NR2C - New Road Construction Concepts

Work Package 2 – Interurban infrastructures

Deliverable 2.3

Concept and research programme for future interurban infrastructures

Modifications follow-up

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1. Introduction

As explained in previous "Vision 2040" report, NR2C project deals with the perception of the road infrastructure in the future by considering the point of view of different type of people. Following this general idea, different research strands have been analysed within the work package 2 which was dedicated to interurban infrastructure. For instance, the researches investigated the lengthening of the laying period under bad weather conditions, the utilisation of recycling asphalt in a high modulus asphalt base layer, the application of a poroelactic layer on pavement blocks, but also cooperative elements in infrastructure for infrared on-board vision systems. Thus, the five different innovations considered in this work package covered various domains of the interurban infrastructure.

In order to go a bit further with the interurban infrastructure, it has been decided to highlight a few research directions for future possible projects that could be performed. Hence, the aim of this report is to close the interurban research part by forwarding recommendations for future research on interurban infrastructure, in accordance with the experience acquired within the NR2C project. Moreover, these ideas have been separated following the concepts developed in work package 0. Hence, by considering each four different topics highlighted in the vision 2040 that are reliable, green, human and safe/smart, a few research ideas have been developed for each topic. These possible research directions that are presented hereafter represent the output of different brainstorming between the partners involved in this work package and it firstly aims at giving some preliminary recommendations, but of course without the claim to be exhaustive.

2. Vision 2040 and the future interurban infrastructure research

Interurban infrastructures are usually designed to last for a very long time and thus represent huge public assets. The mere length of the estimated useful life of the infrastructure requires that the planner reflects over the society's demands not only today but also in a distant future. Looking in the rear mirror tells us that these demands evolve over time. To make the right choices today, we need to have a robust perception of how society wishes to solve its transport needs in the future.

The Vision 2040[1] describes the most likely image of the society with special attention to the part of mobility and transport in the year 2040. It was developed within the NR2C project considering both the general social and economic trends, and several possible scenarios describing how the society and the transport sector could evolve as a consequence of political and external pressure. The Vision 2040 is thus an attempt to find the most probable forecast of the evolution of the European society and its transport needs. But the Vision 2040 also points towards the innovation needs to realizing this likely development of the society.

The interurban infrastructure in the European Union and states aspiring for membership differs especially between the old member states and the new member states. One major target for the EU is to increase the integration between all member states. This process has already come a long way and one major tool for this integration has been to upgrade the interurban and interstate infrastructure in the new member states. Thus, although the present situation differs between the member states in the European Union, the image of the future, in a 35 years perspective, converge to the same vision.

Except integration, other general trends with significance for the development of the interurban infrastructure are:

- **Shortage of clean environment**
- **Shortage of fossil fuel**
- **Shortage of space**

But also:

- **Increased demand of mobility**
- **Increased individual demands**

More specifically, trends exemplifying the general demand of increased mobility are:

[1] Vision 2040 and New Road Construction Concepts

- The number of households per head of the population continues to increase from 186 million in 2000 to 228 million in 2030.
- The number of women working is continuing to increase.
- Higher disposable incomes are generating demand for more leisure and holiday travel. Tourism is continuing to grow, with faster long distance travel.
- Increase of elderly is generating demand for increasing their mobility. Opportunities for economic activity beyond retirement age will also increase the demand for mobility.
- Career paths and opportunities for employment will take people further from their hometowns and national and international travel will become increasingly common.
- Migration of younger people to the cities leading to expansion of urban and suburban areas.
- The trend of globalisation will go on resulting in a complete globalisation of trade.
- In Europe, people will mainly work in the distribution or service sector. The production of goods will be located in low salary/wages countries or will be fully automated and then distributed.
- Travel time and comfort become dominant factors in the choice of mobility mode.

The general environmental demands mentioned could be further illustrated with the following more specific demands:

- Minimize impact of infrastructure (air pollution, noise, vibration, surface runoff on water quality, “aesthetic pollution” etc.) on the direct environment of the road.
- Design more space efficient infrastructure due to scarcity of space for expansion road networks into and near urban areas.
- Reduce the use of prime materials for construction and maintenance and promote the application and upgrading to suitable road building materials of (industrial) waste materials and building rubble.
- Self-supporting road system with respect to the use of energy and the production of sustainable energy.
- Face the consequences of climatic change (e.g. storm, rise of water).

In the NR2C project the general and specific trends were put into three different extreme contexts, describing the evolution of the society. The purpose was to find a robust estimation of the likely development of the society and the demands of the infrastructure of tomorrow. These extreme scenarios were:

- **Public Authorities led scenario.** The state and other public authorities, rather than individual groups are responsible for the major decisions to take care of the right balance between individual freedom and the need for rules and central direction.
- **Market led scenario.** The Governments encourage a more market-responsive decision system and limits themselves to defining and controlling the frameworks. The dominant principle of the society is ‘if you are willing to pay, anything is possible’.
- **Sustainable society scenario.** The 'green' attitude gained the upper hand during decision-making. Non-material values such as community spirit, spiritual development, ecological awareness and sustainability determine the way society is structured.

Together, the trends and the scenarios led to the Vision 2040. The vision has many features, describing the demands of the future concerning road infrastructure. Clustering these features led to four construction concepts. But the process of defining the Vision 2040 also led to a number of directions to take to approach future demands. Some of these directions are presented in more detail in this document.

The Vision 2040 could be summarized in following four construction concepts:

- ***Reliable Infrastructure***
  Availability and reliability are the key issues of durable infrastructure, which means a high quality standard and a low maintenance demand of the construction parts of the infrastructure. In case of maintenance the impact of these activities on the traffic flow has to be minimal. Upgrading of this infrastructure is possible without dismantling of the existing construction. Reliable infrastructure stands for optimising the availability of infrastructure.

- ***Green (environment friendly) Infrastructure***
  Minimizing environmental impacts on communities and natural habitats are the main issues of this concept. Green infrastructure fits in its surroundings and contributes by means of design and composition to minimizing the impact of traffic (noise, air pollution and vibrations) and energy consumption of the transport system. It also optimises the use of non-traditional materials for road building and reduces the use of natural resources. Green infrastructure stands for reducing the environmental impact of traffic and infrastructure on the sustainable society.

- ***Safe and Smart Infrastructure***
  Smart and safe infrastructure observes (traffic flow, circumstances and itself), interprets, decides and acts with the aim to support the road user to travel safe and comfortable and to support the owner of the roads in keeping the infrastructure objects into safe condition. Safe infrastructure stands for optimising flows of traffic of all categories of road users and road construction work safely.

- ***Human Infrastructure***
  The main characteristics of this concept are multi-functionality and multi-use of the space occupied by infrastructure. Human infrastructure offers the main categories of road user the elementary facilities, which guarantee social security. The main points are sharing the space also for not-road users for leisure, etc. and exploring the space above and below the road surface to facilitate other socially relevant functions (transport as well as non-transport related). Human infrastructure stands for harmonizing infrastructure with the human dimensions.

3. Research ideas towards Green Infrastructure

3.1 Recovering energy from pavements for green innovations

a) The problem

Pavements represent large surface areas for which heat is collected from direct and diffuse solar radiation during daylight. As illustrated in figure 1, heat balance at pavement surface requires to determinate the amount of heat exchange with environment and soil due to various heat transfer phenomenon.

