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# Increasing life expectancy of road pavements

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Subject review

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## Increasing life expectancy of road pavements

The objective of this paper is to present the most important factors that contribute to the quality and good life expectancy of road pavements. An overview of American and European research dealing with pavement maintenance issues, as related to the design, construction technology, material selection, and improvement of pavement properties, is provided in the paper. Some future trends relating to the extension of life-expectancy of pavements are also presented.

### Key words:

semi-rigid pavements, flexible pavements, rigid pavements, pavement lifespan, long-life pavements

Pregledni rad

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## Produljenje uporabljivosti kolnika

Cilj je ovog rada predstaviti najvažnije faktore koji pridonose povećanju kvalitete i produljenju uporabljivosti kolnika. U radu je dan pregled američkih i europskih istraživanja koja se bave problemima kolnika iz aspekta održavanja, a vezano uz projektiranje, tehnologiju građenja, odabira građevnih materijala te poboljšanje svojstava kolnika. Predstavljene su i neki budući trendovi vezani za tematiku produljenja uporabljivosti kolnika.

### Ključne riječi:

polukruti kolnici, savitljivi kolnici, kruti kolnici, uporabni vijek kolnika, dugotrajni kolnici

Übersichtsarbeit

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## Verlängerung der Nutzungsdauer von Fahrbahnen

Ziel dieser Abhandlung ist es, die wichtigsten Faktoren vorzustellen, die der Erhöhung der Qualität und der Verlängerung der Nutzungsdauer von Fahrbahnen beitragen. In der Abhandlung wird eine Übersicht der amerikanischen und europäischen Untersuchungen vorgelegt, die sich mit den Problemen von Fahrbahnen vom Aspekt der Instandhaltung beschäftigen, und in Bezug auf die Projektplanung, die Bautechnologie, Wahl der Baumaterialien sowie die Verbesserung der Fahrbahneigenschaften. Vorgestellt werden auch einige zukünftige Trends in Bezug auf die Thematik der Verlängerung der Nutzungsdauer von Fahrbahnen.

### Schlüsselwörter:

halbfeste Fahrbahnen, flexible Fahrbahnen, feste Fahrbahnen, Nutzungsdauer von Fahrbahnen, langlebige Fahrbahnen

## 1. Introduction

Long-life highway pavements are defined differently from place to place, over the entire world. In America, the synonym in use is "perpetual pavement", and is commonly defined as being "a perpetual asphalt pavement designed and built to last longer than 50 years, without requiring major structural rehabilitation and needing only a periodic surface renewal in response to distresses confined to the top of the surface", and "a Long-life Pavement is a type of pavement where no significant deterioration will develop in the foundations or the road base layers provided that correct surface maintenance is carried out".

Pavements used on intensely utilized, high-traffic roads are usually resurfaced once every 10 to 12 years, depending on local conditions and resources. However, within these periods, some other road maintenance-related closures may be needed, when pavement repairs are done (i.e. crack sealing and pot-hole patching). There are many cases where initial pavement construction costs are actually exceeded by maintenance and operation expenditures occurring during the pavement's life extent. Especially on highly used roads with intense traffic, repeated road maintenance interventions are inevitably causing traffic congestions and disruptions to normal traffic flow. Therefore, it is more and more expected to construct highway infrastructures with long-life road pavements, which will require less maintenance, so that future expenditures to both road administrations and traffic participants can be decreased to a minimum.

We wish to present the main factors which influence life extent of pavements, followed by a summary of major American and European research, covering pavement design, material selection, construction, performance, operation, maintenance and repairs, and economic aspects of fully flexible, semi-rigid and rigid pavements. Some possible future trends will be outlined, as well.

## 2. Factors influencing pavement duration

Speciality terms, such as "lifetime" or "duration" cannot obviously be all-encompassing for roads, given that a road is made up of different modules (i.e. earthwork, multi-layered pavement structure, traffic management and engineering facilities, and so on). Every module features characteristic parameters, has its own size, composition material, recommended load and optimal performance range. Therefore, the various component modules have differing expected and actual life durations. There is also an issue regarding the defining with certainty when a road element's life comes to an end because of a set of various "critical conditions" which may trigger it.

