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LIFETIME ENGINEERING PRINCIPLES IN HIGHWAY ASSET MANAGEMENT

Abstract

Introduction. An important tendency of our time is sustainability, good value for money and long-term planning. These are also the goals of the recently developed discipline, lifetime engineering. Although the principles of the science were originally developed for buildings and engineering structures, they can also be adapted to public roads. The article — through a case study in Hungary — presents the applicability of life engineering science to public road asset management. Besides, examples of pavement structure design, durability, maintenance-operation and environmental protection are also presented.

Problem Statement. The typical lifetime engineering science principles used in the presentation were: increasing (pavement) life cycle; complex, multi-disciplinary design methodology; modular design; effective, quality insurance methods; high level satisfaction of the customers' needs; minimisation of lifetime costs; sustainable, end-of-life strategies. It is emphasized that lifetime engineering is based on specific basic principles that effectively promote an up-to-date approach to any discipline related to engineering infrastructure. The paper shows that the efficacy of a road asset management. can be considerably increased if some elements of lifetime engineering are utilized.

Purpose. Road asset management is a vital tool to the traffic management of every country in preserving the value of their highway network and to satisfy continuously the needs of road users at a high level.

Materials and Methods. The main principles of lifetime engineering and the major ambitions of road asset management are considered as starting point ("material") of the paper. A case study is shown on the possible combination of the previous two sciences.

Results. The article — through a case study in Hungary — presents and proves the applicability of lifetime engineering science to public road asset management. This very fact is supported by several examples of pavement structure design, durability, road maintenance-operation and environmental protection.

Keywords**:** road asset management, lifetime engineering, pavement structural design, road maintenance, environmental protection.

Introduction

Among the general trends of our time, sustainability, good value for money and long-term planning can be highlighted. Obviously, these priorities can also be seen in the field of road engineering. Lifetime engineering, which was developed about 35 years ago, can be regarded as one of the important achievements in the direction of attaining the mentioned goals [1-2]. In Finland, this discipline was first developed for buildings and engineering facilities [3], primarily by innovating the design methodology of the facilities, by looking ahead to the entire expected life cycle, requiring the optimisation of technical-economic (financial)-environmental-cultural-human aspects, in the long term. It covers construction, quality control, maintenance, operation, management, and even end-of-life strategies. In the meantime, the basic principles of lifetime engineering were extended to other types of facilities, such as public roads [4-5]. In the following, with the help of a Hungarian case study, there will be outlined how certain basic principles of life engineering science can be utilized in the further development of road asset ma-nagement and certain road sub-activities [6].

Some basic principles of lifetime engineering science

In the 1990s, a Finnish research group (led by Professor Asko Sarja) started from the assumption the traditional planning (and design) technique, which — focusing on construction costs and short-term performance — mainly concentrates on the construction phase, needs further development. The demand for sustainable development is integrated, so-called it requires lifetime planning, which aims to opti-mize the entire operational lifetime of the building. A challenge facing the designers is to ensure the performance and durability of the facility throughout its entire operational life. For this purpose, it is advisable to expand the traditional "design for resistance (reaction)" to "durability design", which re-quires a new type of approach to the design process and the application of other types of calculations. This design methodology, based on the principles of life-cycle engineering, also covers health and safe-ty issues and prioritizes the examination of the reusability of building materials. Integrated planning focusing on quality during the entire life cycle is the main elements: costs, ecology, human factors and culture-related characteristics (**Table 1**) [8]. The new structural design process also cover the fields of mathematics, physics, system organization and other engineering or natural science disciplines [7].

Table 1

Classified requirements of a structure [3]

1. Human requirements
• functionality in use
• safety
• health
• comfort
	2. Economic requirements
	• investment economy
	• construction economy
	• lifetime economy in:
	  ○ operation
	  ○ maintenance
	  ○ repair
	  ○ rehabilitation
	  ○ renewal
	  ○ demolition
	  ○ recovery and reuse
	  ○ disposal

3. Cultural requirements • building traditions • life style • business culture • aesthetics • architectural styles and trends	4. Ecological requirements • raw materials economy • energy economy • environmental burdens economy • waste economy • biodiversity

Life cycle design deals with financial and environmental costs. Lifetime costs are either discounted pre-sent values for the first year or discounted annual costs from manufacturing, construction, mainte-nance, repair, conversion, modernization, renovation, reuse, recycling and disposal. Environmental costs can be: use of non-renewable natural resources (materials and energy), air pollution, water pollu-tion, soil pollution. One of the important objectives is the limitation and minimization of environmental costs.

