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FUTURE TRENDS IN ROAD PAVEMENT TECHNOLOGIES DEVELOPMENT IN THE CONTEXT OF ENVIRONMENTAL PROTECTION

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Abstract. Construction of modern and durable asphalt and cement pavements requires high quality materials and suitable technologies that take into account sustainability concerns which are related to the environmental protection, mitigation and compensation for road construction effects on surface water and groundwater, soil, air, wildlife, landscape, vibration and noise. The objectives of this paper are to identify possible development directions of materials and technologies in road construction in the time perspective of approximately 30 years. In order to achieve that goal a nationwide Delphi survey with 150 invited experts was deployed. The study concluded that binding materials with improved viscoelastic range – and often with specific modifications – would continue to play a leading role. Furthermore, technologies that enable monitoring the state of road pavement condition in a continuous manner would be used to a greater range. Introduction of sensors into the pavement network would lead to the construction of "smart" roads while spreading of nanomaterial technology would improve the durability and reliability of road pavement construction.

Keywords: development, environment, materials, pavement, road, sustainability, technology.

1. Introduction

The main objective of road construction industry in European Union (EU) is to create a network of motorway and expressway links between the main urban centres as well as links with international road system and European metropolitan areas by 2030. 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.

Development of road infrastructure is inextricably connected with the natural environment. Considering large natural wealth of Europe, there are many conflicts between environment and transport network, which is particularly noticeable in the recent years. It is beyond doubt that the development of road infrastructure is necessary to achieve economic and social benefits as long as it is carried out in accordance with the principles of sustainable development. In many countries, public authorities are obligated to conduct environmental impact assessments for linear investments, which reconciles the 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, groundwater, soil, air, wildlife and landscape.

Road construction undergoes dynamic and constant changes, especially concerning road paving technology. It is largely dependent on government policy and the development of science. In order to provide the decision makers with robust information, possible development directions of road pavement technologies need to be evaluated. This article aims to respond to this need. It presents the application of foresight study based on Delphi method for a

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specific, well-defined issue – development directions of road pavement technologies with regard to the sustainability aspects. The objectives of the paper are to identify possible development directions of materials and technologies for use in the perspective of approximately 30 years in road construction and to describe anticipated needs and requirements associated with that development. The second goal of the research was to identify material and technological requirements for road construction in environmentally protected areas.

The research methodology applied in this project is based on the concept of foresight that enables to anticipate future developments from a very broad perspective taking into consideration the social, technological, economical, ecological, political, value-based and legal origins. Foresight may be defined as a process of building alternative visions of the long-term future of technologies, economies, societies and organisations in order to facilitate planning and decision making (Halicka *et al.* 2015; Nazarko, Kononiuk 2013). As noted by Andreescu *et al.* (2013), foresight embraces three basic assumptions, namely: (a) entails a participatory process involving diverse categories of actors and stakeholders; and (b) aims to deliver a shared normative vision of the future as a guide to action and (c) approaches predicted phenomena holistically (Andreescu *et al.* 2013). Foresight studies seem to be gaining importance in the complex contemporary world, especially in the context of evidence-based policy (Nazarko 2015).

2. Literature review

The need to incorporate environmental issues into socio-economic development has been strongly and repeatedly articulated since 1960s. Idea of sustainable development (frequently defined as a process of development that meets present requirements but does not comprise the future generations' ability to meet their own needs) has been gaining importance in scientific and public discourse. The implementation of the concept of sustainable development should lead in particular to: reduction of dependence on non-renewable energy resources, recycling of natural resources, reduction of greenhouse gas emissions, reduction of existing and prevention against new toxic emissions of pollutants into the environment, assurance of equal opportunities of development for present and future generations. In general, "sustainable pavement" should be characterized by low energy requirements, low emissions and environmentally friendly design.

With the widespread acknowledgement of the importance of sustainable development in global and regional development, the debate is still open among researchers and practitioners on the process of implementation in different sectors. In addition, in the construction industry (and in road construction) there seem to be numerous significant unsolved problems requiring further study. At present mostly structural requirements and economic aspects dictate the choice of materials and techniques in road construction. However, ecological factors have gained in importance due to the environmental considerations in politics and society (Thiel *et al.* 2014). Research on road construction in terms of the requirements of sustainable development focus, on the one hand, on the selection of building materials and the analysis of their negative impact on the environment and, on the other hand, on the analysis of the construction process itself. In this context, different Life Cycle Assessment (LCA) studies of road pavements have been conducted in the last years (Santos *et al.* 2015; Thiel *et al.* 2014).

