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THE ANALYSIS OF ROAD BUILDING TECHNOLOGY WITH A DATA NORMALIZATION METHOD

The paper presents a data normalization method for processing the data that makes it possible to choose the road building technology. There are two technologies for road construction, a flexible one and a rigid one, and both of them have their advantages and disadvantages. The main advantage of rigid pavement lays on the fact that it doesn't require higher financial expenditures within 30 years of exploitation (provided that necessary pavement maintenance treatments are carried out). In the case of flexible pavement it is necessary to mill the wear off layer of the road already after 9 years. It leads to the question: which of these technologies should be chosen, which one is better? The problem of the choice of technology for road building still remains to be unresolved.
The work hereby carries on the analysis concerning a comparison of the technologies for road building; the flexible pavement and the rigid pavement. Based on the analysis carried out using the data normalization method it was found that the achieved values of synthetic coefficient for flexible and rigid pavements are close to each other which may indicate that both technologies are comparable within the sectors taken for analyses in relation to accepted technological-technical and usability features.

Keywords: road, pavement, choice, data normalization method

1. Road - categories and classes

In Poland the road category is connected with its function in a road network. The Bill of Public Roads [2] distinguishes the following road categories: state roads, provincial roads, district roads and community roads. A road included in one of these categories, in the understanding of Bill [2] of Public Roads, must meet the technical and usability requirements determined for the following classes:

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- State road – A (motorway), S (express road) or GP (main road for accelerated traffic),
- Provincial road – GP (main road for accelerated traffic) or G (main),
- District road – GP (main road for accelerated traffic), G 9 main) or Z (collect),
- Community road – GP (main for accelerated traffic), G (main), Z (toll), l (local) or D (access roads).

The road class determines technical and usability requirements. The decree of the Minister of Infrastructure of March 2, 1999 concerning technical conditions to be met by public roads and their location (Dz, U. No 43, pos. 430, with later amendments)[3] introduces the division of roads into the following classes: motorways, express roads, main roads for accelerated traffic, main roads, toll roads, local roads and access roads.

Assignments concerning road building, re-building, repair, maintenance, protection and administration and financed by:

- Minister responsible for road transport via General Director for National Roads and Motorways in relation to state roads,
- Provincial self-government administrator in relation to province roads,
- District administrator in relation to district roads,
- Community administrator in relation to community roads.

Within the borders of bigger towns, assignments connected with financing road building, re-building, repair, maintenance, protection and the administration of public roads are paid out of the budgets of these towns. The financing of building, re-building, repair, administration and the protection of private roads is done from the money of their administrators [3,4].

The General Director for National Roads and Motorways plans to build about 860 km of roads with rigid pavement until the year 2020. In 7 years the share of rigid pavement in fast road networks will increase from 18% to almost 27% [4].

2. Road building technologies

In the road infrastructure market two road building technologies exist: a flexible one and a rigid one and each of them has its advantages and disadvantages [4–34]. Flexible pavements are the most commonly used. For flexible pavements it is very important to properly characterize the behaviour of subgrade soils and unbound aggregate layers as the foundations of the layered pavement structure [4]. Flexible pavements will transmit wheel load stresses to the lower layers through grain-to-grain transfer through the points of contact in the granular structure. The wheel load acting on the pavement will be distributed to a wider area and the stress decreases with the depth. Taking advantage of this stress distribution characteristic of flexible pavements normally has many layers. Hence, the design of flexible pavement uses the concept of a layered system [3]. Flexible pavements generally suffer from rutting which results from heavy traffic and severe environmental condition [5]. Flexible pavements are those having negligible flexural strength and are flexible in structural actions under loads [14].