The innovative approach also assumes the operation of an effective quality assurance system (e.g. ISO 9000 and ISO 14000 family of standards).

The main phases of detailed design are: traditional, mechanically based design; durability design; final planning. The purpose of durability planning is to ensure that the intended design life is achieved in the operating environment of the structure. The detailed durability design elements are [2]:

— determination of the target service life and the design service life;
— analysis of environmental effects;
— determination of durability factors and failure mechanisms;
— choosing a durability calculation model for failure mechanisms;

- calculation of durability parameters;
- possible clarification of the calculations of traditional, mechanically based design;
- transferring the durability parameters into the final design.

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Elements and main objective of highway asset management

The responsibility of the owner and manager of public roads is to manage the huge mass of assets efficiently in the long term, taking into account the aspects of the national economy. Asset management is a scientifically based, coordinated activity. The actual practice of road asset management is not consi-dered definitively (finally) established in any country, which no longer requires further development [9]. The importance of road asset management is shown by the fact that one of the Technical Committees of the World Road Association has been dealing with this topic for decades ("Asset Management" Committee). The Committee distinguishes four main elements [10]:

- owner requirements and user needs;
- "business" elements of asset management;
- administrative decisions, especially regarding organizational issues;
- the technical decision support elements (including various management systems).

Owner expectations draw attention to the great responsibility of the owners of public roads in preserving the assets of the network at their disposal and in continuously ensuring that it is able to meet the needs of users at a high level. At the same time, it is essential to continuously assess the needs of road users and utilize the information collected as a result when taking new owner-operator measures.

Road asset management cannot be successful if the various stakeholders cannot be involved in some form in the efforts to achieve the common goal. In this regard, its greatest importance lies in the national economic orientation of performing various construction, renovation and maintenance activities. Thus, the importance of realistic designation of performance-based specifications and, of performance criteria, is to be stressed.

Road asset management also requires solving many organizational issues. The road manager's responsibility (ensuring ownership, achieving stability of financing, management responsibility, and even commercial management of roads) should be clearly recorded. A main goal is the efficiently functioning road quality control system, here the independent quality control institutions have an important role.

Technical decision support elements constitute the "heart" of efficient road asset management. In this context, the Hungarian road industry has the most successful history, some of which started to operate at the international level relatively early and at a high level. The regular sufficiency assessment of the Hungarian national highway network starting in 1979, which provides the opportunity to create valuable condition time series, deserves special attention. In 1981, the gross and net asset values of national roads and bridges were calculated for the first time. Since then, this nationwide activity has been repeated every 4-5 years, only with a slightly changed methodology. In particular, the time series of the ratio of net/gross value in % provides useful information regarding the sufficiency or insufficiency of the road funding level of the previous period. From the point of view of road asset management, it is essential to create road data banks that store a wide range of reliable road-related information. Among the technical decision support tools, the pavement management system (PMS) has the greatest direct effect on ensuring that road decisions are optimal also in the long term. Several Hungarian PMSs have already been developed, and several successful foreign systems have been adapted to Hungarian condi-tions. The Hungarian bridge management system (BMS) is currently the domestic adaptation of the American PONTIS system, but it relies heavily on management elements that have already been develo-ped and proved successful in the country. Even in the long term, optimal road owner or operator de-cisions are increasingly made on the basis of forecast of the costs incurred during the entire lifetime of road pavement structures (Life Cycle Costs, Whole Life Costs). Ensuring the correct development/ maintenance ratio of the national road network is an important element of the road asset management policy.

The major up-to-date directions of highway asset management are as follows: performance indicators, climate change adaptation, resilience, rejuvenation of aging infrastructure, risk management, disaster management.

A manual of World Road Association (PIARC, AIPCR) [11] gives advice: on how asset management principles may be used to support a more efficient approach to maintain road infrastructure assets — road organizations' most valuable assets, and on the implementation and continuous development of road infrastructure asset management. The asset management framework presented in the Manual addresses short- and long-term condition and performance managing for the whole assets life, including ti-preservation actions and considerations of risk and risk management.

Asset Management is not a "high level" discipline addressed exclusively to strategic management; it should be "lived" at every workplace in the organization, so that the managed asset can be optimally operated, maintained and expanded [12]. The basic principles of Asset Management are documented in the ISO 55000 standard [13].