In the area of modification of building materials for the construction of road pavements, exemplary scientific studies relate to the possibility of using stabilized bottom ash (Toraldo, Saponaro 2015), binder modified with a high content of crumb rubber (Pajea *et al.* 2013) and flexible pavement structures (Santos *et al.* 2015). The analyses regarding the potential impact on the environment include the analysis of air pollutants, noise reduction and the reuse of waste. Modern pavements should be constructed with materials allowing for traffic noise reduction and improved water drainage parameters (Freitas *et al.* 2012; Ranieri *et al.* 2012). Using currently available materials and technology a significant improvement in substitution of virgin materials with those from recycling is possible (Gómez-Meijide *et al.* 2015), including both asphalt and cement based technologies (Yang *et al.* 2014). In terms of social costs, long durability periods are required; such solution is possible by e.g. application of so-called asphalt perpetual technology (Lee *et al.* 2007). However, road bitumen contains heavy metals that are environmentally harmful and have negative impact on bitumen aging, i.e. reduce asphaltenes in the structure (Paliukaitė *et al.* 2015). Both environmental and economic factors contribute to the growing need for the use of alternative nature friendly materials in asphalt concrete pavements. The study of Haritonovs and Tihonovs (2014) investigated the use of dolomite sand waste as filler for design of high performance asphalt concrete. The use of alternative indigenous products in semi-flexible pavements emphasised in the study by Koting *et al.* (2014). Finally, "future" technologies are approaching a present construction market, by using of the nano-size materials (Shokrlu *et al.* 2014) and future sustainable solutions (García, Partl 2014).

In general, both traditional materials and road technologies as well as modern, innovative solutions could be used for the construction of sustainable pavements in Europe:

- asphalt pavement – road pavement with bitumen material for binding;
- cement concrete pavement – road pavement with cement for binding;
- pavement with recycled materials – road pavement with demolition waste, material form road re-construction and other post-industrial material 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.

New developments in nano-materials and data collection/communication systems can be observed making them suitable for intelligent pavement construction. 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 concerning the environmental aspects. Once such an information is available, the industry could introduce and implement necessary regulations and strategies.

3. Research methodology and its operationalization

The key methodological features of the Delphi study presented in this paper include multi-stage procedure, anonymity, and provision of feedback and independence of experts' views. Delphi has been used in various formats and different domains such as healthcare, energy, manufacturing, logistics, and education. It has been widely applied in the processes of technology selection and prioritisation (Haluza, Jungwirth 2015). Works related to the application of Delphi method in the research field of road pavement technologies are among the few. De Solminihac *et al.* (2009) have presented an interesting example of Delphi application for pavement management. The main scope of their work was to "develop a simple, flexible, and cost-effective methodology to evaluate the condition level of pavements and shoulders in a road network". The base of this methodology is pavement condition models developed with expert surveys using the Delphi method. Another example of Delphi method application comes from the works of Ma *et al.* (2011). 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 indicators on road safety performance. 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 respect to environmental issues.

In the classical approach, the formulation of Delphi theses and ancillary questions is a first step of Delphi study. Steering committee/project team appoints an expert panel, usually consisting of the leading specialists in a particular field, the aim of which is to design a Delphi questionnaire. Delphi questionnaire consists of statements (theses) that describe dependences between phenomena crucial for the future of the specific field of study. Ancillary questions include items such as assessment of the level of expert knowledge, thesis implementation time, favourable factors of the thesis, barriers to the thesis implementation, and the expected effects of the thesis. In the next stage, broader group of experts called Delphi experts receive the developed Delphi questionnaire. The role of this group is to formulate the long-term judgments/predictions about future developments in the area of research by filling in the Delphi questionnaire. In the next round of the survey, respondents fill in the same questionnaire but have the chance to get acquainted with the summary results of the first round of the survey. Experts, therefore, have a chance to maintain or change their opinion on the development of the phenomena in a given research area. Such procedure results in a more conclusive judgment. Thus, the multistage research procedure allows participants to revise their own views during the entire research process.

Respecting the initial design presumptions, the purpose of the conducted Delphi method was to carry out a consultation with communities of experts with the aim of achieving consensus regarding the picture of the future of road construction. The operationalization of methodology of the Delphi study is presented in Fig. 1.

