research question relating to the future presented in the form of a thesis (the description of dependences). Ancillary questions include items such as the assessment of expert's knowledge level, the implementation time of the thesis, factors favourable to the implementation of the thesis, barriers to implementation of the thesis, and the expected effects of the thesis [22].

Delphi method has been used in different formats and different domains such as healthcare, management, education [23,24]. Recent publications on the method concern enhancing rigour in the Delphi-based research proposing criteria such as: reliability, validity and trustworthiness in judgement assessment [25]. An interesting example of the application of Delphi method for pavement management has been presented in [26]. The main scope of the work was to "develop a simple, flexible, and cost-effective methodology to evaluate the condition of pavements and shoulders in a road network". This methodology is based on pavement condition models developed with expert

surveys using the Delphi method. Another interesting example of Delphi method application has been proposed in the work [27]. The authors describe the application of Fuzzy Delphi Method Application and Grey Delphi Method to quantify experts' attitudes to regional road safety, urban road safety and highway safety with the aim of constructing three sets of road safety performance indicators.

The purpose of the Delphi study presented in this paper is to conduct a consultation with the communities of experts on the topic of the future road pavement technologies and facilitate consensus building as to the possible (and desirable) pictures of the future of road construction. The methodology of the Delphi study is presented in Fig. 1.

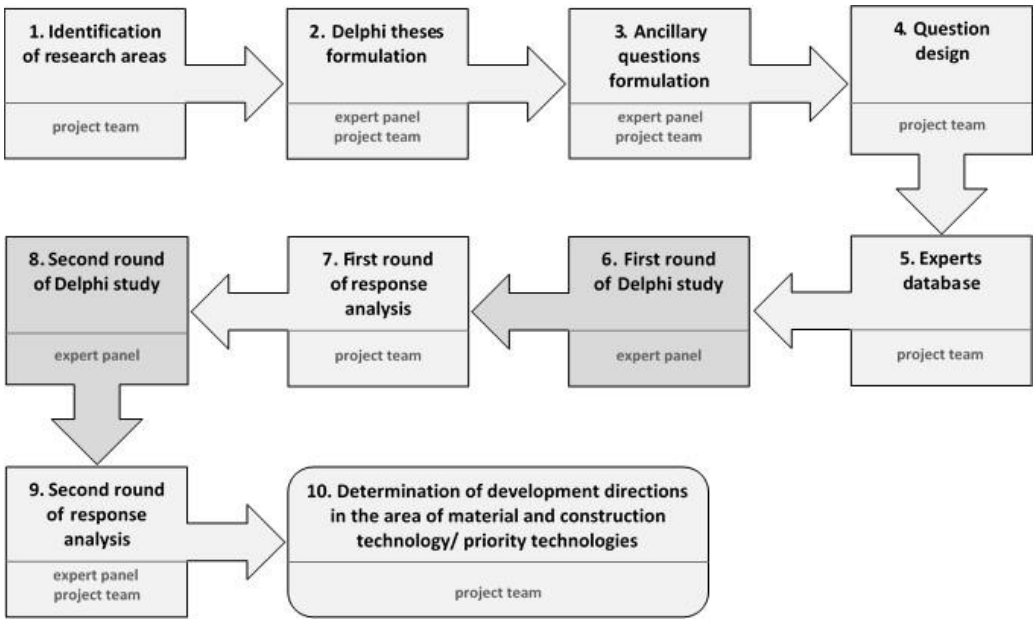

Fig. 1. Delphi methodology utilized in the study.

The first stage of the research is focused on the identification of research areas in the field of road and bridge construction. The purpose of the subsequent phases of the study was to develop a Delphi questionnaire, which was then sent to a wider group of experts. In the next step of the research procedure a creation of a database of the Delphi method experts was carried out. The purpose of the subsequent research tasks was to implement the proper Delphi study on a larger number of experts, i.e. conducting the first round of survey, analysis of the results of the first round of survey, conducting the second round of research and the analysis of the results of the second round. Completion of aforementioned tasks has in effect lead to the final task, which was to determine the directions of development of materials and construction technologies / priority technologies.

4. Delphi research areas and thesis

Basing on the literature review, findings from multiple local and international conferences and backed by brainstorming technique, the project team developed the following research areas [28, 29]:

- OB1: technologies of construction of durable road pavements in Poland (research methods: project team workshop, brainstorming, literature review).
- OB2: material, technological and design solutions of road construction in terms of environmental protection and sustainable development (research methods: literature review, expert panel, brainstorming,).
- OB3: environmentally friendly and durable pavement construction of roads and bridge structures (research methods: project team workshop, brainstorming).

