MIRAVEC

Recommendations for implementation of road vehicle energy consumption in pavement and asset management systems

Deliverable D4.1

November 2013

Coordinator: AIT

Partner 1: TRL

Partner 2: VTI

Partner 3: ZAG

Partner 4: CDV

Partner 5: FEHRL

This project was initiated by ERA-NET ROAD.

Project Nr. 832615

MIRAVEC

Modelling Infrastructure Influence on RoAd Vehicle Energy Consumption

MIRAVEC - Modelling Infrastructure Influence on RoAd Vehicle Energy Consumption

Deliverable 4.1: Recommendations for implementation of road vehicle energy consumption in pavement and asset management systems

Due date of deliverable: 30.11.2013

Actual submission date: 20.12.2013

Start date of project: 01.11.2011 End date of project: 31.10.2013

Author(s) this deliverable:

Darko Kokot, ZAG, SI

Josef Stryk, CDV, CZ

Version: 2.0

Executive summary

CO_2 emissions from road transport represent an important part of the overall greenhouse gas emissions and consequently contribute to the on-going climate change. Efforts to reduce those emissions need to consider all influencing factors on the energy use of road vehicles, where improvement of road infrastructure characteristics related to fuel consumption can contribute to an overall CO_2 reduction in road transport. This requires an understanding of both these interactions and the implementation of results in current pavement and asset management practice.

The objective of MIRAVEC is to build on existing knowledge and models in order to achieve a more holistic view considering a broad variety of effects. The project results will be compiled into recommendations to NRAs on how to implement the findings, models and tools in pavement and asset management systems.

This is a report of the findings in Work Package 4 (WP4) in MIRAVEC. The objectives of this WP are to identify the current role of road vehicle energy consumption and CO_2 emissions in existing pavement/asset management systems and opportunities for its improvement, further analyse potential implications of optimizing for low energy consumption for other objectives and finally to give recommendations on implementation of road vehicle energy consumption (CO_2 emissions) in existing pavement/asset management systems.

The report begins with a summary of the findings and outputs of previous work related to WP4 objectives: from MIRAVEC WP1 (Effects contributing to road vehicle energy consumption), WP2 (Existing modelling tools and evaluation of their capabilities) and WP3 (Assessment of the potential for NRAs to achieve reductions in vehicle energy use); and from the current state in projects MIRIAM and COOEE.

WP4 prepared an on-line questionnaire to obtain an overview of existing pavement/asset management systems (PMS/AMS), in particular with regard to road vehicle energy consumption and CO_2 emissions. Answers were received from 16 experts from 13 different countries. The findings are divided into the following categories:

- General view,
- Implementation within existing asset/pavement management systems,
- Socio-economic impacts,
- Models of energy consumption and CO_2 emissions,
- Outputs of current systems,
- Balancing low energy consumption with other requirements,
- Steps to upgrade optimization process.

With the information generated in previous MIRAVEC project WPs and information found in literature the questionnaire served as a basis to give recommendations for the implementation of models, tools and gathered knowledge into existing pavement/asset management systems. The recommendations were given on the following topics:

- Influencing parameters and investigating schemes,
- Considering CO_2 emissions (including regional particularities and climatic constraints that influence vehicle energy consumption),
- Modelling and optimization with other parameters,
- Implementation.

The resulting recommendations will facilitate implementation of e.g. what was found as the most expected way to present results: prognoses of evolution of CO_2 emission over time, based on different budget levels for the different maintenance treatments/measures modelled.

List of Tables

List of Figures

Table of contents

1 Introduction

“ERA-NET ROAD – Coordination and Implementation of Road Research in Europe” is a Coordination Action funded by the 6th Framework Programme of the EC. The partners in ERA-NET ROAD (ENR) were United Kingdom, Finland, Netherlands, Sweden, Germany, Norway, Switzerland, Austria, Poland, Slovenia and Denmark (www.road-era.net). Within the framework of ENR this joint research project was initiated. The funding National Road Administrations (NRA) in this joint research project are Germany, Denmark, Ireland, Norway, Sweden and United Kingdom.

CO_2 emissions from road transport represent an important part of the overall greenhouse gas emissions and consequently contribute to the on-going climate change. Efforts to reduce those emissions need to consider all influencing factors on the energy consumption of road vehicles, which is directly linked to their carbon footprint. Besides the ‘greening’ of vehicle technologies the improvement of road infrastructure characteristics related to fuel consumption can contribute to an overall CO_2 reduction in road transport. This requires both a thorough understanding of those interactions and the implementation of results in current pavement and asset management practice. In contributing to both objectives MIRAVEC enables National Road Administrations (NRAs) to effectively support the reduction of road transport greenhouse gas emissions.

While some previous and on-going projects like ECRPD or MIRIAM focused on specific topics in this area, the objective of MIRAVEC is to build on existing knowledge and models. In doing so MIRAVEC aims at achieving a more holistic view considering a broad variety of effects (e.g. the interaction between road design and traffic flow). Moreover, MIRAVEC has investigated the capabilities of available models and tools and evaluated the relative importance of different road infrastructure characteristics for different settings (e.g. topography or network type). The project results were compiled into recommendations to NRAs on how to implement the findings, models and tools in pavement and asset management systems.