The first stage of the research is focused around 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 further

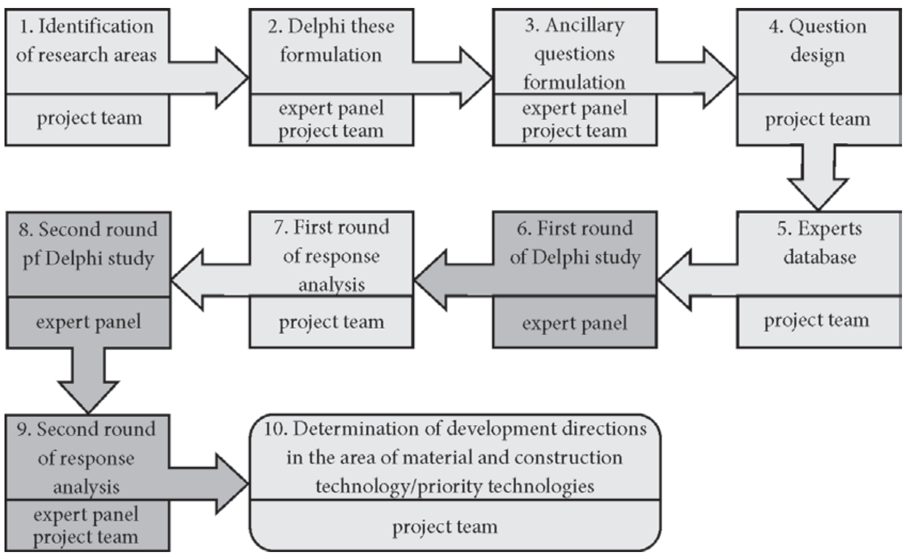

Fig. 1. Operationalization of Delphi methodology designed for the study

step of the research procedure, the creation of a database of the Delphi experts was foreseen. The project followed the following principles of expert recruitment: snowball method, open enrolment application using a questionnaire and the use of existing public databases such as databases of research employees. It was assumed that the group of external experts would consist of the representatives of science, business, environmental organizations, General Directorate for National Roads and Motorways, public administration, political parties as well as the students majoring in the fields associated with the subject of the project. 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 the survey, developing the results of the first round of survey, conducting the second round of research and developing the results of the second round. Completion of the aforementioned tasks has in effect lead to the final task, which was to determine the development directions of materials and construction technologies and the identification of priority technologies.

Implementation of Delphi method implicates the collection of large amount of data. In order to facilitate the analysis of the gathered data some variables of the questionnaire have been presented in a form of indicators which synthesize and organise the results of the large number of observations. In order to determine the importance of a particular thesis for road construction technology development the importance indicators (I_I) have been calculated according to the following formula:

$$I_I = \frac{n_{VI}100 + n_I 75 + n_{RI} 25 + n_{NI} 0}{n - n_{NO}}, \quad (1)$$

where n_{VI} – number of "very important" answers; n_I – number of "important" answers; n_{RI} – number of "rather important" answers; n_{NI} – number of "not important" answers; n_{NO} – number of "no opinion" answers; n – total number of all answers.

Importance indicator reflects which of theses are, in the opinion of the experts, of strategic importance. The indicator values are in the range between 0 and 100. The closer the value is to 100 the higher is the importance of a thesis.

Additionally, in order to determine the level of influence of the factors, obstacles and actions on the thesis realisation, appropriate indicators have been calculated according to the following formula:

$$I_F / I_O / I_A = \frac{n_{VH}100 + n_H 75 + n_M 50 + n_L 25 + n_{VL} 0}{n - \left(n_O + n_{NC}\right)}, (2)$$

where I_F – factors' indicator; I_O – obstacles' indicator; I_A – actions' indicator; n_{VH} – number of "very high level" answers; n_H – number of "high level" answers; n_M – number of "moderate level" answers; n_L – number of "low level" answers; n_{VL} – number of "very low level" answers; n_O – number of "no opinion" answers; n_{NC} – number of "factor/obstacle/action not connected with the thesis" answers; n – total number of all answers.

The values of all indicators are in the range between 0 and 100. The closer the value is to 100, the higher is the level of influence of the factor/obstacle/action in experts' opinion is.

Presented approach allowed a comprehensive analysis of the views of the involved experts on each thesis. The use of described indicators made it possible to carry out a comparative analysis of the various theses in further stages of the study.

4. Delphi study of future developments of road pavement technologies

4.1. Experts in the study

It should be noted that the quality of the Delphi method is largely dependent on the experts' intellectual potential. Hence, the proper selection of experts for both the expert panel and the research per se is the main challenge in conducting a Delphi study. The described project engaged a group of 150 experts. They filled in a research questionnaire concerning their assessment of the theses designed for the project. The respondents constituted a varied group in terms of their professional background. The largest groups represented academia (29% of experts) as well as construction companies (29%). Approximately 16% of experts originated from the governmental administration and nearly 10% were experts representing corporate research and development sector. About one sixth of the experts came from sectors complementary to road construction, such as industrial production (5%), municipal administration (5%) and other sectors (6%), including environmental protection (1%).