Influence of lifetime engineering science to Hungarian road asset management

It is clear that the principles of lifetime engineering can naturally be applied to the especially high-value road network, since in this case, too, it is aimed directly or indirectly at the planning (design) phase to meet the complex social needs during the entire life of the road. Since the lifetime engineering science is gradually becoming known in individual countries, more and more signs can be seen that the basic principles of the science appear in some elements of the road engineering, including road asset management. In the following, an example of this will be presented, focusing primarily on Hungarian practice.

Pavement structural design

Even in its main objective, the pavement structural design seeks to implement the basic principle of the lifetime engineering, which is to prove the successful satisfaction of the customers' (in this case also the road users') needs.

For the design of Hungarian flexible and rigid pavement structures, standardised pavement structures are basically used [14]. During the design phase, the appropriate pavement structure type can be selected based on the basic data and construction characteristics. The wearing course can be replaced once during the design lifetime — supposing that the necessary maintenance work is performed. The stresses generated at the bottom of the asphalt layers as a result of repeated traffic loads cannot exceed the fatigue strength. The lowest layer of the pavement structure does not transfer stress causing perma-nent deformation to the earthworks.

The following aspects of the selection follow the principles of life engineering science outlined in point 2 of the paper [15] to a greater or lesser extent:

- climatic and hydrogeological conditions;
- availability of local materials;
- network aspects;

- environmental protection and energy management aspects;
- the method and schedule of maintenance work;
- the road manager's expectations regarding the properties of the pavement structure.

For the alternative dimensioning of asphalt road pavement structures, a Hungarian procedure [16] has recently been developed, which also implements several basic principles of the lifetime engineering science. It was started from the fact that, in Hungarian practice, it often happens that the layer thick-nesses of the standardised pavement structure types did not meet the subsoil modulus recommended by the applicable technical specification [15]. According to their proposal, by carefully designing the subsoil and the improved soil layer, the bearing capacity of the pavement structure and thus its lifespan can be significantly lengthened. (Thus, the principle of „design of modular elements" of the lifetime engineering [17] has been utilized here). It causes often difficulty that, in the case of a given traffic load class, for economic reasons, the minimum wearing course thickness of 25 mm and binder course thick-ness of 50 mm are chosen. However, according to calculations, these layer thicknesses very often lead to material fatigue before the end of design life. This statement is especially true for unbound bases. Using WESLEA for Windows mechanical pavement analysis software, it was shown that the alternative, flexible pavement structure design method offers technically and economically more favourable pave-ment structures in the whole service life than the version designed using the national specification [15].

Road pavement duration

A Hungarian patent concerns the production of chemically stabilized rubber bitumen [18]. The wi-despread distribution of this new binder has played an important role in Hungary in recent years. This type of rubber bitumen represents, among the basic principles of lifetime engineering, mainly the longer pavement lifetime and the recycling of products among the end-of-life strategies. Laboratory testing of asphalt mixtures with different compositions bound with chemically stabilized rubber bitumen [19] and the long-time behaviour of asphalt layers under traffic [20] provided fairly favourable results.

In the laboratories of MOL and the Budapest University of Technology and Economic several bitumen and asphalt tests were made [21]. DSR (dynamic shear rheometer) bitumen tests were carried out for the comparison and assessment of the performance of unmodified binder, PmB binder and RmB (chemically stabilized rubber modified bitumen).

The wheel tracking tests — for the characterisation of asphalt plastic deformation — were carried out in accordance with EN 12697-22 standard at 60 °C [22]. It could be concluded that the wheel tracking test results of rubber bitumen modified mixtures prove their excellent plastic deformation characteristics having much smaller wheel tracking depths than those for polymer-modified or conventional B50/70 bitumen mixtures (**Figure 1**).