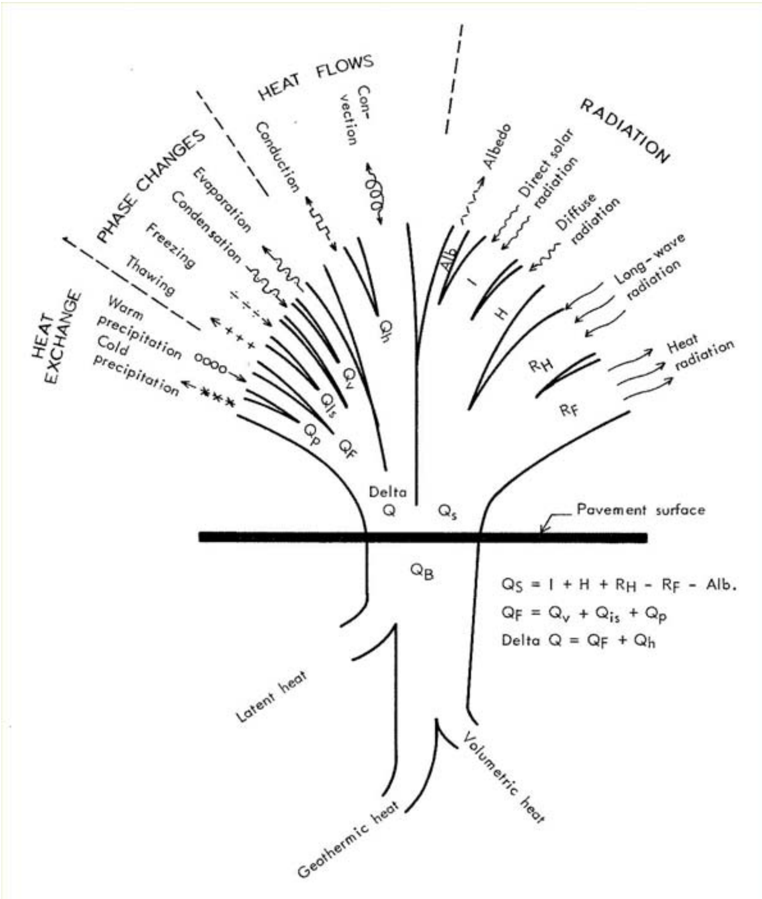

Figure 1: Schematic illustration of heat balance at pavement surface

This process takes place in a completely uncontrolled way, leading to a variety of thermal conditions for the road structure and hence to a variety of conditions for the road driver, good conditions, but also very bad ones. Some of these conditions have very large financial and ecological consequences. They can have a bad impact on the reliability of the road and on road safety. Some examples:

- Cold weather circumstances:

  In this case the temperature of the road surface is too cold and ice and snow may appear on the road surface. Since road infrastructure is crucial for the economy and mobility of people, it is of ultimate importance that roads are safe and accessible for road users, at any time. Hence de-icing products (mostly salts on public roads, liquids on airfields) are in use in most of the European countries to keep the roads free of ice. However these products have many disadvantages for the environment. Via water drainage systems they unavoidably lead to contamination of water and land. Moreover they lead to corrosion problems to vehicles and road infrastructure elements. For a good efficiency, de-icing products require sufficient traffic on the road (problematic on low traffic roads or during night where the problem is however most critical). Hence the roads reliability is questionable and difficult to manage in countries with highly varying road surfaces. A better control of the heat of the road surface would overcome these problems.

- Under hot weather circumstances, road surface and pavements become very hot and for asphalt roads permanent deformation will occur, giving rise to rutting. Rutting is one of the most important distresses on European roads. A better control of the heat of the road surface would avoid these problems.

- The large variations in pavement temperature lead to or contribute to many road deterioration mechanisms, caused by subsequent expansion and contraction of the road materials. This gives rise to road cracking.

All these examples show that a good control of the road temperature would overcome or largely reduce these problems. By a better heat control, many problems could be avoided.

Another parallel observation is that the road infrastructure requires more and more energy for all kind of purposes: lightening, information panels for the road users, communication services (telephones, road sensors, infrastructure – driver communication). Hence, if some of this energy could come from a better control of the heat, a lot of energy savings would be possible and new technology could be introduced much faster.

Therefore we can conclude that a good thermal energy control of the road pavement would have many advantages and would make road infrastructure greener, more reliable, more sustainable and safer.

Such solutions will indeed solve most of the above mentioned problems and disadvantages related to the actual uncontrolled thermal condition of the pavement. Some examples:

- Greener: the bad impact of de-icing salts on the environment (water and land contamination, with bad impact on corrosion) would no longer exist. Energy savings by recovering energy from thermal heat of roads.

- More reliable: the infrastructure remains accessible under severe winter conditions (positive impact on mobility), no problems related to problems of in-accessibility of winter maintenance services, no problems with different spraying depending on the type of road surface.

- More safe: fewer accidents are expected to happen because of less extreme road conditions.

- More sustainable: less road deterioration because of more uniform and less extreme temperature.

b) Solutions to be investigated

There are several solutions to control the heat in the road pavement. Some of them are discussed briefly below.

- ***Pavement constructions with high heat transfer towards the underlying structure***

  One option to keep road surfaces more constant in temperature is to provide a high heat transfer between the upper layers and the underlying structure of the pavement construction. If heat can be easily transferred between the upper part of the construction and the subbase or soil (where temperature variations are limited), sudden temperature drops or increases in the pavement can be highly reduced. Such constructions have advantages in winter and in summer: In winter temperature can be kept more easily above zero (no ice). In summer, sudden rises in temperature are avoided and hence there is a positive impact on permanent deformation.

- ***Pavements that are thermally well-isolated from the air temperature***

  Another option is to construct pavements that are thermally well-isolated from the surrounding air temperature. This solution implies the use of new materials on the road surfaces that act as thermal insulators.

- **Pavement constructions and heat storage**

  Another interesting option, which can possibly be combined with some of the other solutions, is to store heat and use it for other purposes or convert it into other types of energy, which can then be used for lightening, panels, …

- ***Embedding of new materials in road pavements which act as de-icings products.***

  A fourth solution which is particularly useful to keep road surfaces free of ice can be achieved by embedding materials in road pavements that have an impact on the phase transition and lower the freeze-thaw transition temperature of pavement materials. These materials should be high heat capacity materials. Such materials have the same role as de-icing products, but are always present and stay always in-place.

c) Research plan

For each of the solutions the following aspects should be addressed:

- Several suitable technical solutions for a better control of the heat in the road structure should be worked out in detail.

- These solutions will require adequate models to describe the heat transfer in a road infrastructure up to the building of their thermal command laws.

- Detailed designs for these road constructions and for these new road materials will be needed. These are necessary for the contractors, for road authorities and for producers of these new materials and technologies.

- The efficiency of the different solutions needs to be studied, not only for what concerns heat transfer and control, but also the impact on general performance should be studied : Besides heat control, road materials and pavements have to fulfil many aspects of performance: workability, permanent deformation, durability, bearing capacity, resistance to cracking, etc. These new materials and/or constructions will only be accepted if road authorities have the guarantee that equivalent performance can be reached with these products and that contractors can show that they fulfil the performance requirements.

- Some demonstration projects should be realised to convince road authorities, contractors, road designers and policy makers of the new solutions

- Recommendations for production and laying of the materials or road constructions are necessary for contractors, road authorities, notifying bodies or other control instances. These should follow from the realisation of demonstration projects.

- A cost analysis is another necessary step to convince road authorities and road owners, policy-makers, road designers and contractors
- Environmental impacts should be studied for each of the solutions

d) Financial estimate

The cost of such an extensive research project is estimated to be about 10 million Euros. This cost is however negligible compared to the benefits of the project.