4.2. Research areas and theses

Using the brainstorming technique and backed by the literature review, findings from multiple local and international conferences, the project team developed the following research areas (Gaweł *et al.* 2011; Kirby 1996; Piłat, Radziszewski 2010):

RA1: technologies of construction of durable road pavements (research methods: project team workshop, brainstorming, literature review).

RA2: material, technological and design solutions for road construction in terms of environmental protection and sustainable development (research methods: literature review, expert panel, and brainstorming).

RA3: environmentally friendly and durable pavement construction of roads and bridge structures (research methods: project team workshop, brainstorming).

RA4: material and technology selection in areas of special protection (research methods: the CAVI survey).

The project team appointed an expert panel whose task was to develop Delphi theses. Seventeen core experts were invited to the panel of representatives of science, government, administration, business and media. During the first meeting of core experts, preliminary (working) Delphi theses were developed for all areas. The aim of the following meeting was to determine the thesis hierarchy. The indication method was used for this purpose: each of the experts had a possibility of indicating three most important – in his/her opinion – theses in each of the seven research areas. The obtained results allowed arranging the theses in the order of their importance measured by the number of indications. Finally, because of the work of the expert panel, research theses were developed as presented in Table 1.

Experts selected three most important theses in the area of future road pavement durability in analysed region (RA1). The theses state that both cement and asphalt concrete technologies will be used in the next thirty years. The assurance of prolonged durability (reaching up to 50 years in case of roads and expressways) will be possible thanks to the application of 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 mainly on highways; nevertheless, asphalt surfaces are expected to remain the core technology in the future.

The second area (RA2), devoted to issues of materials and technologies in road construction, included two theses deemed most important. They concern the binders' quality and the use of recycled materials. It is anticipated that the properties of produced binders will be adapted to withstand the harsh climatic conditions in northern European countries. These are primarily modified binder, including rubber modified bitumen and new additives generation. According to the involved experts, the implementation of the principles of sustainable development to the construction practice will increase the use of recycled materials by 70%.

In the RA3 field, the highlighted theses were related to long-life pavement construction. These are "perpetual" technologies that enable energy acquisition from the heated surface, with built-in systems to monitor condition of road surface, with self-healing systems and with systems that allow traffic safety improvement.

Table 1. Theses by the research areas

RA1: Technologies of permanent roads construction	
1.1	Development of asphalt and cement concrete technologies will provide at least thirty-year durability of roads built in harsh climatic conditions
1.2	Paving cement concrete will be used mainly for the construction of motorways and express roads
1.3	Asphalt pavements will be used for the construction of all categories of roads
1.4	Cement concrete pavements will be used mainly for the construction of motorways and express roads
1.5	Concrete pavements will built in technologies that would minimize shrinkage and thermal cracking
1.6	Road surfaces will be built in technology not requiring expansion joints such as highly durable composite thin courses
1.7	Unconventional materials (e.g. graphene) assuring high functionality and decade-lasting durability will be used to cover road surfaces
1.8	Technologies of complex surfaces will be used in full access traffic areas (parking lots, intersections)
RA2: Material, technological and design solutions for road construction in terms of environmental protection and sustainable development	
2.1	Asphalt and modified asphalts manufactured in Poland will meet the requirements of variable local climate conditions.
2.2	Recycled materials will be commonly used for the construction of road courses
2.3	Only material and technological solutions entirely compliant with the principles of sustainable development will be used for the construction of roads in EU
2.4	The road design process will encompass earth works balancing including noise protection embankments
2.5	It will be possible to use materials of anthropogenic origin (resulting from human activity) to build road courses
RA3: 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	Durable "perpetual" asphalt pavements will be constructed
3.4	Pavements that clean storm water will be constructed
RA4: Material and technological solutions in the areas of high natural value	
4.1	Non-bonded aggregate technology will be primarily used in construction of low traffic category roads in areas of high natural value
4.2	Silent pavement technology will be commonly used in road construction and maintenance in the areas of high natural value in order to limit the use of noise barriers
4.3	Local materials will be commonly used in construction of road courses in the areas of high natural value
4.4	Hard, improved surfaces will not be built in the areas of high natural value
4.5	Road structures will be constructed without affecting the subsoil

Note: rows in grey indicate theses which received the highest number of indications as the most important ones.