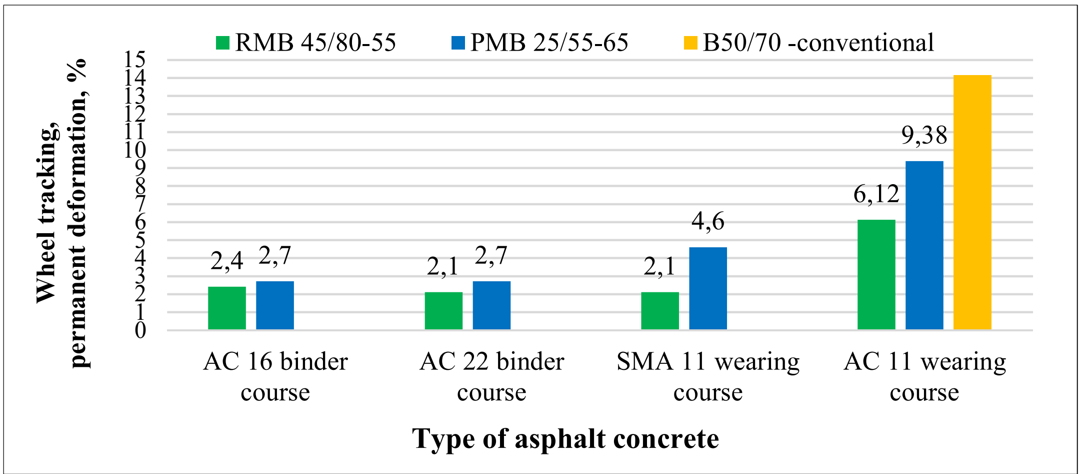

Figure 1 — Rut depths of asphalt types measured by wheel tracking tests [20]

Fatigue resistance of asphalt mixtures AC 16 (mI) base, AC 22 binder (mI), and SMA 11 wearing (mI) was tested, while in the 2019 research SMA 11 wearing asphalt mixtures were tested (**Figure 2**). In all cases, the tests were carried out at a test temperature of 20 °C and a frequency of 30 Hz, according to the relevant Hungarian road technical regulation [23], in the analysis of test results the deformation value corresponding to the load repetition number of 106 was considered.

Although the specification for the requirements of mixtures of asphalt paving [23] does not contain a value to be achieved for the fatigue of stone mastic asphalt, the minimum values in the specification are 110 and 130 μstrain, respectively. Regarding the test results of fatigue resistance,it can be clearly stated that for all asphalt mixtures of different types, binder mixtures modified with rubber bitumen achieved better results and longer fatigue life than polymer-modified binder mixtures.

Compared to earlier fatigue tests carried out on other asphalt mixtures, it is observed that in 2019 the fatigue resistance of the rubber modified bitumen (RMB binder) SMA 11 wearing asphalt mixture turned out to be extremely high, namely 328 μstrain [24].

One of the main ambitions of lifetime engineering is to forecast the deterioration trend and expected lifetime of the road pavement as exactly as possible during its design phase. There are several options for this forecast shown in **Table 2** [25]. It can be seen that section monitoring can give the most reliable results, but it takes too much time. In this case, the compromise can be that pavement performance models (average deterioration curves for pavements with given structure, traffic load and subgrade type) are developed, and utilized for pavement design.

Table 2

Road pavement performance forecasting options [25]

Forecasting option	Time need	Reliability
Computerized performance models	days	rather limited
Laboratory test series	weeks	limited
Accelerated loading tests	months	appropriate
Trial (experimental) section monitoring	(10) years	excellent

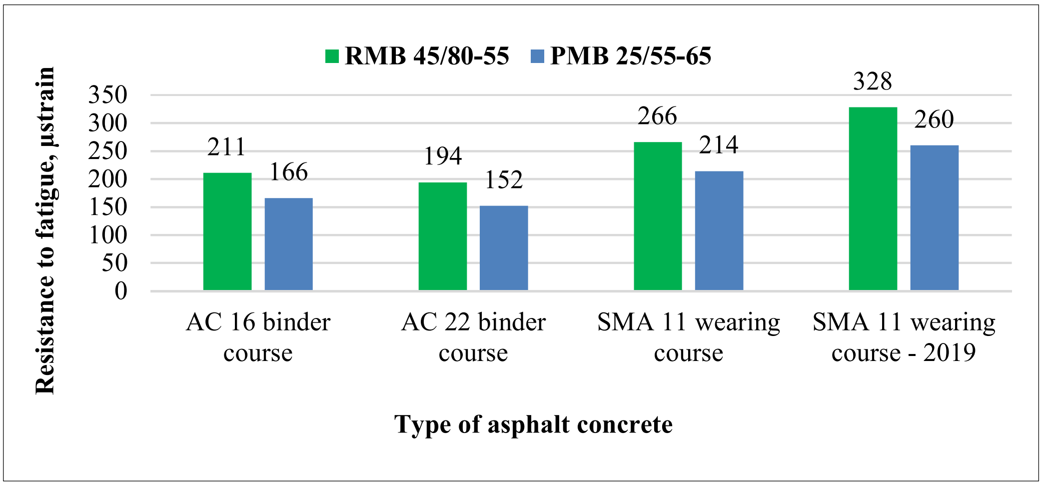

Figure 2 — Fatigue resistance of asphalt mixtures tested [24]