- A complete or very drastic reduction of consumption of de-icing products in Europe
- A very drastic cut in the budget for road rehabilitation, since rutting and cracking will be highly reduced.
- A drastic cut in the total cost and loss that result from accidents that are the consequence of severe winter circumstances
- A drastic reduction of the cost related to a reduced mobility
- A gain in energy from thermal heat of pavements, which can be used in the aside energy consumption, such as panels, lightening, vehicle-infrastructure communication.

3.2 Preserving natural resources in road construction

a) The problem

In many areas of Europe it is becoming increasingly difficult to obtain high quality aggregate resources for road construction. There are two main reasons for this development:

- Local authorities do not permit new quarries to be opened for reasons of natural protection
- Good materials are becoming scarce, resulting in high costs.

The problems are usually solved by transporting high quality materials from areas where the supply situation and prices are more favourable. This means extensive transport with heavy trucks resulting in increased fuel consumption and CO_2 emissions and at the same time also increased wear of the existing road network.

In some regions aggregates can be manufactured by crushing of suitable rocks. This process however requires energy for the crushing process.

Another option which is gaining more and more interest as a result of these expected developments is to use local materials of a quality which would normally not be considered good enough for road construction.

The problem of scarce resources is of regional/national character. It can be expected that it will be of growing importance as the protection of natural resources and nature areas is getting more and more attention.

It can be envisaged that in the future the scarce resources of high quality construction materials would be restricted to use in more critical constructions like bridges and buildings. A result of such an approach would be that the road construction industry will have to make best use of the materials that are left.

The main economic interest in this problem area lies with the road authorities that will experience the higher costs resulting from these expected developments. Also society costs resulting from increased transport should be considered.

b) Solutions to be investigated

In order to substitute virgin aggregate with marginal/local and recycled materials, already existing methods for stabilisation and/or recycling should be promoted and further developed. The methods and products to be considered include:

- In-situ recycling of existing pavements, both bituminous and cementitious and also unbound materials.

- Further development of binder technology for in-situ recycling and stabilisation; cement, bitumen, foam bitumen etc.
- Soil improvement by use of lime, cement and special road binders.
- Stabilised base layers with recycled/alternative/local materials.
- Chemical stabilising agents.
- Further use of locally available alternative materials like demolition rubble, fly ash, municipal solid waste bottom ash.
- Further development and implementation of national and international standards for environmental friendly road construction.

These methods are to some extent already used, however in many countries more traditional methods still prevail as virgin aggregates have been easily accessible and at the same time road professionals have had more confidence in the traditional well-documented methods.

In order to promote the use of these alternative road construction methods, a number of demonstration projects could be set up, where it is defined as a prerequisite, that practically no virgin aggregate must be hauled to the construction side, i.e. all construction should take place using materials that are either recycled or found in the immediate vicinity of the construction site. For the case of local marginal materials this would usually require that these materials must be stabilised with various binders/stabilising agents.

With the present technology, wearing course materials would have to be excepted from this requirement, since these must live up to strict functional requirements like good friction and noise reduction.

More precisely, as a starting point it could be defined that less than 10% of the total materials used at a specific construction site should be virgin materials, this including new binders and wearing course materials. With the methods currently available the fulfilment of this requirement is not unrealistic.

Such demonstration projects should ideally be realised in a number of different countries or regions in order to demonstrate the feasibility with different local materials and construction practises. Furthermore, demonstration projects would be very important to raise the awareness in the local road construction communities of the challenges of depleting resources and the various new methods to meet these challenges.

Life Cycle Assessment methods will be important tools to evaluate the economic and environmental viability of the new construction practises.

c) Expected benefits

With the present market situation, costs may initially be higher than for a traditional solution, where good quality aggregate is transported from other regions. However, envisaging higher costs for (and possible restrictions on) transport of high quality aggregate in the future, a favourable total economy can be expected.

This will especially be the case in regions where traditional road construction materials have already now become very costly. Construction methods where small amounts of relatively expensive binder materials are added to local marginal materials can prove very cost effective.

Other important benefits include large potentials for reduced environmental loads through transport savings. These savings will be realised through reduced hauling of virgin materials, but also through reduced excavation and deposit of materials that will have to be removed from the construction site when using traditional methods.

4. Research ideas towards Smart and Safe Infrastructure

4.1 Smart road infrastructure

a) The problem

In many countries, the optimisation of the maintenance work and the increasing of the security aspects are a permanent challenge for the road owner. Indeed, by optimising these aspects, the road authority would be able to limit the expenses and make a more accurate planning of the further job sites. Thus, costs will be saved for the road owner, but also for the road user as a better infrastructure management would limit the congestion on the road network

Moreover, infrastructure performances and reliability are considered to be very good indicator of the development of a road network for a given region. Indeed, a good road infrastructure is a first important condition for the economical, societal and ecological development.

Considering these aspects, it seems obvious that a smart and intelligent road would allow the road owner to have a more accurate planning and consequently reduce the allocated costs to its infrastructure.

On the other hand, very important developments have been achieved in the measurements systems, this by applying various technologies. This evolution of the devices for measuring different characteristics could also be used in order to obtain a smart and intelligent road infrastructure

b) Solutions to be investigated

In order to propose some solutions to the current needs, a special emphasis has been put on these road aspects, this in particular during the last decades with the very important developments in intelligent road systems (ITS) and the effort put in research by performed by car manufacturer as well. Indeed, a certain number of development have been carried out in different domains and a combination of various techniques would allow a better pavement analysis and management system.

The general scope of the solution proposed would be to consider the road as a patient which goes to the doctor that is the road owner or manager. Hence, a first phase would be to identify what are the critical parameters that need to be measured on a road section, this in order to assess the pavement "health". For instance, it has been found that following parameters are first importance for a pavement assessment:

- Deformation at the bottom of the asphalt layer, for the verification of fatigue resistance
- Rutting at the top of the pavement
- Surface characteristics as for example skid resistance and evenness
- Pavement surface distresses like cracks, potholes, …
- …

After the first phase of pavement characteristics identification, the next step consists in the measurement of the selected parameters. In order to achieve this, a wide range of measurement system exists and the selection will be performed in function of the reliability, installation procedure, data acquisition system and price as well.
For the measurement of the deformation at the bottom of the asphalt layers, different solutions exist with strain gauges as commonly used or innovative technologies like optical fibre. Nowadays, different researches have been performed or are still in progress in order to identify the potential of optical fibre and its possible application in road infrastructure. Indeed, optical fibre represents a very promising measurement system with a good reliability and accuracy.
For the measurement of surface characteristics, some very important information can be provided by the car behaviour. Indeed, by measuring the effort on the car axle during braking and the braking

distance as well, some information concerning the road evenness and polishing could be deduced. Moreover, the installation of very compact accelerometers on a car would also provide some data about the road evenness. For all these measurement using cars, the car-to-car communication properties could be used, this especially for the security aspects. Indeed, by analysing the braking distance and determining the road condition, a selected car could send the collected information to the upcoming cars and this permit to avoid some incidents.

In addition to the possible novel technologies, the utilisation of existing measurement systems would also be very appreciate. Indeed, a weight in motion (WIM) station will give some key data for a further calculation using pavement deformation for instance. Moreover, the WIM station could be modified with a warning system in order to directly identify the overloaded vehicles and maybe, register these vehicles with a camera coupled to the WIM. In addition to the repression aspect of such a system, this would allow a more important lifespan of the road infrastructure by identifying the overloaded vehicles that are a major cause of accelerated pavement deterioration.