As far as the areas of high natural value are concerned (RA4), experts predicted a decrease in the use of binding materials in pavement construction. Instead, local materials are to be commonly utilised in non-bonded aggregate technology. In the aforementioned zones the applied materials and technology should provide low levels of traffic noise.

5. Research results and discussion

The task of the Delphi experts was to evaluate the importance of the theses for the development of road construction, to determine the probability of realisation of each thesis in a given time and to evaluate factors, obstacles and activities, which influence the realisation of a thesis. The article presents the obtained results pertaining the theses highlighted in Table 1.

5.1. Thesis importance

The results of the assessment of thesis importance for the development of road construction point at four most important theses for which indicators have reached levels above 0.90 (Fig. 2).

The highest level of significance index was reached by the thesis 3.3 dealing with perpetual pavement. The next two theses of very high importance were related to the second area (RA2). According to the experts, it was very important for the development of road construction that bitumen meets the requirements of the changing climatic conditions. Equally important was a wide use of recycled materials for the construction of pavement structural layers. Very high level of importance indicator was also observed for the thesis 1.1, which stated that the development of technology of asphalt and cement concrete would provide at least thirty-year service life of pavement built in harsh climatic conditions. It is important to highlight the fact that most of the theses obtained even higher levels of importance after the second round of the Delphi survey.

5.2. Thesis realisation period

Experts also indicated the most likely period of implementation (realisation) of particular theses in the future (Fig. 2). After calculating the median realisation time for the theses it can be noted that the majority of the theses have a high chance to be accomplished by 2030. Only thesis 3.2 dealing with the use of road surfaces enabling energy recovery has a realisation time set for the farther future (after 2030). In general, it can be stated that, according to the experts' judgment, road technology development is characterised by a high change dynamic. Technology maturity periods are much shorter as compared to the past decade of 20th century when technology implementation period was typically about twenty years.

5.3. Factors affecting the thesis likelihood

As a part of the research, the experts estimated how strong were the factors affecting the realisation of the studied theses. The factor list was the same for each of the analysed thesis and it had the following contents:

– Increase of investment in R&D sector;
– Strengthening of the cooperation between the scientific institutions and enterprises;
– Introduction of appropriate legal and economic mechanisms;
– Increasing social acceptance (e.g. through appropriate information campaigns);
– High quality workmanship of road works.

Particular indicators of the factors enumerated in the first and second round of Delphi research are shown

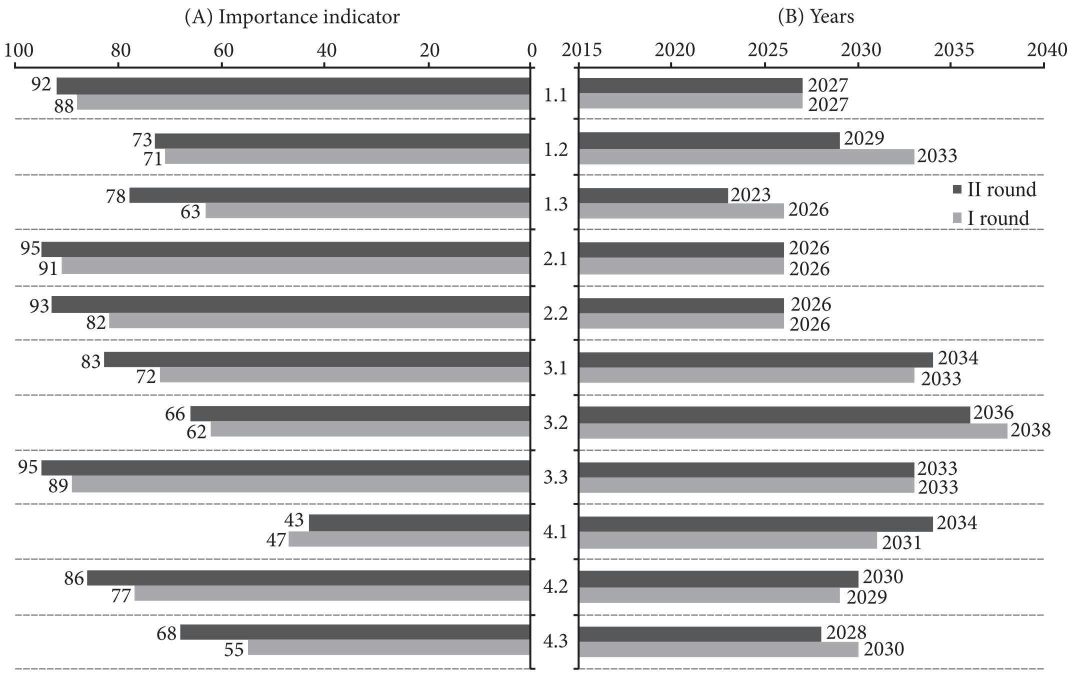

Fig. 2. Levels of significance index for examined theses (A) and the thesis medians realisation time (B) in the two rounds of Delphi research