In Hungary, 60 sections of the public road network of “normal” traffic have been yearly monitored since 1991. The time data series of several condition parameters obtained from the test sections, made it possible to develop highway performance models for several pavement structural, traffic and environ-mental variants [26]. Semi-rigid, flexible and super-flexible (macadam-type, unbound base) structure categories, three traffic categories and three environmental (subsoil type or bearing capacity) classes were considered. The realistic variants (combinations) of the parameters mentioned were represented by 4-6 test sections. The following condition parameters of the 500-m long trial sections have been evaluated, and ana-lysed: longitudinal unevenness (IRI, International Roughness Index using Swedish laser RST); rut depth (using laser RST); macro texture (using laser RST); micro texture (using laser RST); pavement bearing capacity (using KUAB falling weight deflectometer); surface defects (visual eva-luation aided by a special keyboard apparatus "Road Master)". Besides, the traffic parameters of, and the major maintenance (rehabilitation) actions on all sections have been collected. The major goal of trial section monitoring is the development of pavement performance models, the average (typical) deterioration curves in a structure-traffic-subsoil type combination. The performance models of the road categories can be attained by putting regression curves on the points representing condition parameter levels as a function of time. (Similar curves are determined as a function of the traffic passed). The function types applied in the development of the HDM-III model organised by the World Bank [27] were selected for the condition parameters. (Exponential functions were chosen for unevenness and rut depth, while linear functions for the other condition parameters monitored). The performance models for each road category and each condition parameter have been determined, every monitoring year, utilising also the latest condition information (**Table 3**).

Table 3

Example for pavement performance model

Flexible pavement structure, AADT = 1501-3000 veh.unit/day; subgrade CBR = max 7 %		
Condition parameter	Performance model as a function of	
	pavement age	traffic passed
Surface defects (note)	1.47+0.09 AGE	1.44+0.11 TRAF
Unevenness, IRI (m/km)	1.74 exp (0.12 AGE)	1.79 exp (0.13 TRAF)
Rut depth (mm)	2.09 exp (0.10 AGE)	2.15 exp (0.09 TRAF)
Micro texture	0.29-0.009 AGE	0.34-0.011 TRAF
Macro texture	0.54-0.014 AGE	0.61-0.014 TRAF

Note AGE — pavement age in years;
TRAF — number of vehicles passed expressed in vehicle units during pavement age.

Figure 3 presents an example for the deterioration curves of a trial section monitored between 1999 and 2014 [28]. No determined trends could be found for bearing capacity parameters (deflection value or stiffness modulus) yet as a function of time or traffic passed. The seasonal and the yearly strength fluctuations due to environmental reasons seem to be more pronounced than the fatigue of pavement structures [29].

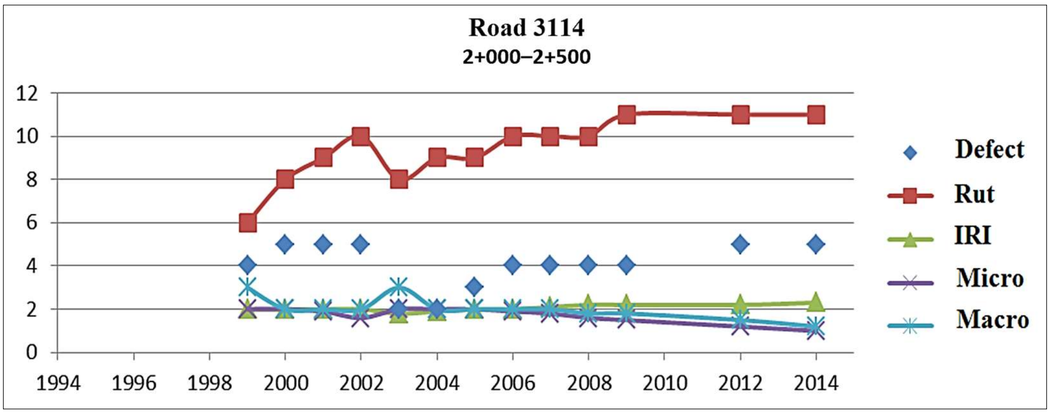

Figure 3 — Deterioration curves of a trial section monitored between 1999 and 2014