The major flexible pavement failures are fatigue cracking, rutting, and thermal cracking. The fatigue cracking of flexible pavement is due to the horizontal tensile strain at the bottom of the asphaltic concrete. The failure criterion relates the allowable number of load repetitions to tensile strain and this relation can be determined in a laboratory fatigue test on asphaltic concrete specimens. Rutting occurs only on flexible pavements as indicated by a permanent deformation or rut depth along the wheel load path. Rutting in flexible pavements is a major distress mode and relatively difficult to simulate in computational analyses, mainly for the following reasons:

- The constitutive relations of the materials are nonlinear and complex. Most pavement materials are very difficult to characterize under repeated and moving loads.
- The asphalt concrete material is viscoelastic and viscoplastic, i.e., strong loading time and temperature dependent. The other unbound materials base, sub base, and subgrade are only slightly time dependent.
- The temperature and moisture of the materials vary with every load repetition.

Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below. Compared to flexible pavement rigid pavements are placed either directly on the prepared subgrade or on a single layer of granular or stabilized material. Since there is only one layer of material between the concrete and the subgrade this layer can be called base or sub-base course [3]. In rigid pavement the load is distributed by the slab action and the pavement behaves like an elastic plate resting on a viscous medium. Rigid pavements are constructed with Portland cement concrete (PCC) and should be analysed using the plate theory instead of layer theory, assuming an elastic plate resting on a viscous foundation. The plate theory is a simplified version of the layer theory that assumes the concrete slab as a medium thick plate which is plane before loading and is to remain plane after loading. The bending of the slab due to wheel load and temperature variation results in tensile and flexural stress. The stress condition of rigid pavement was analysed using finite element analysis [12]. The cement concrete pavement slab can serve well as a wearing surface and as an effective base course. Therefore, usually the rigid pavement structure consists of a cement concrete slab below which a granular base or sub base course may be provided [14]. Concrete pavements, often called rigid pavements, are made up of Portland cement concrete and may or may not have a base course between the pavement and subgrade. As a general rule, the concrete, exclusive of the base, is referred to as the pavement. The concrete pavement, because of its rigidity and high modulus of elasticity, tends to distribute the applied load over a relatively wide area of soil; thus, the major portion of the structural capacity is supplied by the slab itself [18].

The advantage of a rigid pavement lies in the fact that within 30 years of exploitation it will not require large financial expenditures (providing that necessary surface maintenance is carried out). In flexible pavement, milling of the wear off layer is already necessary after 9 years [5–15]. This leads to the question: which technology to choose, which one is better?

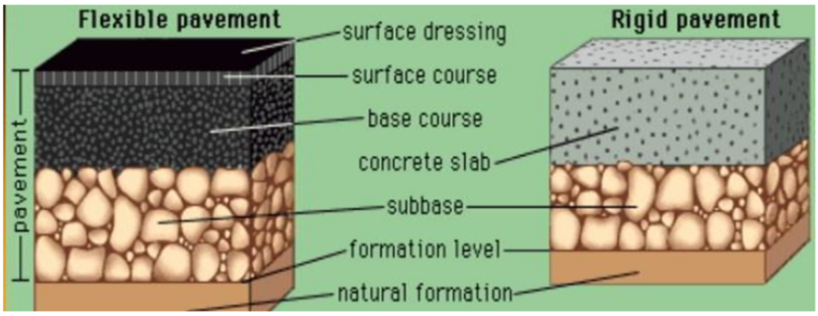

Fig. 1. Road building technologies: a flexible pavement and a rigid pavement according with [35]

3. The analysis concerning with road building technologies

The comparative analysis of two road building technologies: a flexible one and a rigid one are presented. It is assumed that all variables: technological-technical – usable ones, statistically are of the same importance and can positively or negatively influence the choice of road pavement technology. For the calculations, the normalization method and synthetic coefficient of development was used [36–38]. In accordance with Table 1 and Table 2, the divisions and features important for the choice of road building technology were determined for features in divisions were calculated as well as meters for individual divisions and synthetic meters for both technologies. Five groups – thematic divisions were determined (Table 1).

Table 1. Thematic divisions for road building technologies

No.	Feature
1	Building costs per 1 m²
2	Maintenance cost per 1 m²
3	Usability features
4	Environmental protection
5	Investment process

For the purpose of analysing the values of weights for individual divisions, as well as the weights for individual features in divisions were defined subjectively. The sum of weights is always 1.0.