In the case of road pavements (pavement structures), there are several conditioning parameters (such as bearing capacity, longitudinal unevenness, skid resistance, etc.), that could be considered when identifying the end of pavement lifetime. Some of these parameters pertain in exclusivity to the top layer (wearing course), while some parameters also refer to structural layers underlying the pavement. Interventions are to be performed according to the status of condition parameters,

namely when the state of these conditions causes pavements to lose their economical operability potential.

The level of intervention is usually expressed as a performance criterion. How fast deterioration of pavement condition parameters takes place, is never the same, as it varies from case to case. Therefore, a given road element's end of life is determined by a lowering of a critical condition parameter's value, up to where it reaches the intervention level, even though the other condition parameters are still above their intervention levels.

Previously discussed definitions of pavement lifetime suppose that a condition improving intervention is to be carried when the intervention threshold of any condition parameter is reached. However, due to ever-present financial constraints, needed interventions are often delayed or omitted altogether, and the damaged pavement section is kept in operation ("over-operated"). In this case, the actual pavement rehabilitation measures are carried out only after several years of delay. This kind of pavement life is referred to as the "financial lifetime", this being different from the traditional "technically economic life"

A full reconstruction of the entire pavement structure is rarely necessary. Typically, the wearing course and sometimes even the second asphalt layer is replaced applying reclaimed material. The timing for this kind of intervention is usually considered to be the end of the life cycle, which is a phase in the lifetime of the entire pavement structure. Following, we will review the main parameters influencing the actual duration of road pavement structures, and which should be taken into consideration already in the design phase.

### a) Traffic parameters

Characteristics of traffic load are primarily influencing the rate of deterioration and duration of any road pavement structure. There are a number of major parameters to be also considered, such as the number of passing vehicles (traffic volume) and vehicle type distribution (traffic composition). In general, when heavy vehicle traffic grows, there is a more than proportional increase in pavement damage caused by the growth in axle weight. Functionally, this relationship is approximately exponential, at best, as numerous studies produced an exponential factor of 4, which can be accepted as the rule, although estimates of the exponent's power substantially varied. A number of other traffic-related parameters deserve to be noted: axle configurations of vehicles, vehicle suspension systems, daily, seasonal and yearly traffic flow distribution (influence of varying temperature, humidity, etc.), short and medium-term traffic flow forecasts (predictions), width of traffic lanes (traffic wander and danger of load-related failures along pavement edges).

### b) Environmental effects

Certain environmental parameters which influence pavement acknowledged and adequately considered from early stages of the design phase, but some parameters can only be forecasted to occur as future events with an approximated probability. Nevertheless, all these parameters must be taken into consideration when designing the structure of a complex

pavement. The most influent parameters which are available as given in the design phase are local soil conditions (such as load capacity and water susceptibility), microclimate (seasonal distribution of precipitation and temperature), seismic activity induced risks and risk of periodical floods. However, climate change, defined as an increased occurrence of severe weather events, and being a typically stochastic phenomenon as of yet, is a most significant environmental factor, and can only be forecasted in the design phase with a certain probability.

### c) Design-related issues

Designer expertise, thoroughness and carefulness all play an important role in achieving a high quality pavement design. However, there are a number of relevant specifications on which design is based upon (i.e. standards, road technical specifications, etc.). When the designer fails to fully meet any of the above mentioned human qualities or ignores relevant specifications, a dramatic decrease in expected pavement duration will occur.

### d) Construction-related issues

Pavement deterioration (lifetime) greatly influenced by qualitative-quantitative parameters of the pavement, the latter being the contractor's performance level. It is an obvious fact that expected lifespan of a pavement layer decreases when its executed thickness is less than the value designed, or its craftsmanship is of poor quality, leading to lower E-modules, reduced bearing capacities, lower than specified densities, poor strength values, etc. In order to avoid these problems, experienced, thorough and conscientious contractor craftsmanship must be ensured. Additionally, detailed, professional and third-party quality control must be performed, according to pertaining ISO standard specifications. Performance-based contracting is recommended, so that contractor is directly interested to comply with the interests of the client, or of the national economy.