The trial section monitoring in Hungary has been performed since 1991. During this long period, a high share of the monitored trial sections deteriorated to such an extent that some kind of rehabilitation (surface dressing, resurfacing or strengthening) was needed. It was decided to go on with the regular condition evaluation since the additional survey could provide other kinds of useful information. The condition parameter levels in the years before and after the intervention can be utilised for the deter-mination of the actual condition improving effect of various major maintenance techniques. Further-more, the continuation of trial section monitoring for several more years can provide information about the deterioration trends after the intervention which can be compared to the tendencies during the former life cycle or life cycles. It is obvious that the information types mentioned can be also readily used in the lifetime engineering making the prediction of pavement deterioration more reliable [26]. The effects of strengthening on surface defects, unevenness, rut depth, macro texture and micro texture were analysed. In the group "resurfacing using thin asphalt layers", the consequences of the same condition parameters were evaluated as in pavement strengthening group. For the surface dressed trial sections, mainly the changing in pavement surface defects, macro and micro-textures were evaluated.

There is here another important fact to be considered: the deterioration speeds of various pavement condition parameters are usually not identical. When the "most rapid" of them, the critical parameter reaches its intervention level – and thereby necessitates pavement rehabilitation — other parameters are still at a relatively appropriate level, at which the condition improving rehabilitation actions are not needed yet. (However, the typical rehabilitation techniques improve the actual condition of all parame-ters including the ones that are still at an acceptable level [30]). The analysis of trial section perform-ance data makes it also possible together information on the critical condition parameters of different road types that can be considered as a basic knowledge for the further development of national pavement design theory and practice. Similarly, the actual levels of critical parameters before the condition improving actions coming from trial section monitoring are important piece of knowledge.

Before and after surface dressing, all of the condition parameters mentioned before were collected, and evaluated. The changing of texture parameters was considered of high importance [6].

Figure 4 shows the effect of pavement strengthening on the visual condition state (characterisation of surface defects), rut depth and IRI [6].

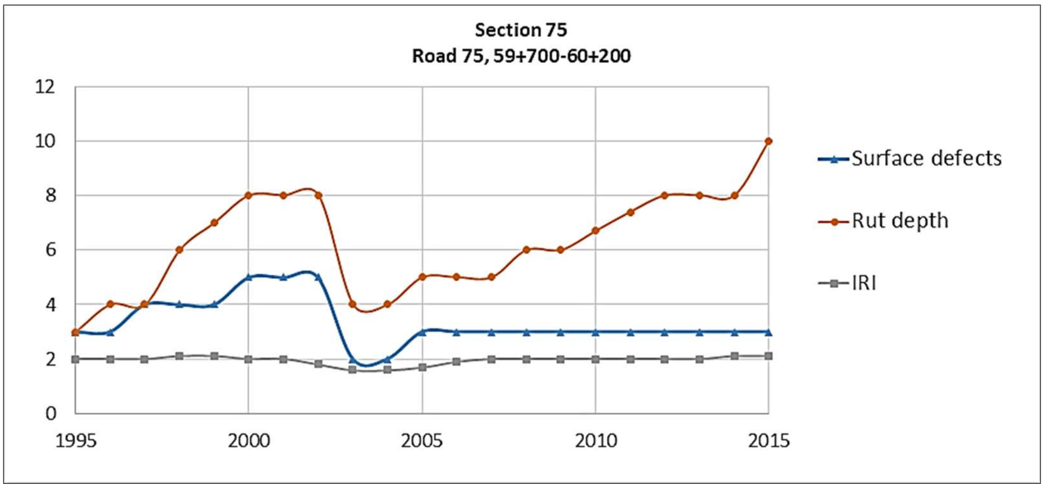

Figure 4 — Deterioration curve of 3 condition parameters on a trial section before and after a pavement strengthening in 2002 [6]

The private sector and pavement performance

A lot of countries all over the world are making increasing use of the private sector for highway maintenance and operation activities. The United Kingdom can provide a good example of this since it has a considerable background of this kind of change process. A TRL research report has shown that the method when the service provider and manager are from separate organisations is more efficient by reducing the need for repetition activities [31]. This statement is based on the outcome of the comparison with the methodology of combining managers and service providers in one organisation. The separation of the functions for highway maintenance and operation activities can be recommended, sincet here is a danger of maintenance becoming driven by the available resources of the organisation in question than the actual needs of the road network.

In Hungary — driven by a basic lifetime engineering goal, the minimisation of whole life costs — started to involve the private sector in the maintenance of expressway network [32]. MKIF (Magyar Koncessziós Infrastruktúra Fejlesztő Zrt., Hungarian Concession Infrastructure Development Limited Liability Company) is active since 2022. Based on a 35-year concession contract with the Hungarian State, it operates and maintains the already built expressway network (1 237 km motorway + 636 km expressway), as well as the planning, development, and construction of newly constructed sections. In the following 10 years, 272 km new expressways will be built, and more traffic lanes will be added to existing motorways in 273 km.