Preliminary/working Delphi theses for all areas were developed during the first panel of core experts. The aim of the next panel of experts was to determine the thesis hierarchy. Finally, as a result of the work of the expert panel, research theses were defined as presented in Table 1.

Table 1. Theses by the research areas.

OB1: Construction technologies of permanent roads in Poland	
1.1	Development of asphalt and cement concrete technologies will provide at least thirty year durability of roads built in Poland
1.2	Paving cement concrete will be used mainly for the construction of motorways and expressways
1.3	Asphalt pavements will be used for the construction of all categories of roads
OB2: material, technological and design solutions of road construction in terms of environmental protection and sustainable development	
2.1	Asphalt and modified asphalt manufactured in Poland will meet the requirements of variable climate conditions in Poland
2.2	Recycled materials will be commonly used for the construction of road courses
OB3: Environmentally friendly and durable road and bridge pavements	
3.1	Road surfaces will have a built-in driver warning systems
3.2	Energy recovery pavements will be constructed
3.3	"Perpetual" durable asphalt pavements will be constructed

In the first area concerning the durability of road pavement built in the future in Poland the panel of experts selected three theses that state that in the perspective of the next thirty years both cement and asphalt concrete technologies will be used. The assurance of prolonged durability, reaching up to 50 years in the case of roads and expressways, will be possible thanks to the application of the modified cement concrete technology and asphalt technology, high-quality materials and construction of a new generation of "perpetual" type pavement. Cement concrete pavements are to be constructed in large numbers mainly on highways, but nevertheless it is anticipated that asphalt surfaces will remain the core technology in the future .

The second area devoted to the issues of materials and technologies in road construction will include two theses on the binder quality in Poland and the use of recycled materials. It is assumed that the properties of produced binders will be adapted to withstand the harsh climatic conditions in Poland. These are primarily modified binders, including rubber modified bitumen and new additives generation. The implementation of the principles of sustainable development to the construction practice will increase the use of recycled materials by 70%.

In the third field, three most important theses related to the long-life pavement construction were highlighted. These are "perpetual" technologies that enable energy acquisition from the heated surface, built-in systems to monitor the condition of road surface, self-healing systems and systems that allow for traffic safety improvement.

5. Delphi study results and discussion

The experts' task was to evaluate the importance of the theses about the development of road construction technologies, to determine the probability of the theses implementation within a given time, to evaluate factors, obstacles and activities which influence the realisation of the theses. The article presents the results concerning the theses listed in Table 1.

5.1. Thesis importance

The Delphi theses were evaluated from the perspective of their importance/significance. Four most significant theses emerged with importance indicators reaching above 0.90 (Fig. 2) The highest level of significance index was observed in relation to the thesis 3.3 dealing with perpetual pavement. The next two theses of very high importance concerned the material and technological solutions in terms of environmental protection and sustainable development (OB2). According to the experts' judgement, it is very important for the development of road constructions that bitumen meet the requirements of the changing Polish climatic conditions. Equally important is the wide use of pavement structural layers constructed out of recycled materials.

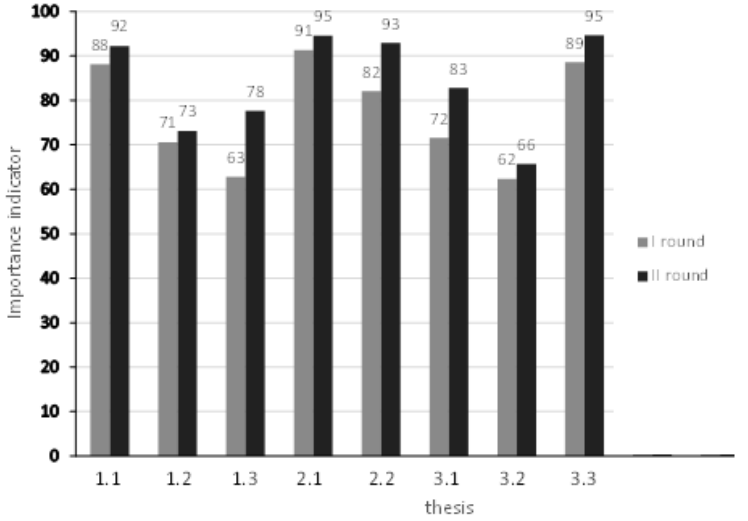

Fig. 2. Levels of importance indices of the theses examined in the first and second round of Delphi research.