A recent Hungarian research project performed by the KTI Institute of Transport Sciences Non-Profit Ltd. [1] scrutinized the actual role of poor construction quality in the unexpectedly short road pavement life (cycle). The research report has identified the significant influence of the low-quality execution on pavement performance based on the evaluation of the major road contractors active in Hungary and the actual long-term deterioration process of the highway pavements built by them. An algorithm was suggested for the calculation of "contractor quality levels" of each competing contractor., which may be taken into consideration as an important indicator, when evaluating bids submitted by companies in future public procurements. Application of the suggested evaluation methodology may also lead to increased competition between road pavement companies, which may lower their quoted prices and thus, save public money. During trial calculations, the suggested methodology proved to be readily applicable in assessing distinctive quality parameters (performances) of various highway contractors. Actually, this kind of information could be used in road construction procurements, when evaluating tendered bids, providing that these indicators are based on reliable, detailed calculations.

### e) Maintenance and rehabilitation-related parameters

Professionally executed, scheduled pavement maintenance can prevent or reduce the apparition of various types of pavement defects, and/or repair pavement problems which have already developed. Combined effects of traffic loading and environmental stresses inevitably cause any pavement to deteriorate over time, no matter how well-designed/constructed it may be. This deterioration process can be slowed down, or even stopped by performing proper maintenance and rehabilitation. Maintenance operations, including crack sealing, joint sealing, fog seals and patching, assist in slowing down the rate of deterioration, by identifying and mitigating specific pavement deficiencies, which cumulatively contribute to overall pavement deterioration. Instead of ad-hoc interventions, only professional and well-scheduled pavement maintenance operations are guaranteed to prolong the life of pavements. In the long run, preventive maintenance actions are usually more cost efficient than corrective/reactive ones.

A high level of quality in pavement rehabilitation design and execution is prone to improve pavement performance and lengthen pavement duration. Time and space required for pavement interventions are considerably affecting the full life-costs of pavement structures and cause different levels of disturbance felt by the road users.

The above issue is based mainly on Hungarian experiences in the field; that is why, some relevant research results of two other countries are also outlined.

An American research work [2] concentrated on the investigation of factors that affect the performance of pavement preservation techniques. As inputs the condition of pavements, the actual quality of the execution of pavement preservation, the quality of the materials used, traffic parameters and climatic factors were utilized. Several American databases were scrutinized in order to identify the actual sensitivity of the above influencing parameters on the life cycle (performance) of various condition-improving technologies. As an alternate methodology, experts in the field were surveyed. At the end, the following factors proved to control the performance of pavement preservation techniques: Pre-treatment pavement condition, materials selection and quality, construction and workmanship, design,, traffic parameters and climatic condition. Another paper identifies the factors affecting road construction projects performance in Uganda through review of literature [3]. A lot of road construction projects all over the world are never completed within the predetermined (previously agreed) time and cost in addition to various quality problems. Other issues include: change of scope, health and safety issues, functionality and environmental anxiety. If the most significant factors affecting paved road project performance are identified, it can contribute to the use of the scarce resources where they are most needed. It was revealed that poor project planning and poor management of the implementation are the major factors affecting paved road project performance.

Another American research work concentrated on the effects of traffic size and weights on highway infrastructure and operations [4]. Some of its findings:

- Forecasting the effects on freight traffic are difficult, mainly because of various service qualities.
- The actual pavement damage coming from traffic loads depends primarily on the number of axle passes and axle weights.
- The relationship between vehicle axle spacing and resulting pavement damage is a rather complex phenomenon.
- Higher truck speed has mixed effects on pavements (for a truck moving over a smooth pavement has a static load, while increase in the vehicle's speed would not affect stress intensity on the road pavement, but would decrease pavement duration and the measure of pavement damage).
- The pavement cost per mile travelled by a heavy vehicle varies greatly between pavements, being greater on pavements designed for light duty than on sturdier pavements.
- Increases in truck size and weight (TS&W) limits leading to increased axle weights can have high pavement costs.
- Higher TS&W limits – encouraging the use of trucks with more axles – do not necessarily result in higher pavement costs; they can even attain cost savings.
- The long duration of fully flexible pavements can be achieved by properly executing the new constructions, or by adequately strengthening the existing structures
- Only construction of long-life options of heavily trafficked pavements is economical, as their life cycle costs are relatively low
- A total thickness of minimum 300 mm of the asphalt structural layer is needed for attaining the long duration of fully flexible pavement structures (see Table 1)
- Tensile strain at the bottom of asphalt layers should not surpass 50 µm in the entire service life of fully flexible pavement structures
- A given minimum subgrade strength has to be provided during the whole pavement life
- Careful and professional construction workmanship is required, with quality control performed by an unbiased third party.
- Even long-life pavement structures inevitably require that the top layer of the structure is exchanged, typically every 10 to 12 years.

### 3. Long-life pavements

#### 3.1. ELLPAG

The European Long-Life Pavement Group (ELLPAG) is an organization established to identify the current state of knowledge on long-life pavements in Europe. They focus on practical issues, such as how to design, construct and maintain long structural life pavements. Obtained findings are summarized in studies and reports, which assess the current state-of-the-art practices used in fully flexible long-life pavements (LLP), semi-rigid and rigid pavements technologies, effectively sourcing combined know-how and best practice experiences gathered from pavement experts from the entire continent. These reports are created along the same chapter structure, as follows: new pavement design, assessment and upgrading, maintenance and treatment design, economics and identifying knowledge gaps [5].

##### 3.1.1. Fully flexible pavements

The original survey included fully flexible pavement structures, featuring bituminous and/or unbound structural layers [6-7]. The structural capacity of fully flexible pavements depends on every component layer's features, as opposed to that of rigid pavements, where the properties of the concrete slab provide the structural capacity. The load intensity of flexible pavements decreases with depth, due to load spreading in each of the pavement's structural layers. In case of a fully-flexible pavement structure, the deflection basin is set at a relatively deep level, as it must depend on the underlying layers. Elasticity (strength) modules of flexible pavements are rather low. More important conclusions regarding long-life (min. 35 years) fully flexible pavements are as follows:

Table 1 presents the asphalt thicknesses of fully flexible pavements in various European countries (actually, the member countries of ELLPAG-project Phase I), for an expected 100 million standard axle load repetition number (design traffic). As shown, reference standard axle is generally 100 kN, except in France and Greece with 130kN, and in Italy, Switzerland and the United Kingdom, where it is 80 kN. The reference standard axle in the USA equals to 80kN, as well. The design period for heavily trafficked highways is usually taken as 20 years in the majority of European countries. This value is 30 years in France and Germany, 40 years in the United Kingdom (and in the USA), and 10 years in Denmark.

**Table 1. Asphalt design thicknesses for 100 million standard axles (80 kN) design traffic**

Country	Asphalt thickness [mm]
Spain	350
Germany	340
France	330
The United Kingdom	330
Belgium	320
Poland	310
Netherlands	310
Hungary	300
Austria	280
Portugal	270
Greece	260
Sweden	250
Romania	200
Croatia	190

### 3.1.2. Semi-rigid pavements

Semi-rigid pavements are made up of one or more asphalt layers, laid onto a hydraulically bound pavement layer. This type of pavement utilises different construction materials. Several deterioration modes are characteristic to this construction type. In Europe, semi-rigid pavements became popular during the 1970s when, during the oil crisis, oil prices were drastically increased, and accordingly, the unit cost of asphalt hit all-time-high values, and semi-rigid pavements need less asphalt than fully-flexible options. In recent years, pre-cracking techniques were introduced, which reduce the adverse effects of reflection cracks, allowing for semi-rigid pavements to be widely used again.