A Hungarian research work concentrated on the possibility of the “objective” evaluation of highway contractors’ past performance for using this information in the evaluation of construction tender bids [33]. The trial calculation has proved the applicability of this methodology for making distinction between the quality parameters (performances) of various highway contractors. Actually, this kind of information could be used in the evaluation of road construction tender bids if these indicators are based on reliable, detailed calculation. The idea of the whole approach is that the eventual some % savings in construction cost are not acceptable from national economy viewpoint if the poor performance of the project causes much higher additional expenditures because of its early and/or increased maintenance and rehabilitation needs. (This goal of the novel methodology is obviously practically identical to one of the major principles of lifetime engineering, namely of the long life and favourable performance of road pavements). Another positive consequence of the general use of the proposed project quality analysis methodology can be that increased competition between pavement contractors can lower prices and save public money. At the same time, stimulating competition between pavement industries is a win-win for everyone — taxpayers, public authorities and industry! The following steps could be recommended for the development of this project evaluation method [34]:

a) involvement of many pavement sections with possibly long history for the characterization of a road pavement contractor’s performance (general contractor and main sub-contractors are to be included);

b) widened data gathering for the sections on its pavement condition parameters before rehabilitation, traffic evolution during investigation period, design information, quality management system during construction, pavement qualification outcome, guarantee period, condition improving activities during and/or at the end of guarantee period;

c) detailed information on the repair and non-structural maintenance carried out on the pavement sections during the period investigated;

d) detailed information on the structural maintenance performed on each pavement section during the period investigated;

e) identification of the performance-influencing factors that can be considered independent on the activities of contractor, these are, typically, client-, design- or operator-related mistakes or overweighted vehicles, serious financial constraints at the time of construction, eventually, natural catastrophes;

f) estimation of the synergistic effect of the factors mentioned before, then considering it at the evaluation of contractor’s performance OR if it cannot be done reliably, exclusion of this section from the analysis;

g) consideration of actual (mainly heavy) traffic evolution rate of the road sections which could also modify the life cycle considered if the changing in traffic is significantly different from the forecasted one in the design phase; thus, a “modified life cycle” can be calculated in the determination of the pavement deterioration rate;

h) gathering all pavement condition data time series in the period in question, from the opening of the section on;

i) characterization of some of the condition parameters by non-linear deterioration trends as e.g. the condition evolution of longitudinal and the transversal unevenness of pavement surface is modelled by exponential functions in the Hungarian trial section monitoring [30];

j) decision about the list of pavement condition parameters to be used in the deterioration rate analysis for a given pavement section;

k) selection of weighing factors for the condition parameters to be considered in the calculation of the “complex deterioration rate” of a pavement section (e.g. bearing capacity 5, surface defects 2, unevenness 1, rut depth 3).

The systematic collection and analysis of road contractors’ performance information characterized by the relative deterioration rates of the pavement sections constructed by them several years ago would provide with a useful tool for the Clients in their selection of road-related public procurement bids. In such a way, the Client would be able to represent the long-term national economy interests in their decisions by heavily considering also the actual “quality references” of bidders, in addition to bid prices. It is obvious that a contractor would build a project by an increased national economy level risk if its past projects have been constructed at a below-average quality level [35].

Environmental sustainability issues

A new design methodology was developed in Hungary for durable pavement structure rehabilitation (overlaying, strengthening with site recycling, strengthening by local repair) that can be connected with at least two basic ambitions of lifetime engineering principles, namely increasing of pavement life cycle and the complexity of pavement structural design [37 – 38]. The main steps of the methodology are as follows:

- client’s data supply and disposition;
- data processing and site condition evaluation;
- selecting pavement deflection measuring points, carrying out the measurement, evaluation of result;
- laboratory tests;
- further correction of deflection data;
- selection of pavement structure strengthening methods;
- choosing design subsections;
- correction of the equivalent thickness of new asphalt course;
- calculation of the thickness of new asphalt layer;
- calculation of strains in wearing course.