1.1 Objective of WP4

The main objective of Work Package 4 (WP4) is to give recommendations for the implementation of models, tools and gathered knowledge into existing pavement/asset management systems and to identify associated opportunities and risks.

To reach this objective WP4 has completed some activities, with the core one preparing an on-line questionnaire, gathering data and analysing the replies. With this questionnaire the current level of integration of vehicle energy consumption considerations into pavement/asset management systems across Europe has been assessed. Different levels of implementation of existing energy and CO_2 emission elements or models have been sought for, particularly those that open up different opportunities for improvements. However, it should be noted that the implementation of improvements may be impeded by difficulties like management systems which are not well suited for the integrations of new parameters.

Additional activities to gather relevant information include a review of literature, the provision of information by project partners through targeted interviews and close cooperation with work packages 1-3 to assess the suitability and usefulness of the information generated there for the end users.

The resulting recommendations will facilitate decision making regarding new investments in and maintenance of road infrastructure and will help to achieve national greenhouse gas emission goals for 2020.

1.2 Structure of WP4

Work package 4 was split into 3 tasks.

1.2.1 Task 4.1

In this task the work has been divided into defining the state of the art in existing pavement/asset management systems with regard to road vehicle energy consumption and CO_2 emissions and evaluating the opportunities for improving the current practices by the introduction of new parameters/models.

Work was focused on identification of already existing elements and good practice in pavement/asset management systems connected to CO_2 emission and road vehicle energy consumption; and identification of possible risks and obstacles for the introduction of new parameters and models with the potential for contributing to energy savings and a decrease of CO_2 emissions.

1.2.2 Task 4.2

This task was directed to implications of the need to balance low energy consumption with other requirements for road infrastructure assets, especially with regard to road safety and noise emissions.

1.2.3 Task 4.3

Recommendations for the implementation of new models and elements in pavement and asset management systems was prepared on the basis of results in previous work packages and the results obtained in task 4.1 and task 4.2.

Following these recommendations will enable national road administrations to better include the impact of road infrastructure on vehicle energy consumption and CO_2 output in their decision making.

2 Summary of previous MIRAVEC work packages and literature review

Activities to gather relevant information for preparing recommendations for the implementation of new models and elements in pavement and asset management systems include a review of literature, the design and assessment of the results of an on-line questionnaire and close cooperation with work packages 1-3 to assess the suitability and usefulness of the information generated there for the end users.

2.1 Work Package 1

The objectives of WP1 were to identify the most important effects contributing to road vehicle energy consumption which are governed by interaction with the infrastructure and their associated parameters. This work package created a compilation of effects and parameters [1] which have served as a basis for the detailed work plans of Work Packages 2 and 3.

The factors investigated were categorised into the following groups A to E:

A. Pavement surface characteristics (rolling resistance, texture, longitudinal and transverse unevenness, cracking, rutting, other surface imperfections)

B. Road design and layout (overall design standards, road trajectories, gradient and crossfall, lane provision)

C. Traffic properties and interaction with the traffic flow (e.g. free flowing traffic vs. stop-and-go, speed limits, access restrictions)

D. Vehicle and tyre characteristics including the potential effect of technological changes in this area

E. Meteorological effects (e.g. temperature, wind, water, snow, ice)

NRAs have a large influence on the effects contributing to road vehicle energy consumption and identified within groups A to C, and these were included and asked about in some questions of the WP4 questionnaire.

2.2 Work Package 2

The main objective of WP2 was to provide a description of existing modelling tools and evaluation of their capabilities with respect to analysing the effects identified in WP1 [2]. The focus was on models used in other projects such as IERD [3], ECRPD [4] and MIRIAM [5], and to evaluate these projects and identify deficiencies and strengths.

The review carried out in WP2 found that there are numerous traffic models that can be used to simulate traffic at different aggregating levels. It was decided that a microscopic model that simulates individual vehicles was the most appropriate one to use for analysing the influence of road variables on traffic fuel consumption, since this allows the description of detailed input data. The review also found that most microscopic traffic simulation models focus on the vehicles, their interaction with other vehicles and the infrastructure and that typical simulations are performed to evaluate road traffic management systems and the traffic flow for complex traffic problems such as junctions. But there are some models available where the interaction of the vehicle and road can be described in detail, including fuel use due to changes in driving resistances. Examples of such models are VETO and the coupled FTire/Dymola/Modelica, used in previously mentioned MIRIAM project. VETO has also been used in IERD and ECRPD projects.

The sensitivity analysis, carried out in WP2 and using the available information of the Swedish state road network, showed that there is a close to linear relationship between relative changes in the analysed road variables and the relative change in fuel use. This relationship makes it less complicated to estimate the effect of changes.