Table 2. Defined features for individual divisions [1,4–34]

No.	Feature	Unit	Flexible pavement	Rigid pavement	Weight
Building costs per 1 m²					
1	KR1	PLN/m^2	169.17	177.39	0.167
2	KR2	PLN/m^2	204.54	189.79	0.167
3	KR3	PLN/m^2	249.14	266.84	0.167
4	KR4	PLN/m^2	288.92	278.69	0.167
5	KR5	PLN/m^2	319.27	302.39	0.167
6	KR6	PLN/m^2	346.62	316.96	0.167
Maintenance costs per 1 m²					
1	KR1	PLN/m^2	533.28	370.00	0.167
2	KR2	PLN/m^2	653.10	396.91	0.167
3	KR3	PLN/m^2	707.70	481.41	0.167
4	KR4	PLN/m^2	764.12	516.31	0.167
5	KR5	PLN/m^2	810.88	570.55	0.167
6	KR6	PLN/m^2	854.54	605.46	0.167
Usable features					
1	Longitudinal evenness		1	0.6	0.2
2	Furrowing		0.1	1	0.2
3	Anti-slip properties				
3.1	Motorways	Conclusive factor of friction	0.39	0.51	0.10
3.2	State roads	Conclusive factor of friction	0.44	0.47	0.10
4	Noise [21]	Average (4.1 to 4.6)	10.20	10.23	0.06
Motorways					
4.1	50 km/h	Index CPX	92.8	90.1	
4.2	80 km/h	Index CPX	100.1	97.4	
4.3	110 km/h	Index CPX	104.6	102.4	
State roads					
4.4	50 km/h	Index CPX	90.4	92.1	
4.5	80 km/h	Index CPX	97.8	100	
4.6	110 km/h	Index CPX	102.5	104.6	
5	Colour of pavement				
5.1	Visibility		0.7	1	0.025
6	Surface heating	Degrees C	46.97	36.08	
Calculation value as 1//Degrees*100			2,13	2,77	0.025
6	Resistance to permanent deformation		0.7	1	0.19
7	Breaking distance at 100 km/h	Average [m] (7.1 to 7.2)	1.20	1.38	0.10
7.1	Wet surface	m	109	96	
7.2	Dry surface	m	58	49	
Environmental protection					
1	Emission of CO_2	Average (1.1 to 1.4)	11.3	2.56	0.34
1.1.	Emission of CO_2 From asphalt and concrete production (kg of CO_2/ton) [17]	kg CO_2/t	27.4	694	
1.2	Emission of CO_2 from production of 1 t of mineral-asphalt mixture and 1 t of concrete (kg of CO_2/t) [18]	kg CO_2/t	10.3	107.3	

Table 2 (cont). Defined features for individual divisions [1,4–34]

No.	Feature	Unit	Flexible pavement	Rigid pavement	Weight
1.3	Emission of CO_2 from building 1 km of asphalt and concrete motorway (kg of CO_2 / km)[20]	kg CO_2/km	347	1497	
1.4	Emission of CO_2 from maintenance of 1 km of asphalt and concrete motorway (kg of CO_2 /km) [20]	kg CO_2/km	500	1610	
2	Index of influence of building1 km of motorway on the environment	Aaverage (2.1 to 2.4)	5.81	3.61	0.33
2.1	Greenhouse effect potential (GWP) [19]	[kg of CO_2 equivalent]	1712501.5	2765765	
2.2	Stratospheric ozone layer deterioration potential (ODP) [19]	[kg of CFC-11 equivalent]	0.395	0.13	
2.3	Photo oxidant synthesis potential (POCP) [19]	[kg of C_2H_4 equivalent]	422	384.5	
2.4	Acidification – potential (AP) [19]	[kg of SO_2 equivalent]	8353.5	6426	
2.4	Eutrophication – potential (EP) [19]	[kg PO3-4]	1248	1092	
3	Index of influence on the repair and exploitation of 1km of motorway on the environment		5.81	3.61	0.33
3.1	Greenhouse effect potential (GWP) [19]	[kg of $_{CO2}$ equivalent]	996135	62245.5	
3.2	Stratospheric ozone layer deterioration potential (ODP) [19]	[kg of CFC-11 equivalent]	0.225	0.01	
3.3	Photo oxidant synthesis potential (POCP)	[kg of C_2H_4 equivalent]	294	46	
3.4	Acidification – potential (AP) [19]	[kg of SO_2 equivalent]	5638.5	267.5	
3.5	Eutrophication – potential (EP) [19]	[kg PO3-4]	743.5	36.5	
Investment process					
1	Stage of design				
1.1	Knowledge of the design engineers		1	0.8	0.15
1.2	Experience of the design engineers		1	0.1	0.15
2	Stage of building				
2.1	Number of offers – big contracts	number of offers	28	26	0.35
2.2	Number of offers – local market small contracts	number of offers	5	2	0.35