in Table 2. Clearly, the factors contributing to the implementation of the majority of the theses are primarily the increase in R&D expenditure and the high quality workmanship of road works. For the theses from the fourth area concerning the material and technological solutions in the areas of natural value (RA4) it is necessary to first introduce appropriate legal and economic mechanisms.

5.4. Thesis obstacles

Delphi experts were also asked to evaluate possible barriers to the realisation of the theses under examination. The set of obstacles was the same for each thesis and it had the following contents:

– Insufficient development of technical facilities.
– Insufficient legal regulations.
– High cost of technology implementation.
– Underdeveloped enterprise sector incapable of implementing modern (advanced) technologies.
– Low quality of workmanship of road works.

The experts evaluated the power of the obstacles in relation to each thesis (Table 3). According to their views, the biggest obstacle for most of the theses are insufficient legal regulations in the area of innovation support. That phenomenon was clearly visible after second Delphi round of the survey.

Table 2. Power of factors supporting the implementation of the Delphi theses

Thesis number	Factors									
	Increase of investment in R&D sector		Strengthening of cooperation between the scientific institutions and enterprises		The introduction of appropriate legal and economic mechanisms		Increasing social acceptance (e.g. through appropriate information campaigns)		High quality workmanship of road works	
	I round	II round	I round	II round	I round	II round	I round	II round	I round	II round
1.1	85	84	82	82	77	78	56	48	92	90
1.2	75	75	75	68	71	69	59	48	85	87
1.3	72	72	69	72	68	69	50	48	80	85
2.1	89	90	84	86	66	67	52	43	77	87
2.2	79	86	78	81	82	84	63	60	78	88
3.1	79	82	76	77	73	76	65	66	69	69
3.2	91	94	87	86	73	74	62	61	79	81
3.3	84	90	80	84	72	75	53	54	88	89
4.1	49	56	50	51	71	76	66	67	66	68
4.2	80	82	76	77	80	81	71	66	85	86
4.3	58	60	61	57	70	71	53	58	68	68

Note: the darker the field colour the more indications were registered for a particular thesis.

Table 3. Power of factors hindering the implementation of the Delphi theses

Thesis number	Obstacles									
	Insufficient development of technical facilities		Insufficient legal regulations		High cost of technology implementations		Underdeveloped enterprise sector incapable of implementing modern (advanced) technologies		Low quality of workmanship of road works	
	I round	II round	I round	II round	I round	II round	I round	II round	I round	II round
1.1	70	48	72	90	79	66	68	71	80	74
1.2	73	48	67	87	76	75	76	64	84	77
1.3	62	48	62	85	68	59	63	65	76	65
2.1	73	43	62	87	73	73	68	65	75	78
2.2	73	60	79	88	67	76	69	86	75	73
3.1	75	66	73	69	85	77	73	72	67	85
3.2	87	61	69	81	90	91	82	75	76	91
3.3	73	54	67	89	79	78	68	74	83	80
4.1	45	67	71	68	48	46	43	71	64	46
4.2	71	66	75	86	81	67	73	79	78	77
4.3	52	58	62	68	52	54	51	68	62	53

Note: the darker the field colour the more indications were registered for a particular thesis.

5.5. Actions required for the thesis realisation

Finally, respondents were asked to assess the extent to which it is necessary to take certain actions that would allow the implementation (realisation) of each thesis. List of actions has been developed. They were:

– Increase in expenditure on research.
– Adjustment (targeting) of the education system.
– Introduction of appropriate legal, administrative and economic mechanisms.
– Efforts to increase social acceptance.
– Improving the quality of workmanship of road works.

Levels of influence of the aforementioned actions on the realisation of the Delphi theses together with the frequency of their indication by the experts are presented in Table 4. Results indicated that the implementation of the studied theses is mainly possible by increasing investment in scientific research and introduction of appropriate legal, administrative and economic mechanisms. Experts were convinced that research acceleration (stimulated by appropriate funding) is required especially in case of modern technologies such intelligent pavements. It should be noted that experts recognised a possibility to improve green road construction without significant expenditure on research.

6. Conclusions

Conducted research and analysis allow drawing some preliminary conclusions regarding the future developments of road pavement technologies:

1. 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.