During the last years, the increased awareness of environmental issues and the quest for more sustainable pavement solutions has added to the popularity of semi-rigid pavements. Some of the main conclusions of the semi-rigid phase (Phase II) coming out of the ELLPAG project [8-9] are:

- Typical semi-rigid pavement structures used in Europe are: 150-290mm asphalt layers and 150-300mm hydraulically bound underneath layers (they can be considered long-life ones from 35 years of life cycle)
- The aggression coefficient of the traffic load considered in the design of semi-rigid pavement structures is up to 2-4 times higher than that of fully flexible pavements, due to basic differences between the deterioration modes of flexible and rigid pavement layers
- Some techniques are effective for reflection cracking repairs in pavement structures: micro-cracking using vibratory compaction, application of galvanized steel netting, geo-grid, geo-net, glass grid, paving fabric, geo-composite, SAMI (stress absorbing membrane interlayer), Nova Chip, saw and seal
- Unlike in other European countries, in France, the appearance of reflection cracks on the surface of the pavement surface is not considered as the end of the lifespan. Instead, the cracks are just filled up.

**Table 2. Typical semi-rigid pavement structures in 8 European states (members of ELLPAG Phase II)**

Country	Thickness of hydraulically bound layer [mm]	Total thickness of asphalt layers [mm]
Austria	300	160
Belgium	200	160
France	250	200
Hungary	200	180
Poland	220	190
Spain	220	200
Switzerland	170	190
The United Kingdom	200	190

### 3.1.3. Rigid pavements

Rigid pavements are made up of a concrete layer, this being the main structural element, that is laid on top of a bound or unbound sub-base layer. Concrete is a rather strong construction material, of high durability and stability. This material presents a high stiffness; therefore, vehicle load is distributed well. Consequently, only low stresses are propagated down to the lower structural layers, underneath the concrete pavement, or in the subgrade itself. Rigid pavements can be built using a wide range of aggregates and binders, which contributes significantly to their sustainable construction.

Other positive properties are resistance to a vehicle fire on the surface, lack of harmful fume emissions, high fire safety factor. A negative property to be considered is that concrete is subjected to volume change (expansion or contraction) during thermal variation [10-11]. Some of the main conclusions of the rigid phase (Phase III) of the ELLPAG project are:

- Typically a jointed, unreinforced concrete pavement lasts a longer (25-40 years) life than an asphalt pavement (about 12 years). A note to be placed: an asphalt pavement is generally economically more feasible than other pavement types investigated to other parts of the World.
- Stiff concrete pavements distribute loads of highway vehicles over a wide area of the subgrade; therefore, eventual changes in subgrade strength have limited influence on the bearing capacity of the pavement structure
- A strong, solidly bound base course with a homogeneous quality is a prerequisite requirement for a long-life (min. 40 years of duration) concrete pavement
- Continuously reinforced concrete pavements (CRCP) are protecting the pavement from the creation of transverse contraction or expansion joints, except at bridges or pavement ends.
- Jointed, unreinforced and continuously reinforced concrete pavements are generally built in Europe.
- Based on real case observations, an estimated lifetime of 40-50 years can be viewed as attainable.
- Application of steel bars in the continuously reinforced concrete pavements is an accepted practice. This is performed to minimize pavement surface cracking patterns by longitudinally reinforcing the pavement. In this case, increasing pavement strength is not the primary goal.
- Primarily, empirical or mechanistic-empirical design methods are used in the European countries; very often trial sections' performance data and laboratory test results are combined.
- Concrete pavement design is also influenced by the maximally permitted axle loads in the given country. This value is generally 100kN for single axle loads, however, there are countries where 80 or 130kN is allowed.
- Most countries in Western and Central Europe design their concrete pavements to last for 40 years. Yet, quite often, the number of cumulated equivalent single axle loads can also be a design requirement to be applied.

- Compressive, bending and splitting tensile strengths are readily selected for the characterization of concrete pavements of highways, as higher strength improves load distribution and fatigue characteristics.
- The thickness of concrete pavements in European countries ranges from 220 to 300 mm.

Table 3 presents the design strengths of road concrete in some European countries.