Environmental effects considered in the methodology. The actual strength of a bituminous bound road pavement structural layer is influenced by its temperature. The properties of other pavement structural layers are practically not dependent on their temperature, except for the strength increase coming from the freezing of layers (mainly subgrade) with high moisture content. Reference temperatures are chosen to be used in the conversion of measured deflection values and in the mechanical calculation. 20 °C happened to be the most common temperature, so it was selected as reference temperature. In Hungary, the pavement deflection values have been adjusted to the “critical” (early-spring) ones since the 1950s [39] using a correction factor as a function of the month of measurement. This useful methodology cannot used in the present, due to the rather variable (unsteady) climate anymore [40].

Conclusions

Some 35 years ago, a new science branch, the so-called lifetime engineering was developed in Finland. The main idea was to create various infrastructure types of lifetime planning in order to optimise the entire operational lifetime of the facility. The traditional “design for resistance (reaction)” was expanded to “durability design”. It requires the optimisation of technical-economic- environmental-cultural-human aspects, in the long term. It covers construction, quality control, maintenance, operation, management, and even end-of-life strategies. Typically, some elements of the facility have shorter life cycle than that of the entire infrastructure; that is why, a so-called modular design is suggested considering the appropriate special load, material and life cycle of a given facility module. However, this discipline was first developed for buildings and engineering facilities, primarily by innovating the design methodology of the facilities. In the meantime, the basic principles of lifetime engineering were extended to ot-her types of facilities, such as public roads.

A Hungarian case study was outlined how certain basic principles of life engineering science can be utilized in the further development of road asset management and certain road sub-activities. The most important findings shown in the paper (lifetime engineering aspects in brackets) were:

— standardised pavement structures (availability of local materials; environmental protection and energy management aspects; road manager's expectations on the properties of the pavement structure);

— alternative dimensioning of asphalt road pavement structures (design of modular elements);

— chemically stabilized rubber bitumen (longer pavement lifetime; recycling of products among the end-of-life strategies);

— pavement performance models (more reliable prediction of pavement deterioration);

— pavement maintenance by private firms (longer pavement lifetime; minimisation of lifetime costs);

— “objective” evaluation of contractors’ past performance (longer pavement life);

— durable pavement structure rehabilitation (increasing of pavement life cycle; complex pavement structural design).

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ПРИНЦИПИ ЖИТТЄВОГО ЦИКЛУ В УПРАВЛІННІ АКТИВАМИ АВТОМОБІЛЬНИХ ДОРІГ

Анотація

Вступ. Важливою тенденцією нашого часу є стійкість, ефективність використання коштів та довгострокове планування. Ці ж цілі переслідує й нова дисципліна — інженерія життєвого циклу. Хоча принципи цієї науки були спочатку розроблені для будівель і інженерних споруд, їх також можна адаптувати до автомобільних доріг. У статті, на прикладі угорського кейсу, показано можливість застосування інженерії життєвого циклу в управлінні активами автомобільних доріг. Також представлені приклади проєктування дорожнього покриття, його довговічності, технічного обслуговування та охорони довкілля.

Постановка проблеми. Основними принципами інженерії життєвого циклу, що використовуються в даній роботі, були: збільшення життєвого циклу (дорожнього покриття); комплексна, міждисциплінарна методологія проєктування; модульне проєктування; ефективні методи забезпечення якості; високий рівень задоволення потреб клієнтів; мінімізація витрат протягом життєвого циклу; стійкі стратегії завершення життєвого циклу. Підкреслено, що інженерія життєвого циклу базується на конкретних базових принципах, які ефективно сприяють сучасному підходу до будь-якої дисципліни, пов'язаної з інженерною інфраструктурою. У статті показано, що ефективність управління активами автомобільних доріг може значно підвищитися за рахунок використання деяких елементів інженерії життєвого циклу.

Мета. Управління активами автомобільних доріг є важливим інструментом у забезпеченні ефективного дорожнього руху в кожній країні, зберігаючи вартість своєї мережі автомобільних доріг та постійно задовольняючи потреби користувачів доріг на високому рівні.

Матеріали та методи. Основні принципи інженерії життєвого циклу та головні завдання управління активами автомобільних доріг розглядаються як початкові точки («матеріал») даної роботи. У статті наводиться кейс на прикладі можливої комбінації цих двох наук.

Результати. У статті, на прикладі угорського кейсу, показано та доведено можливість застосування інженерії життєвого циклу в управлінні активами автомобільних доріг. Це підтверджено низкою прикладів проєктування дорожніх покриттів, їхньої довговічності, технічного обслуговування доріг та охорони навколишнього середовища.

Ключові слова: управління активами автомобільних доріг, інженерія життєвого циклу, проєктування дорожнього покриття, технічне обслуговування доріг, охорона довкілля.