Calculations were performed based on the following algorithm [36–38]:

- Based on the matrix of standardized in-coming data for all analyzed features, in each division a model object was appointed having coordinates (standardized changeable values) in accordance with (1):

$$\mathbf{O}_0 = \lfloor z_{oj} \rfloor, \quad j=1,2,...,m. \tag{1}$$

- Coordinates of the model object for each feature in each division was determined based on the following formulation (2):

$$z_{oj} = \begin{cases} \max\limits_i \{z_{ij}\} \text{dla } z_j^S \\ \min\limits_i \{z_{ij}\} \text{dla } z_j^D \end{cases}, \quad j=1,2,...,m. \tag{2}$$

- For each division its distance to model object was calculated based on Euclidean metric as follows (3):

$$d_{i0} = \left[\sum_{j=1}^{m} \left(z_{ij} - z_{0j} \right)^2 \right]^{\frac{1}{2}}, \quad i=1,2,...,m. \tag{3}$$

- Standardized features for individual divisions were calculated according to formulations (4) to (7):

$$s_i = 1 - \frac{d_{i0}}{d_0}, \quad i=1,2,...,m. \tag{4}$$

where:

$$d_0 = \overline{d}_0 + 2R(d_0) \tag{5}$$

$$\overline{d}_0 = \frac{1}{n} \sum_{i=1}^{n} d_{i0} \tag{6}$$

$$R(d_0) = d_{\max} - d_{\min} \tag{7}$$

The standardization of features (Table 3) was the introductory phase which enables obtaining total multi-criteria assessment of each considered division.

Table 3. Standardized features

No.	Feature	Flexible pavement	Rigid pavement	Weight
1	Building costs per 1 m²	0.43	0.71	0.24
2	Maintenance costs per 1 m²	0.60	1.00	0.24
3	Usable features	0.16	0.27	0.24
4	Environmental protection	0.60	1.00	0.18
5	Investment process	1.00	0.60	0.10

- Synthetic coefficient for both technologies were obtained by the aggregation of measures within each division for the analyzed technology. The value of the synthetic coefficient is a value of the weight average of individual synthetic measures calculated for all analyzed divisions (formulation 8, Table 4):

$$M_k = \sum_{k=1}^{5} (S_j w_k) \quad (i = 1,...,34 \text{ and } i = 1,...,) \tag{8}$$

Synthetic coefficient takes a value from the interval [0;1]. The nearer a given object is to the model, the higher these values are.

Table 4. Synthetic coefficients for individual types of pavement

No.	Pavement	Synthetic coefficient
1	Flexible pavement	0.96
2	Rigid pavement	0.98

Based on the analyses made with the use of the data normalization method, it can be said that the obtained values of synthetic coefficients for flexible and rigid pavements are quite close which indicates that the technologies within the divisions taken for analyses in relation to the features technological- technical-usable ones are comparable.

4. Conclusions

When choosing a road building technology the choice cannot be limited only to building costs but it is necessary to consider the costs of maintenance and exploitation some 30–40 years later as well. When choosing the road building technology the main purpose is to build the roads of such quality that their long time exploitation and usage would be fulfilled. Based on the analyses made with the use of the normalization method it is possible to state that both technologies the asphalt one and the concrete one can be competitive since it leads to their progress and development. Considering the growth of traffic on the roads concrete can be perceived as a technical and economic alternative to asphalt structures which is confirmed by presented analyses.

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