**Table 3. Design strengths of concrete pavements in some European countries (member states of ELLPAG Phase II)**

Country	Design concrete strength	
	Age at testing [days]	Value [MPa]
Belgium	90	C = 62.5
Czech Republic	28	C = 25-32; B = 3.5-4.5
France	28	S = 2.7
Germany	28	C = 30-37
Hungary	28	C = 37; B = 4.0; S = 3.0
The Netherlands	28	C = 35-45
Poland	28	B = 4.5-6.0
Switzerland	28	C = 30; B = 5.5
The UK	28	B = 4.5-6.0
Note: C - compressive strength. B - bending strength. S - splitting tensile strength		

### 3.2. Long-life surfacing for roads (OECD-project)

An OECD-sponsored highway project analysed long lifetime of wearing courses in pavement structures exposed to intensive heavy traffic volumes.

There are numerous countries, where up to half their highway budget is used for building new roads [12]. The remaining resources are spent on maintaining and rehabilitating existing roads. OECD’s Long-life Pavements Project [13] has assessed whether the expenses of future maintenance, repaving and road user delay would economically justify the construction of long-life pavements. In order for this to be the case, decreased maintenance and other associated costs (such as road user costs) would need to compensate for increased expenditures of building long-life pavement structures. Conclusions were drawn on suitable materials that could be most appropriate for long-life road top layers. The objective of Phase II was to evaluate the real suitability of candidate materials for their intended use. There is a shift towards full maintenance contracting, which has significantly contributed to the reduction of costs. Instead of short-term contracts, increasing use of long-term contracts has helped in developing more durable pavement types. When designing and constructing a long-life road pavement,

actual performance of the entire pavement is to be taken into consideration, from wearing course (top layer) down to its foundation, even to the subgrade below. The OECD-project focused on the top (surface) layer of pavement structures. As a part of Phase I of the project, an economic analysis was carried out. Its results proved that considerable economic benefits could be expected in developing new, long-life pavement surface layers for heavily trafficked roads. Approximately three times the expense of traditional wearing courses would be economically feasible for a long-life surfacing in case of high traffic roads. This statement is valid for an expected life of 30 years, discount rates of maximum of 6 % and an annual average daily traffic (AADT) of minimum 80,000 vehicle unit/day.

American calculations proved that, a three-fold increase in top layer expenses would mean an increase in the whole costs of the road (pavement structure + earthworks + drainage + line markings + safety fences) of up to 25 %. If costs of bridges and tunnels in the investigated road section are also included in the calculation, higher costs of the wearing course would have an even less significant (10 to 15 %) influence over the full costs of highway construction. If a completely new road scheme would be examined, this percentage would be even lower when total costs including costs of structures, land purchases, design costs and communications are taken into account.

Long-life advanced top layers were evaluated during Phase I of OECD’s project, and are not in general use up to present. Only a few small-scale trial projects have been completed to date. The research effort concluded that two types of materials had the potential to fulfil the requirements: These are the following:

- *Epoxy asphalt*: Considerable field data and performance histories exist on epoxy asphalt on various bridge decks in several countries. Some of them are still performing well after 60+ years of heavy traffic operation.
- *High-performance cementitious materials with an epoxy friction course*: for high-performance cementitious materials (HPCM), although all data originate from laboratory tests only, and consist mainly in strength and flexure results, their values are outstanding. Poor noise and splash reduction, and friction are potential disadvantageous properties that should be addressed in the planning technological developmental phase.

Phase II of the “Long-life Surfacing for Roads” project of OECD included nine countries, where the above outlined two potential techniques were studied. Laboratory and ALT test results positively proved the epoxy asphalt’s potential use, primarily in long highway sections loaded by heavy traffic. HPMC’s mechanical properties proved to be encouraging also, as an alternative solution.

Phase III of the project covered full-scale field tests, performed in France during the period of 2009 - 2012, and in New Zealand and the United Kingdom, as well. Application of the epoxy asphalt technology generated significant results, which suggested that a transfer of this technique from bridge surfacing

to road pavements at an industrial scale seems to be a possible solution. The HPMC technology application did not prove to be a sufficiently mature approach, as trials showed that it is difficult to be applied on an industrial scale.