Finally, after a measurement campaign of all the "vital" aspects of the road infrastructure, a synthesis and some calculation can be drawn in order to assess the pavement health. The general idea behind this pavement instrumentation and analysis is to provide to the road owner a tool for assessing the road network at any time, without going on the road site and closing the road. Indeed, one of the main aspects is the data acquisition that has to be very efficient with the possibility to make the measurement continuously or in a triggered mode. Then, all the data can be sent to a ftp server before to start the next measurement session if needed.

Of course, this survey of the pavement health could not be performed for the whole road network and a first step would be to identify the critical link to be monitored. This kind of solution would firstly lead to an intelligent and smart road that could communicate with its owner and provide some crucial information concerning its deterioration process. Moreover, this better comprehension of the pavement health will also have some repercussions on the security aspects that would be increased as well.

c) Research plan

For each of the solutions the following aspects should be addressed:

- For local on site measurement systems optimisation of detector positioning in the infrastructure has to be studied ;
- For field measurement their ability to work on board of dedicated vehicles or common vehicles has also to be studied, but also their performances ;
- A real scale experiment has to be built and study, mixing existing infrastructure and new infrastructure for complete trials.

d) Expected benefits

The expected benefits of a "smart and intelligent road" are very important. Indeed a good instrumentation and data analysis would lead to an optimisation of the maintenance work on one hand, and to an increased security on the other hand. However, these benefits are very difficult to estimate because they will vary from case to case, for instance in function of the size of the network, and frequency of measurements.

4.2 Road construction innovations to improve safety

Skid resistance aspects

a) The problem

Road Safety is an important issue. Nowadays not only the cost of maintenance, but also the hindrance has to be minimized. Since road infrastructure is crucial for the economy and mobility of people, it is of ultimate importance that roads are safe and accessible for road users, at any time. The road traffic volumes and axle loads are constantly growing in every country. The road administrator wishes to guarantee the quality of the road and contractors must be able to deliver a good pavement with a long maintenance free period. The grip on the road is provided by the skid resistance properties of the road in combination with the friction characteristics of the tyre. Investigations have shown that more accidents happen on road surface with low skid resistance. To guarantee the skid resistance during the service life of the road the interaction between road surface and tyres has to be improved. Hence the roads safety is questionable and difficult to manage in countries with highly growing traffic and more needs of new aggregates. Some examples:

- Tyre – Road contact has been changed. Not only the axle loads became higher. Also the tyre tension has grown with the introduction of super singles. Currently the properties of road surfaces and tyres are not optimised to balance all of these effects. Rather, road engineers or tyre manufacturers concentrate on one or two separate aspects. Knowledge of how these effects interact with each other is very limited. Therefore, optimisation of tyres or road surfaces for one main effect could lead to negative impacts on the other properties.

- The behaviour of the skid resistance is not always what till now was expected. Because of the heavy traffic and high intensity the well-known road pavements has more wear and tear. So the road surface becomes more abraded. The skid resistance will end under the safety line and the service life will decrease when the usual good acting materials are used. The quality of the aggregate seems to be not appropriate anymore.

- Due to the need of silent roads the texture of the surface is changing. The skid resistance (friction) depends on the textural aspects of the mixtures. Also the need of roads that can resist the forces of the traffic growth, the mix composition changed. To improve the durability and/or to make silent roads other bitumen is used: The new bitumen is better resistant against wear and tear / abrasion. It lasts longer before the bitumen has disappeared from the surface of the stones, which give the road the normal skid resistance. The initial skid resistance braking force coefficient of these roads is not enough. When the bitumen has disappeared from the top of the surface, the aggregate gives the road surface the right properties.

- Good aggregates become rare: The quarry with good aggregates will exhaust one day. So we have to find new aggregates or alternatives. The standard test methods will not be appropriate anymore.

All these examples show that the skid resistance can be optimised in different ways.

Therefore we can conclude that an optimising of the road and tyre characteristics would make road infrastructure greener, more reliable, more sustainable and safer.

Such solutions will indeed solve most of the above-mentioned problems and disadvantages related to the actual uncontrolled thermal condition of the pavement. Some examples:

- Greener: less maintenance is needed. So the need of new materials and energy is lower.

- More reliable: the infrastructure remains accessible. Less hindrance from accidents due to slippery roads.

- Safer: fewer accidents are expected to happen because of safer road conditions.

- More sustainable: less deterioration of the skid resistance helps to extend the period to maintenance.

b) Solutions to be investigated

There are several solutions to control the skid resistance of the road pavement. Some of them are discussed briefly below.

- **TYROSAFE**[2] – TYre and Road surface Optimisation for Skid resistance And Further Effects

Tyre – Road contact has been changed. Not only the axle loads became higher. Also the tyre tension has grown with the introduction of super singles.

However, although improving the tyre-road interaction to increase skid resistance has positive effects of improving safety, there may be negative effects such as increased rolling resistance and noise emissions. A higher rolling resistance means the use of extra energy to overcome this effect, which could lead to higher fuel consumption and CO_2 emissions. In these times, where environmental questions like noise, air quality and consumption of energy are becoming more and more important, any consideration of the safety benefits of improved skid resistance therefore needs to focus on rolling resistance and noise emissions as well.

To be able to assess the interdependencies between road and tyre it is necessary to measure the respective values for skid resistance, rolling resistance and noise emission. To accomplish this task, especially for skid resistance and noise, most European countries have developed their own measuring methods. To ensure the comparability of measurement results it is necessary to establish a common basis to which the different techniques can refer. In this context, the policies and standards of individual countries relating to skid resistance, rolling resistance and noise emissions vary considerably across the EU.

The same is true of the impact of climatic change, since current standards are based on historic responses to national requirements and climatic conditions. The potential effects of climate change, however, could mean that the assumptions on which these standards are based will change. Other measures needed to manage the effects of climate change may also have side effects on the characteristics of road surfaces and the skid resistance that they can provide.

Many of these issues have already been addressed and different EU countries have carried out research separately but there is a need to bring ideas together and establish what scope there is for developing a harmonised approach for the future. This is necessary to ensure increasing safety and greening of transport on European roads and not just on a national level.

This Coordinating Action will not only focus on the road surface but also on tyres and on the interaction between the road surface and tyres. Only an optimised interaction can lead to a high level of safety for drivers on the roads in European countries while ensuring the most positive greening effect, through reduction of CO_2 output and noise emissions.

This project will provide a synopsis of the current state of scientific understanding and its current application in national and European standards. It will identify the needs for future research and propose a way forward in the context of the future objectives of European road administrations in order to optimise three key properties of European roads: skid resistance, rolling resistance and tyre/road noise emission.

- ***Reconsidering the desired values in the standard, extended with a new test to predict the behaviour of the skid resistance in the future due to the increasing (heavy) traffic.***

[2] TYROSAFE is a FEHRL project supported by the European Commission under the 7th Framework Programm

The behaviour of the skid resistance is not always what till now was expected. The project was started after the skid resistance on different roads acts not the way that could be expected from the PSV-value of the aggregate. Because of the heavy traffic and high intensity the well-known road pavements has more wear and tear. So the road surface becomes more abraded. The skid resistance will end under the safety line and the service life will decrease when the usual good acting materials are used. The quality of the normally used aggregate seems to be not appropriate anymore, when aggregates with a relatively low PSV (polished stone value), approved in the standard, are used. With an extended test road surface can be abraded in the laboratory, with the Wehner & Schulze-test, so the long-term behaviour can be predicted again. And some aggregates with a relatively low can still be used. To investigate the road surface in situ, the Wehner & Schulze test will also be carried out in situ.