Very high level of importance indicator was also observed for the thesis 1.1 which states that the development of technology of asphalt and cement concrete will provide at least thirty-year service life of pavement built in Poland. It is important to highlight the fact that most of the theses registered even higher levels of importance after the second round of the Delphi survey.

5.2. Thesis implementation time

Experts also indicated the most likely time of implementation of particular theses in the future (Fig. 3). After calculating the median implementation time for particular theses, it can be noted that, according to the experts, the majority of theses has a high chance to be accomplished by 2030. Only thesis 3.2 dealing with the use of road surfaces enabling energy recovery is deemed to be accomplished in the further future (after 2030). In general, it can be stated that road technology development is highly dynamic. Technology maturity periods are much shorter as compared to the past decade (XX century) when technology implementation period was typically about twenty years.

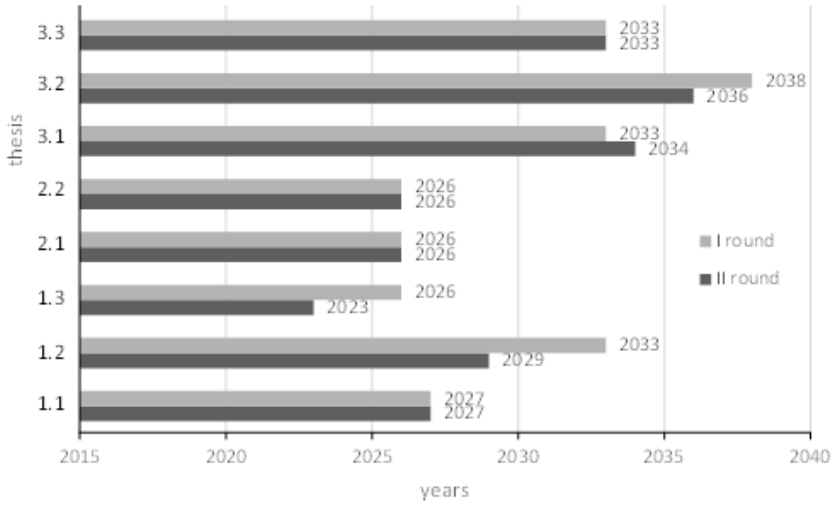

Fig. 3. Thesis implementation time (medians)

5.3. Factors affecting the thesis likelihood

Experts engaged in the study estimated how strong the factors affecting the implementation (or completion) of the thesis are. The list of factors was the same for all analysed theses:

- increase of investment in research and development (R&D sector),
- extending cooperation of the scientific institutions with the enterprises,
- introduction of appropriate legal and economical mechanisms,
- increase of social acceptance (e.g. through appropriate information campaigns),
- high quality workmanship of road works.

Clearly, the factors contributing to the implementation of most of the thesis are primarily increasing expenditure of research and high quality workmanship of road works. For the theses from the area concerning the material and technological solutions in the zones of special natural value, it is necessary to first introduce appropriate legal and economic mechanisms.

6. Conclusions

Conducted research and analyses allow to draw some preliminary conclusions regarding the future of the road pavements:

- the most important research areas of road pavement technology development are material and technological solutions for special nature preservation areas, durable road structures and recyclable, locally available materials;
- the experts ascribed the highest importance to the theses related to high durability asphalt and cement concrete pavements (perpetual), special innovative material design to meet Polish climatic requirements and wider usage of recyclable materials;
- as far as binding materials are concerned, high durability binders with improved viscoelastic range will continue to play a leading role. The second group of binding materials will include polymer modified binders and binders modified with chemical additives customized to fit specific applications;
- it should be noted that technologies that enable monitoring the state of road pavement in a continuous manner will be used to a greater extent in the future. Sensors and nanomaterial components in the pavement network will lead to the construction of "smart" roads.

The conducted research on the future of road pavements has proven the high utility of foresight approach to the questions of long term technological development. Three distinctive characteristics of foresight studies (openness to multiple futures, participation of various groups of stakeholders and orientation at policy action) [30] make it a suitable instrument of a systematic reflection on the future of complex and uncertain issues. The application of a specifically tailored Delphi method has facilitated the consensus building process in the community of road construction experts and Polish decision makers responsible for sustainability and innovation policy [31].

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