2. Based on the analysed theses, the highest importance is ascribed to high durability asphalt and cement concrete pavements (perpetual), special innovative material design to meet the European climatic requirements and the wider usage of recyclable materials.

3. As far as binding materials are concerned, high durability binders with improved viscoelastic range will, according to experts, 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 various specific applications.

4. It is expected that the technologies that enable monitoring of the state of road pavement in a continuous manner will be used largely in the future. Introduction of sensors and nanomaterials into the pavement network would lead to the construction of "smart" roads.

5. In order to allow the extensive road pavement development, some obstacles should be overcome. Legal regulations improvements, development of technical facilities together with high workmanship quality and extending cooperation between enterprises and scientific institutions are the main actions required for successful development and application of new road pavement technologies.

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Table 4. Level of influence of particular actions on the realisation of the theses

Thesis number	Actions									
	Increase in expenditure on research		Adjustment (targeting) of the education system		Introduction of appropriate legal, administrative and economic mechanisms		Efforts to increase social acceptance		Improving the quality of workmanship of road works	
	I round	II round	I round	II round	I round	II round	I round	II round	I round	II round
1.1	82	81	76	76	72	62	54	48	88	86
1.2	76	73	71	68	71	60	59	54	88	88
1.3	70	73	66	67	63	58	50	48	79	82
2.1	80	89	53	68	60	57	14	44	58	82
2.2	80	85	81	87	67	59	61	60	80	84
3.1	79	82	76	76	63	58	61	60	69	70
3.2	90	91	73	77	71	62	60	59	76	77
3.3	83	87	70	78	67	64	55	58	84	87
4.1	52	54	70	75	48	49	66	64	67	65
4.2	79	81	79	80	62	58	66	64	81	82
4.3	59	59	68	69	51	51	52	55	70	68

Note: the darker the field colour the more indications were registered for a particular thesis.

References

Andreescu, L.; Gheorghiu, R.; Zulean, M.; Curaj, A. 2013. Understanding Normative Foresight Outcomes: Scenario Development and the 'Veil of Ignorance' Effect, *Technological Forecasting and Social Change* 80(4): 711–722. http://dx.doi.org/10.1016/j.techfore.2012.09.013

Freitas, E.; Mendonça, C.; Santos, J. A.; Murteira, C.; Ferreira, J. P. 2012. Traffic Noise Abatement: How Different Pavements, Vehicle Speeds and Traffic Densities Affect Annoyance Levels, *Transportation Research Part D: Transport and Environment* 17(4): 321–326. http://dx.doi.org/10.1016/j.trd.2012.02.001

García, A.; Partl, M. N. 2014. How to Transform an Asphalt Concrete Pavement into a Solar Turbine, *Applied Energy* 119: 431–437. http://dx.doi.org/10.1016/j.apenergy.2014.01.006

Gaweł, I.; Piłat, J.; Radziszewski, P.; Kowalski, K.; Król, J. 2011. Rubber Modified Bitumen, *A Volume in Woodhead Publishing Series in Civil and Structural Engineering*: 72–97. http://dx.doi.org/10.1533/9780857093721.1.72

Gómez-Meijide, B.; Pérez, I.; Airey, G.; Thom, N. 2015. Stiffness of Cold Asphalt Mixtures with Recycled Aggregates from Construction and Demolition Waste, *Construction and Building Materials* 77: 168–178. http://dx.doi.org/10.1016/j.conbuildmat.2014.12.045

Halicka, K.; Lombardi, P. A.; Styczynski, Z. 2015. Future-Oriented Analysis of Battery Technologies, in *Proc. of the IEEE International Conference on Industrial Technology (ICIT).* vol. 2015-June, no. June, 16 June 2015: 1019–1024. http://dx.doi.org/10.1109/ICIT.2015.7125231

Haluza, D.; Jungwirth, D. 2015. ICT and the Future of Health Care: Aspects of Health Promotion, *International Journal of Medical Informatics* 84(1): 48–57. http://dx.doi.org/10.1016/j.ijmedinf.2014.09.005

Haritonovs, V.; Tihonovs, J. 2014. Use of Unconventional Aggregates in Hot Mix Asphalt Concrete, *The Baltic Journal of Road and Bridge Engineering* 9(4): 276–282. http://dx.doi.org/10.3846/bjrbe.2014.34

Kirby, H. R. 1996. Prospects for Progressing Research through Partnership: Comment on Trends in the United Kingdom and the Technology Foresight Program, *Transportation Research Record: Journal of the Transportation Research Board* 1565: 20–28. http://dx.doi.org/10.3141/1565-05