- ***Improving the initial skid resistance by removing or adaptation of the bitumen on the surface***

Due to the need of silent roads and the need of roads that can resist the forces of the traffic growth, the mix composition changed. To improve the durability and/or to make silent roads other bitumen is used: The new bitumen is better resistant against wear and tear / abrasion. It lasts longer before the bitumen has disappeared from the surface of the stones, which give the road the normal skid resistance.

1. Improve the skidding resistance at young age by micro-incrustatation.

2. Removing the bitumen form the top of the surface with different techniques. Like air, sand and ice blasting.

3. Add special material to the asphalt mix to improve the initial skid resistance.

4. Sanding of the surface with special equipment on the asphalt paver.

- **Acceptance of new materials with among them the right specifications for skid resistance**

On some roads with porous asphalt ravelling appeared when it was not yet expected. Also on other locations in seemed the normal service life was shortened by the appearance of early ravelling. In the end it appeared that the aggregate was used from quarries with not only stones, but also a certain amount of clay. The aggregate was shipped and in the end used in the mix. It appeared that the clay was not really baked in the mixing process of asphalt. In the usual tests the clay “stones” dissolves when the aggregate is sieved out to determine the grading. And the material is not tested on the stone specifications.

Within a year the first clay stones disintegrated and disappeared in the matrix of the porous asphalt. Nowadays the use of the specific material from two quarries is forbidden.

Good aggregates become rare: The quarry with good aggregates will exhaust one day. So we have to find new aggregates. We have to be sharp and anticipate at the fact that for instance clay pollution can be among the delivered material, which can have a bad influence on the service life of the pavement. Every advantage has its disadvantage. When one specification is upgraded often another specification devaluates. We have to keep in mind to check all the properties of new materials otherwise some specifications can have a bad influence in the life cycle of the pavement. The standard test methods will not be appropriate anymore.

c) Research plan

- **TYROSAFE** – TYre and Road surface Optimisation for Skid resistance And Further Effects

First of all the coordination of the existing know-how is necessary. The TYROSAFE project does not do any research. The main objectives of the TYROSAFE project are to raise awareness, coordinate and prepare for European harmonisation and optimisation of the assessment and management of essential tyre/road interaction parameters to increase safety and support greening of European road transport. Through the following operational objectives the consortium will work towards achieving this target.

- Setting up a platform and organising workshops/expert working groups
  - To collect and share existing knowledge including past, current and future research activities about skid resistance, rolling resistance and noise emissions,
  - To raise awareness concerning the safety relevance and greening influence of road surface parameters.
- Studying national standards/policies of different EU and neighbouring countries concerning skid resistance, rolling resistance and noise emissions, to document current practice in EU countries, to provide recommendations for a common European policy on skid resistance, rolling resistance and noise emissions.
- Developing a road map/an implementation plan including specific stages for the short, medium and longer term (2010, 2015 and 2020) towards the final harmonisation of skid resistance test methods and reference surfaces based on research work.

Creating one or more matrices showing interdependencies and environmental effects of the factors that influencing road surfaces and tyres in relation to skid resistance, rolling resistance and noise emissions. This matrix will allow knowledge gaps to be identified and indicate the need for future research work.

- ***Reconsidering the desired values in the standard, extended with a new test to predict the behaviour of the skid resistance in the future due to the increasing (heavy) traffic.***

For the second solution a research plan is approved and some laboratories has been inscribed. So the status op the project is ongoing research. The investigations are now focussed on validating the system on local popular mixes. The new system can be used in other countries to predict the skid resistance and make better use of the materials by using good aggregate with bad skid resistance aspects in another later than the top layer.

- ***Improving the initial skid resistance by removing or adaptation of the bitumen on the surface***

In different countries different techniques to improve the initial skid resistance are investigated or developed. The test results are only in the language of the country available. Together it is easier to solve a problem. Sharing the knowledge by translating the native reports is a first step to find out what techniques has to be developed.

- **Acceptance of new materials with among them the right specifications for skid resistance**

The standard test methods will not be appropriate anymore and extra tests have to be added for good quality insurance. In the case of the clay pollution it is easy to examinate the aggregate before sieving. It is important to share such knowledge in all countries.

d) Financial estimate / benefits

The costs the projects are hard to estimate. A global indication is given.

- **TYROSAFE** – TYre and Road surface Optimisation for Skid resistance And Further Effects
  - o Low costs, as no research infrastructure is needed for a Coordinated Action
  - o Social benefits: increase in safety, reduction in pollution

- ***Reconsidering the desired values in the standard, extended with a new test to predict the behaviour of the skid resistance in the future due to the increasing (heavy) traffic.***
    - Some costs, as in different countries research has to be carried out to infrastructure. In some countries research is probably not needed, because the problem doesn't exist because of there is no lack of high quality materials. (Rough estimate € 100.000, -)
    - Increase in safety

- ***Improving the initial skid resistance by removing or adaptation of the bitumen on the surface***
    - Some costs, because the reports on the subject must be translated. In the end we can find out if more research is needed. (Rough estimate € 200.000, -)
    - Increase in safety

- **Acceptance of new materials with among them the right specifications for skid resistance**
    - Low costs. At this time only the problem of the clay pollution of aggregates is discussed. A new test must be implemented.

Solution for tunnels

a) The problem

Road Safety is an important issue. Frontal and side crashes are very critical accidents; in tunnels the risk is higher, because a car/truck cannot manoeuvre to the side. Also a big accident in a tunnel has more impact. Not only the number of people and cars involved. Also the repair works after an accident will give lots of hindrance.

Unsafe overtaking and not keeping the lane can be a problem in a tunnel. Not only in tunnels that travel both ways. Also a burning engine of a truck that is in a tunnel is a problem. Trucks going up the mountain produce polluted air. In a tunnel with two driving directions the air is not really ventilated. In countries with winter sports special telepheriques and cable cars are developed for the skiing and boarding people. The technique is available. With less snow and more environmental guard, the need of new installations decreases.

Combining a new lane keeping system with a motorised cable pulling / lowering system can prevent accidents and save energy.

If the tunnel safety increases it has a good influence on different aspects. Some examples:

- Greener: less air pollution in the tunnel.
- More reliable: the infrastructure remains accessible. Less hindrance from accidents due to frontal and side crashes or overheated engines.
- Safer: fewer accidents are expected to happen because of safer road conditions.
- More sustainable: fewer replacements in the tunnel.

b) Solutions to be investigated

At first it is important that the trucks keep their own lane. With a cable car system it can be possible. The energy for pulling a truck up the hill can be recovered from trucks going downhill in the tunnel.

c) Research plan

- Investigate what the possibilities are and what it will cost,
- Setting up a platform and organising workshops/expert working groups to collect and share existing knowledge

d) Financial estimate / benefits

The cost the projects are hard to estimate. It depends on the possibilities to integrate a system in old and new tunnels.

Road geometry adaptation

a) The problem

A **safe design** of the road lay-out is one of the elementary basics. Offering road users a clear and proper design is an important step to safety, as it enables them to recognise and assess the situation.

A rather simple way of achieving extra capacity on the highway system is to allow the use of hard shoulders during rush hours and in the case of accidents. The development of dynamic road markings makes it possible to optimise the use of the existing square metres of roadways. By narrowing the lane width (in combination with speed limitation), an extra lane can be created in cross section. At all network levels, dynamic road markings bring automatic changes of travel direction in reach. Less popular but effective is the creation of buffer zones holding cars near the access to a network. Restricted access (car by car) from these zones prevents exceeding the capacity on a congested road section. It is the choice between every car standing still or the majority proceeding on their journey. All these examples of measurements aimed at optimising the use of the existing roads directly or indirectly affect the behaviour of the road infrastructure. Changes of loading the pavement construction affect the performance. The problem is that the dynamic road marking systems are not yet durable enough.