### 3.3. Perpetual pavements

The Pavement Economics Committee (PEC) in the United States of America seeks to develop scientific data support which can position asphalt as pavement material of choice [14]. A special task team formed in 2013 develops supporting materials to communicate PEC research to different stakeholders. This project has proved that the majority of the States underestimates future service lives of asphalt pavements. Typically, a service life of 10 to 15 years is assumed for asphalt pavements; however, this analysis shows a mean service life of 17.5 years, where the data is coming from hundreds of road pavements undergoing scrutiny. The criteria identified for the Perpetual Pavements [15] included the duration of pavement structure (minimum 50 years); bottom-up type of design and construction; "perpetual" fatigue life pavement, renewable pavement surface, elevated resistance to rutting, uneven, homogenous and safe driving surface and a high level of environmental-friendliness. There is no need for expensive pavement reconstruction. Tensile strain is minimized by applying increased pavement thickness. Relatively thick asphalt pavements ensure lower strain, while lower than fatigue limit strains results in indefinite "perpetual" lives of pavement structures.

Previous American research efforts based on the results of several full-scale tracks and accelerated pavement tests prove that rutting in a Perpetual Pavement occurs exclusively in upper asphalt layers. Municipal pavements can also be designed with Perpetual Pavements, where increasing the thickness of the hot mix layers by 25 to 35 % will likely result in the achievement of a perpetual pavement.

Any American state or municipality can have a Perpetual Pavement Award for asphalt layers, which have the following criteria:

- Pavement must be at least 35-year-old.
- The uppermost two layers of the pavement structure must have hot-mix or warm-mix asphalt types.
- Eventual rehabilitation activities during the preceding 35 years have not increased the total pavement thickness by more than 100 mm.

A few recent American research projects which dealt with long-life asphalt pavements [16-17] are as follows:

- Pavem pavement management system (development and implementation), included a change from reactive to proactive maintenance and rehabilitation, a 10-year look ahead of needs, has integrated Caltrans databases and an automated state-wide pavement condition survey.
- Further development of mechanistic design using CalME, a software program developed by Caltrans/UCPRC using the

Mechanistic-Empirical (ME) methodologies for analysing and designing the performance of flexible pavements.

- Testing of a performance-related binder and asphalt mix and development of specifications for wide implementation (related to mechanistic pavement design and use of multi-scale testing).
- Utilization of new asphalt (bituminous bound) materials, including a more effective innovation in the field, a wider-spreading application of recycled asphalt materials, more forms and uses of recycled tyre rubber; methods and additives for "perpetual pavement recycling" and use of asphalt/cementitious and other hybrid materials.

## 4. Conclusions

During recent years, road infrastructure investments in many countries have increased at a slower pace than the increase in road traffic was to demand it. A continuing of this trend will lead to unfavourable outcomes, including the exponential increase of intensity of road traffic on the highway networks in the upcoming years. Specialists are sharing the opinion that as an outcome, there will be an increasingly higher number and proportion of highly trafficked roads, therefore the need for more durable pavements will considerably rise, even if overall construction costs will stress even more the highway budgets [18].

Currently, highly trafficked roads use pavements which are typically resurfaced every 10 to 12 years, depending on local conditions and limitations. Over the above mentioned period, other miscellaneous maintenance activities, including pavement repairs like patching and crack sealing, and this may cause various closures and delays. Quite often, initial construction costs of pavement structures are often exceeded by the costs for their life-cycle maintenance and operation activities. As far as the planning of highway budgets is concerned, the costs of future maintenance operations may seem to be preferable, as opposed to increased capital expenditures right now.

In addition to the maintenance expenditures, road administration also requires significant costs placed on road users, as well. Particularly on highly trafficked roads, road repairing activities are likely to cause traffic congestions and disruption to normal traffic flows. Despite measures taken by road maintenance operations, the costs to users, including traffic operation costs, time delay costs and traffic accident costs, are highly expensive and their costs are continuously increasing. Thus, there are increasing pressures placed on authorities to build long-life road infrastructure pavements that require less maintenance and save substantial expenditures in the long run, for both highway manager entities and the road user communities.

The presented three projects are only some of the flagship efforts worldwide, to come up with technologies for increased lifespans of road pavements, in order to meet transport and financial demands of the 21<sup>st</sup> Century.

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