Koting, S.; Karim, M. R.; Mahmud, H. B.; Hamid, N. A. A. 2014. Mechanical Properties of Cement-Bitumen Composites for Semi-Flexible Pavement Surfacing, *The Baltic Journal of Road and Bridge Engineering* 9(2): 191–199. http://dx.doi.org/10.3846/bjrbe.2014.24

Lee, H. J; Lee, J. H.; Park, H. M. 2007. Performance Evaluation of High Modulus Asphalt Mixtures for Long Life Asphalt Pavements, *Construction and Building Materials* 21(5): 1079–1087. http://dx.doi.org/10.1016/j.conbuildmat.2006.01.003

Ma, Z.; Shao, C.; Ma, S.; Ye, Z. 2011. Constructing Road Safety Performance Indicators Using Fuzzy Delphi Method and Grey Delphi Method, *Expert Systems with Applications* 38(3): 1509–1514. http://dx.doi.org/10.1016/j.eswa.2010.07.062

Nazarko, Ł. 2015. Polityka innowacyjna – inteligentny interwencjonizm?, *Optimum. Studia Ekonomiczne* 73(1): 85–96 (in Polish). http://dx.doi.org/10.15290/ose.2015.01.73.08

Nazarko, J.; Kononiuk, A. 2013. The Critical Analysis of Scenario Construction in the Polish Foresight Initiatives, *Technological and Economic Development of Economy* 19(3): 510–532. http://dx.doi.org/10.3846/20294913.2013.809030

Pajea, S. E.; Luonga, J.; Vázqueza, V. F.; Buenoa, M.; Miró, R. 2013. Road Pavement Rehabilitation Using a Binder with a High Content of Crumb Rubber: Influence on Noise Reduction, *Construction and Building Materials* 47: 789–798. http://dx.doi.org/10.1016/j.conbuildmat.2013.05.008

Paliukaitė, M.; Vaitkus, A.; Zofka, A. 2015. Influence of Bitumen Chemical Composition and Ageing on Pavement Performance, *The Baltic Journal of Road and Bridge Engineering* 10(1): 97–104. http://dx.doi.org/10.3846/bjrbe.2015.12

Piłat, J.; Radziszewski, P. 2010. *Nawierzchnie asfaltowe*, Wydawnictwo Komunikacji i Łączności, 540 p. (in Polish).

Ranieri, V.; Ying, G.; Sansalone, J. 2012. Drainage Modeling of Roadway Systems with Porous Friction Courses, *Journal Transportation Engineering* 138(4): 395–405. http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000338

Santos, J.; Ferreira, A.; Flintsch, G. 2015. A Life Cycle Assessment Model for Pavement Management: Road Pavement Construction and Management in Portugal, *International Journal of Pavement Engineering* 16(4): 315–336. http://dx.doi.org/10.1080/10298436.2014.942862

Shokrlu, Y. H.; Babadagli, T. 2014. Viscosity Reduction of Heavy Oil/Bitumen Using Micro- and Nano-Metal Particles During Aqueous and Non-Aqueous Thermal Applications, *Journal of Petroleum Science and Engineering* 119: 210–220. http://dx.doi.org/10.1016/j.petrol.2014.05.012

de Solminihac, H.; Marquez, W.; Halles F.; Chamorro, A.; Valdes, M. 2009. Pavement and Shoulder Condition Models Developed with Expert Surveys: the Chilean Application, *The Arabian Journal For Science and Engineering* 34 (1B): 137–142.

Thiel, C.; Stengel, T.; Gehlen, C. 2014. Life Cycle Assessment (LCA) of Road Pavement Materials, in F. Torgal-Pacheco, L. Cabeza, J. Labrincha, A. De Magalhaes (Eds.). *Eco-Efficient Construction and Building Materials. Life Cycle Assessment (LCA), Eco-Labelling and Case Studies.* 368–403. Woodhead Publishing Limited. 617 p. http://dx.doi.org/10.1533/9780857097729.2.368

Toraldo, E.; Saponaro, S. 2015. A Road Pavement Full-Scale Test Track Containing Stabilized Bottom Ashes, *Environmental Technology* 36(9): 1114–1122. http://dx.doi.org/10.1080/09593330.2014.982714

Yang, Z.; Kowalski, K.J.; Olek, J.; Nantung, T. 2014. Effects of Sand Characteristics and Fly Ash Contents on Properties of Flowable Fill, *ACI Materials Journal* 111(5): 543–552. http://dx.doi.org/10.14359/51686600

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