When a dynamic road marking system can be used, it would make road infrastructure more reliable and safer.

Such solutions will indeed solve most of the above-mentioned problems and disadvantages. Some examples:

- More reliable: the infrastructure remains accessible. Less hindrance because of the possibility to improve the capacity with some sped limitations for safety.
- Safer: fewer accidents are expected to happen because of safer road conditions.

b) Solutions to be investigated

In the area of layout and outfitting, continued development of dynamic markings is the most striking development. After a number of demonstration projects and short-term pilots, two situations with dynamic markings have now been created and are being evaluated. Also the implementation in the road law is necessary.

c) Research plan

Full scale testing on the demonstration projects gives more information about the durability and the reaction of the road users.

d) Financial estimate / benefits

The cost the projects are hard to estimate.

5. Research ideas towards Reliable Infrastructure

5.1 Management of highway assets

a) The problem

The roads are built to satisfy the needs for the safe, economic and comfortable transport of persons and goods. So, these properties of the road have to be created and maintained throughout the whole lifetime. The road owner has the responsibility to ensure the conditions mentioned above, besides the preservation of the assets value is among the main tasks of the road proprietor who usually transmits these activities to the road manager with a high share of responsibility.

Every country's highway network is considered as national assets. So, this network is owned by the state itself and the roads are managed by central and regional institutions appointed by government bodies. However, it is very hard for them to fulfil the expectations coming from the travelling public (safe, economic and comfortable journey) and from the state (preservation of road assets) due to the following two main reasons:

- the available financial means are always far from the justified needs,
- the expectations are often partly contradictory.

The number of road vehicles, and, consequently, the highway traffic volume and axle loads are constantly growing in every country. The higher GDP-levels create higher living standards which increase the expectations of the people towards quality highway service. They need more roads, preferably expressways with higher comfort and safety standards. If they are not satisfied with the highway infrastructure available, they utilize more and more the civil bodies (associations) to express their lack of satisfaction, even protest against the present situation with certain political consequences. So, it is the interest of the proprietor and the manager of roads to find an organized activity co-ordination, the so-called asset management for relieving the tension mentioned.

The problem is similar for road networks owned and managed by local authorities, municipalities etc.

The road sections in poor condition still have a certain value. The knowledge of this actual value, the so-called residual value is of utmost importance for the responsible preservation of the assets. The development of special evaluation techniques to measure this one is needed with various performance indicators, preferably uniform throughout Europe.

b) Solutions to be investigated

A sophisticated and well co-ordinated highway asset management can significantly contribute to the solution of the problem mentioned.
Partly the road authorities in their proprietary and manager roles, partly the road users (even the whole society) could utilize the results of the research activities listed in the following main selected topics:

- Elaboration of an organized methodology for the regular evaluation of road user needs (handling with complaints, organizing questionnaire surveys, meeting with the representatives of civil organisations, etc.),

- combination of user needs with the owner's (client's) expectations, and their use in the road managing decisions,

- proposals for the organisational system (number, size, regional distribution, interdependency, special expertise of staff, machinery etc.) for the most efficient management of road assets, (the "optimum" system would, of course, depend on the local situation),

- detailed analysis of the various business arrangements (e.g. own “in-house” work, outsourcing, PPP-constructions, etc.) from the point of view of long-term efficiency for the highway network; sensitivity analysis of the eventual local factors for the consequences of a decision in the topic,

- elaboration of a scientifically based road asset valuation system which allows the follow-up of the road infrastructure assets value (gross and net assets values for roads, bridges, tunnels etc.),

- elaboration of a scientifically based road condition monitoring survey system with high-speed measuring devices utilizing the “optimum” measuring frequency as a function of the deterioration speed of the condition parameter characterized and the pavement age,

- establishment of sophisticated Pavement Management System, Bridge Management System, Tunnel Management System, etc. preferably with the possibility for combining them into Road Management System or Infrastructure Management System for making higher level, nearly optimum decision in road management.

A recent world-wide questionnaire survey of a PIARC Technical Committee has proved that fully operational and really successful road asset management has nowhere been completed yet. So, the research activities recommended are highly necessary and timely.

c) Expected benefits

The estimated expenditures of these extensive research activities can be some 10 million Euros. However, the expected much higher benefits can come from the following main sources:

- the whole management system is organized better than before, resulting in significant cost savings,

- the most reliable knowledge on the technical and condition data of the highway network concerned, as well as the availability of sophisticated management systems as useful technical tools can highly contribute to “nearly optimum” decisions with long-term benefits as lower life-cycle costs,

- the resulting high quality highway asset management reduces the costs of road users in terms of lower vehicle operating costs, accident costs and time (delay) costs (less traffic disruption is needed from the higher life cycles of more efficient pavement condition improving interventions).

Since the assets value of the national highways system in the countries of the European Union usually amounts to 10-100 billion Euro, and 1.0-2.0 % of the gross value (some 100-2000 million Euro) is spent yearly for maintenance and rehabilitation. If just 5 % (1 %) of this management cost can be saved by better management of the assets, in a single year (5 years) can be saved much more money than the research expenditure estimated.

5.2 Answers of the road sector to climate change

a) The problem

The past years can be characterised by the increased variability of the climate of Earth. Besides, a changing of the climate which is generally called global warming has been identified. The main features of the climate change are as follows: increasing the mean temperature on earth surface; damaging of ozone cover; changing in precipitation; more frequent extreme climatic events; general sea level rise. This changing in climate has a direct impact to the environment, economy and society. That is why, a lot of international protocols and agreements have been formulated and/or come into force recently. All of them try to find answers to the major challenges of this climate change. Since the meteorological processes mentioned affect also the performance of highways, the road sector has to react to this challenge.

b) Solutions to be investigated

Since the actual features of climate change are rather complex, the possible answers can be found in various directions. Some of the feasible measures in the planning, design, construction, maintenance and operation of highways will be outlined emphasizing the fact that these ideas are just examples; some more can also come into foreground in the future.

“The past is no longer the key to the future”. Several models have to be investigated for the future climatic trends which concentrate on the time series of temperature, precipitation, frequency of extreme events (storm, flooding etc). Risk management is needed in the field.

Combination of the adaptation and mitigation is necessary, however, there is more room for the former activities since the mitigation needs more time and co-ordinated action on behalf of the parties concerned.

The global warming means the exposure of road pavements to durable high temperatures, and in such or way, the resistance to the deformation of pavement structures should be increased. One of the possible ways in this field is the use of high-modulus asphalt preferably with polymer modified bitumen. This asphalt type can be effective in reducing the longitudinal and transverse waves of pavement surface if used as base courses (or binder course if any). The deformability of the structure could be practically discontinued if rigid pavement structures are built. The jointed and the continuously reinforced cement concrete pavement do not have lower E-moduli in hot weather, so they can lately withstand to the thermal load without rutting or longitudinal unevenness. (The actual pavement type selection is, of course, influenced by economic, environmental, human, traffic, geological, hydrological etc. parameters, and even local traditions.)

The more frequent extreme weather events (e.g. almost “tropical storms”) can have imminent traffic safety hazard as well as negative consequences to pavement surface. The road engineers should strive for ensuring the high level of the skid resistance of pavement surface possibly all the time independent on the actual weather. This goal can be reached by careful geometrical design of roads, constructing surfacing with high macrotexture, ensuring the continuous well-functioning of drainage system, although a really effective solution to the problem can be expected from the use of drain asphalt wearing course with high porosity. (The reduced life cycle of these porous asphalts compared to that of the dense asphalt variants can limit their use). The very intense rain can deteriorate the slopes of earthwork if no special slope protection measures are taken.

The unexpectedly high precipitation can cause a high rise in ground water level, even flooding. As a consequence, the moisture content of subgrade increases reducing its strength.

Consequently, the performance of pavements is jeopardized by the poor support. The risk of this failure can be decreased, among others, by the following measures: building higher road embankments eventually with granular drainage courses in the fills, increasing the initial sub- grade strength e.g. by building capping layers, using bound mixtures for sub-base courses instead of unbound materials. Besides, there are, of course, several hydrological measures to be taken to reduce the risk of pavement failure.

Other extreme event related to precipitation can be a long dry period. They are favourable from the view point of traffic safety due to the lack of wet pavement surface. However, they can have a negative effect to subgrade bearing capacity lowering its moisture content far below the optimum water content with high strength. The possible protection of subgrade from the ambient weather can be an eventually costly solution.
Among the possible extremities, the particularly severe winter conditions with much snow and ice can be still mentioned. Its traffic safety hazard is evident. The answers to this challenge can be, among others, meteorological stations along major roads, on-board ITS information on icy-snowy road sections, electrical heating system in the pavement structure of most important highway sections, preventive road winter maintenance, high-performance machinery for snow removal.

The actual consequences of the climate change can be, of course, slightly different in various European countries. However, this difference means that not all of the extreme situations are supposed to happen everywhere. So, the main task, finding efficient answers to climate change challenges, is common all over Europe, and the complexity of the problem necessitates a comprehensive and co-ordinated European-wide research in the field.

c) Expected benefits

The cost of the suggested extensive research project (or project group) can reach 20 million Euros. However, the possible danger (significant reduction in performance) in European highway due to climate change can be estimated in several billion Euros. If the successful research work would be able to reduce this loss considerably, it can be a highly efficient activity.

6. Research ideas towards Human Infrastructure

6.1 Life-time engineering for roads

a) The problem

A typical problem of the infrastructure assets of high value is that preserving its relatively long life with regards to the decisions on short-term repairs and maintenance are or can be rather contradictory. It is also true for the highways in case of “traditional” structural design which can be characterised by the following main features:

- the design concentrates on the reaction-resistance (and not the durability) of the structure to the anticipated loads mainly just after the completion of the facility,
- it considers primarily the construction (initial) costs, less the later maintenance and rehabilitation expenditures, almost never the future environmental and human aspects throughout the lifetime,
- the design activities deal with the whole structure as an entity, do not consider its “modules” separately although their loads, lifetime expectancies and eventual recycling techniques are sometimes basically different (that is no “modular” design is applied),
- the designers generally do not co-operate with the experts of other sciences (e.g. physicist, chemists, mathematicians, system engineers, etc.) who could considerably contribute to the complexity and profoundness of the road design.

The obvious and world-widely accepted need for sustainable development including sustainable transport makes the problem outlined rather urgent. The short-term and too confined (not complex) design activities do not count with the future consequences which can be of economic, environmental and/or human nature. This attitude should be changed as quickly as possible to a structural design methodology which is much more responsible for the next generation.

b) Solutions to be investigated

The lifetime engineering, a new science developed during the mid-1990’s can be the solution of the above problems. Although, the main principles of lifetime engineering were applied first for buildings, industrial facilities and bridges, they can and should also be used for highways.

The use of the basic principles of lifetime engineering for roads (mainly highway pavement structures) can significantly contribute to the “sustainable development” in the countries considered. This is obvious from the very fact that lifetime engineering forecasts and takes into account not only the technical and economic issues but also the environmental and human aspects throughout the whole life of the road infrastructure. Besides, this integrated life cycle design includes the forecasting of re-use, recycling and disposal of the building materials (elements of the deteriorated pavement structure) at the end of its lifetime.

For life cycle planning, a modular methodology is preferred which allows the systematic allocation and optimisation of the target service life, as well as life cycle economy and ecology of different elements (e. g. layers) of the structure.

This integrated lifetime design is also an important link in construction: translating the requirements of owners, user and society into performance requirements of the technical systems; creating and optimising technical solutions which fulfil those requirements; and proving through analysis and dimensioning calculations that the performance requirements will be fulfilled over the entire design service life.

Significant economic results can be expected if – following the basic principles of lifetime engineering – the traditional "reaction (resistance) type" pavement design is transformed to "durability type" meaning that the forecasted changing of loads and reactions (strength) of the pavement structure during the entire life is considered allowing the minimisation of life cycle cost.

The impact of life cycle principles in construction is in the application of life cycle criteria in the quality assurance procedure. Multiple life cycle criteria are also applied during the selection of products, although most of the product specifications have already been produced at the design phase.

Integrated life cycle supports an improved quality approach, which can be called life cycle quality. Financial, ecological, cultural and human areas are treated over the life cycle of structures, and controlled in the design by technical performance parameters.

The life cycle performance is highly dependent on maintenance. The structural system of the highway facility needs a users' manual, just like a car. The manual should be produced gradually during the design process in co-operation with those involved in design and construction.

The obvious main party interested is the road designer, whose traditional activity is to be widened and deepened by considering more aspects and much longer time ranges than before, as well as by needing more co-operation with the experts of other related sciences. The road authorities (as owners or managers) are also highly interested in this new type of design (integrated lifetime design) since their road assets could be preserved more efficiently which is one of the main goals of their asset management. The whole population (society) including travelling public would also benefit from the use of the principles of lifetime engineering for roads since this type of structural design is highly sensitive to environmental issues and, more importantly, human aspects like toxic ingredients, safety, comfort, etc.

The successful implementation of the lifetime engineering principles in the road pavement design is (would be) used by the whole community for the following reasons:

- The realistic anticipation of the future (traffic and environmental) loads allows the forecast of pavement deterioration already during the pavement design phase, so the necessary condition improving interventions can be optimized allowing the higher satisfaction level of the road users in respect to safety, comfort and economy,

- the whole life costs of the road infrastructure can be reduced by the minimization of road user costs since the time delay costs, the extra vehicle operation costs and the additional accident costs during road works are much lower than before,

- the new principles concentrate also on the minimization of environmental harms (use of toxic materials, air pollution, water pollution, soil pollution, traffic rolling noise, etc.) which the whole population can benefit from,

- the recycling (or eventually the reuse) of road materials are also forecasted and planned already in the early design phase resulting in environmental benefits and financial saving for the sake of the whole community (everybody is interested here due to the fact that the tax-payers' money is used for the development and the management of public highway networks),

- human factors such as safety, comfort, health risks are among the aspects considered in the lifetime engineering related to the whole pavement duration.

c) Expected benefits

The preparation activities of the implementation of lifetime engineering principles for roads need several interrelated research works necessitating some 5-10 million Euro expenditure. Since the road designers and various experts would cooperate to achieve higher level road projects, they need additional, specialised expertise. Their teaching and training for some 1-2 million Euro in a European Union country of average size cause an additional cost.

However, the benefits coming from the successful application of the principles of lifetime engineering for road pavements are much higher than the implementation costs. The yearly public road management costs in an EU country amounts to 100-2000 million Euro. If – conservatively – just 5 % cost saving in the road management is forecasted coming from the much more complex pavement design based on lifetime engineering principles, the benefits would compensate the whole costs in some months, maximum 1 year, depending on the country size.

6.2 Reducing traffic nuisance

a) The problem

Recent estimates indicate that more than 30% of EU citizens are exposed to road traffic noise levels above that viewed acceptable by the World Health Organisation (WHO) and that about 10% of the population report severe sleep disturbance because of transport noise at night. In addition to the general disruption of activities and quality of life, there are additional adverse health and financial effects.

The WHO has identified a range of specific adverse health effects caused by environmental noise some of which are medically related. Although there are significant problems in establishing a direct causal link between exposure to transport noise and the deterioration in the health of individuals, there is a growing body of research evidence that support the contention that noise and health are related. For example, international literature studies and evaluations carried out in connection with the development of the Danish Road Noise Strategy have shown a relationship between road traffic noise and incidences of high blood pressure and heart disease. The study also estimated that around 800-2200 people in Denmark are admitted to hospital each year with high blood pressure or heart disease due, it is considered by the study authors, to the additional risk brought about by traffic noise. It was also tentatively estimated that between 200-500 people die prematurely in Denmark each year as a result of exposure to high levels of transport noise. It is estimated that the cost of such health effects for Denmark is of the order of €80-450M per year.

In addition to the costs of dealing with health issues, there are other potential costs that can be attributed to high transport noise levels. These include effects on the value of property, loss of amenity due to noise and the costs of control measures and enforcement. In the EU Green Paper on future noise policy published in 1996, it is estimated that in Europe the external costs of traffic noise, which take account of such factors as the costs on the quality of life and health effects, are 0.2 - 2% of GNP. In total, therefore, a rather significant part of the economy of Member States is affected by noise impact and noise reduction policies.

Additionally to the noise problem there are other major environmental problems, increasing with the road traffic volume increase. The special attention is put also to air pollution and traffic induced vibrations. The harmful particulates and gas emissions are in constant increase due to traffic growth. Benzene, hydrocarbons, nitrogen and carbon oxides and particulates are affecting the health of a large number of people, residents in urban and suburban areas, the environment and other living creatures, exposed to the traffic nuisance.

There has been a large abatement of the emissions in the past more than 10 years due to public awareness, legislation restrictions and consecutive severe engagement of automotive industry. On the other hand this abatement is still prevailed by the contemporary increase in production and use of means of transportation, being the source of more and more new emissions.

The road traffic induced vibrations are another annoying source, affecting the residents, living near to the road infrastructure. They are also potential source of damages to the buildings and to the equipment, e.g. highly technological appliances. As an annoying source, the complaints against the vibrations are typically accompanied with complaints about road traffic noise. This makes the reduction of the road traffic noise and induced vibrations a very important issue in the urban and suburban areas to be dealt with.

b) Solutions to be investigated

Reducing the traffic nuisance is headed towards inventing and selecting solutions that are compromise between environmentally friendly and suitable concepts, a sustainable use of resources, road safety and total construction and maintenance costs.

The reduction of traffic noise considerably improves the quality of life in urban and suburban areas. The noise control and abatement is a fundamental component of the common environmental policy of the European Parliament and this is also introduced in the EU's Directives for the Environmental Management.

The substantial reduction in the tire/road surface noise must be achieved. With the increase of the traffic volume, volume of engines and average speed the noise level increased, so the noise reduction must be addressed also to the engine noise.

From the road pavement point of view, the resonant pavements are suitable to control noise generation and to control the propagation of tire noise emissions. This is obtained by the texture optimization and the sound absorption of the top layer and by acoustic resonance due to use of new materials and structural solutions.

New composite pavement solutions like eco-technical and euphonic type pavement solutions have been designed, implemented and validated with specific on site measurements, showing their performance in practice.

The generation of the tire noise emissions is controlled also with the resilient pavement solutions. This is obtained with the texture optimization of the top layer and through the choice of raw materials, mixes and layers with its mechanical impedance.

As a possible type of low-noise road surface is a block pavement with soft cover. The block pavement is made of interlocking cement concrete blocks laid on a stable foundation; while the soft cover is a so-called poroelastic layer. The poroelastic surface combines the desires of having a quiet and at the same time aesthetically pleasing surface. The poroelastic cover is anticipated to produce less noise in contact with tyres due to its softness, be self cleaning and thus have a lasting noise reducing performance. Because of high percentage of voids it drains away the run-off water from the road surface making traffic more safe and comfortable.

The nuisance mitigating infrastructures should be complex solutions to reduce noise, air and vibration pollution. A possible complex solution where integrated approach is applied, is an ecotechnical road system, composed by permanently clean safety barriers, permanently clean noise-abating safety barriers, air-depollutants with ground filtering and with vegetation barriers, and noise- and vibration-dampening pavements.

c) Expected benefits

It is difficult to fully evaluate the costs and benefits from mitigating traffic nuisance. The successful development and implementation of possible road pavement solutions would be wholesome to the community because of (in combination of road traffic nuisance mitigation measures) minimizing the adverse effects of road traffic noise, air pollution and vibration, affecting both population and environment. It would be wholesome to the community because of decrease in health costs due to the traffic noise and air pollution effects. Last but not least it would decrease in potential costs: loss of amenity due to noise, air and vibration pollution.

In terms of noise impacts the magnitude of costs can be determined from studies of how property values are affected by noise. For example, a study of the influence of road noise on house prices carried out in Spring 2003 by the Danish EPA indicated that house prices were lower by about 1% for each dB increase in noise for houses located near to busy roads. Although it is uncertain how much of this drop in value can be attributed solely to noise impacts, it is clear that noise is a significant ingredient governing property valuations. The total cost of noise to Danish society has been estimated to be between €780M-1150M per year (health effects and reduced house prices).

A study carried out in the UK has examined revisions to the vehicle noise test procedures and included an examination of the costs and benefits of reducing vehicle noise. It was estimated, making a number of assumptions that need to be tested, that the benefit to the UK population of a 1 dB reduction in noise measured at dwellings would be of the order of €800M per year. When this figure was applied to the option of reducing the exposure to traffic noise through the reduction of noise levels from vehicles as part of the type approval process, a minimum cost benefit ratio in excess of 100-1 was found to apply. In other words the costs of this form of noise control was small in relation to the overall benefits that could be achieved

Clearly, although the absolute costs to society of the impacts of transport noise are difficult to determine with precision, it is clear that since the magnitudes are potentially very large the financial benefits of tackling the problem, irrespective of the benefits attributable to the quality of life, are also likely to be very significant.

7. Concluding remarks

As explained in introduction, this report aimed at giving some research topics that could be studied within a further project. The different themes have been separated in function of the four NR2C concepts (green, smart and safe, reliable and human) and they cover various problems identified for interurban infrastructure. Of course this represents only a small sample of research ideas and it is not exhaustive.

For each research topic mentioned, the problem has been explained in the first part, before to propose some solutions and make a raw evaluation of the associated costs and benefits if possible. As the different research ideas cover a wide range of topics, a classification between the different themes would be rather difficult and highly dependent of the evaluation criteria.

However, the present report treats some crucial topics for future interurban road infrastructure. For instance, the climate change effects are currently more and more important because of the recurrent natural hazards. Indeed, the intensity of flooding events, temperature variations or heavy snowfall are increasing with more important consequences on human being and infrastructure than in the last decades. Thus we can ask us if the road infrastructure is strong enough to support it or if some specific development should be carried out. Thus, one of the recommendations would be to put a special emphasis on the analysis of the climate change effects.
Another important topic that emerged during the elaboration of the deliverable is the energy aspects. Indeed, it has been found that the construction and utilisation of a road infrastructure are very important energy consumers. Hence, some solutions have to be investigated in order to recover energy from pavement for instance, or decrease the energy consumption this especially during the laying phase. Indeed, the energy aspects are nowadays a major theme in all the research domains and it seems obvious that the road sector should be able to bring its contribution.