WP2 found that in general, among road variables rise & fall leads to the largest impact on fuel use, followed by MPD (as a measure of pavement surface macrotexture) and average degree of curvature. The fuel use of trucks with trailer is most affected by these parameters, since the relative changes are larger the heavier the vehicle. Passenger cars, being the majority of vehicles travelling on the roads, will most likely be responsible for the largest changes in overall fuel use.

Road measures to improve the road variables will have an effect on driving resistance but inevitably also on driving patterns. When making improvements of one road link, it would be expected that apart from influencing the traffic distribution between links it may also increase the total number of trips made. It was found that there was no single model that takes all of the relevant aspects into consideration and is able to perform a complete analysis of the effect of fuel use and traffic emission due to road measures.

2.3 Work Package 3

The main objective of this WP was to assess the potential for NRAs to achieve reductions in vehicle energy use and understanding how this is influenced by the traffic flow, vehicle characteristics and infrastructure design [6].

To aid NRAs in the assessment of fuel consumption WP3 has developed a spreadsheet tool, which incorporates:

- The effect of road roughness on fuel consumption (measured using IRI),
- The effect of macro texture depth on fuel consumption (measured using MPD),
- The effect of road geometry on fuel consumption (measured using the degree of curvature and rise and fall/gradient),
- The effect of vehicle speed on fuel consumption,
- The traffic distribution and volume.

The MIRAVEC tool estimates the average vehicle speed from the road geometry, the level of rutting and ride quality present, the level of traffic and the split of heavy to light vehicles. In addition, a simple method for estimating the effect of idle time due to traffic congestion has been developed and implemented. It further enables users to estimate vehicle fuel consumption associated with a specific route and to explore the effects of various changes to the road infrastructure on the fuel consumption. This spreadsheet tool has been used to assess the potential benefits to be gained from making improvements to the infrastructure (i.e. the capacity for NRAs to provide energy reducing road infrastructure) by considering different scenarios and using statistical data available from national road networks.

WP3 found that most of the changes applied have small effects on the average CO_2 output per vehicle per km and therefore significant changes in the fuel consumption will be most easily achieved on lengths with high traffic levels. With multiple intervention options available to NRAs the effectiveness of each intervention will depend on the condition and traffic levels of the site. A good example of that is the introduction of an additional lane that can have a large impact on fuel consumption on sites where idle time/congestion is a significant factor, but this same treatment would have little or no impact on a site with lower traffic densities.

While it is expected that improved unevenness or lower texture depth would reduce vehicle fuel consumption, the case studies considered also that the reduction of fuel consumption varies from site to site (mainly due to the differences in traffic levels and the initial condition of the sites).

The sensitivity analysis carried out in WP3 showed that in general and among road variables rise and fall/gradient leads to the largest impact on fuel use. Although reducing the gradient of a route can significantly affect the fuel consumption per km, WP3 case study showed that if the new route is sufficiently longer than the original, it can still increase the overall fuel consumption.

WP3 finally recommended investigating schemes on a case by case basis and providing input data, particularly traffic flow, appropriate to the case being considered. This seems very appropriate if we consider previous findings. Furthermore, changes in traffic composition which result in reductions in fuel consumption (e.g. increased use of electric vehicles and/or low-energy tyres) will reduce the impact of interventions that the NRA carries out. However, increasing traffic levels, or an increase in the proportion of HGV traffic, will increase the impact of interventions that the NRA carries out.

The MIRAVEC spreadsheet tool can be used for such investigation and WP3 recommended the following methodology to be used:

A. Populate route 1 with the current condition of the route, with either current or future traffic levels.
B. Populate route 2 with the condition of the proposed intervention, with the same traffic data used in route 1. Note, depending on the intervention this may be a longer or shorter route than route 1 (e.g. due to a bypass)
C. Examine the fuel consumption statistics in the output stats sheet. If the routes are of different lengths then the fuel consumption per km (shown on the route sheets) should also be investigated.
D. Consider the differences in fuel consumption found from step C in relation to other factors, e.g. journey time, road surface condition, cost of works, noise etc.
E. Repeat for any additional proposed interventions.

2.4 MIRIAM Subproject SP4

MIRIAM is a project started by twelve partners from Europe and USA. The aim of this project is to provide sustainable and environmentally friendly road infrastructure by reducing rolling resistance - hence lowering CO_2 emissions and increasing energy efficiency.

As part of the work done in Subproject SP4 an online questionnaire has been prepared to seek answers concerning possibilities for implementing new parameters such as rolling resistance (RR) in existing management systems and how this could be tackled [7].

Answers from targeted experts show that rolling resistance is considered important for reducing greenhouse gases (GHG) and for energy efficiency. The most often recognized regional and climatic specifics which would influence RR, are: winter conditions (use of salt, use of studded tyres, icy roads, low temperatures); road surface types (roads with high fraction wearing course, unpaved roads,…); diverse climate conditions and different terrain; driving habits and some specific weather conditions such a desert temperatures (high temperatures) and heavy rain.

Different national road classifications were identified as a constraint to being able to apply general models for RR into existing systems. In general heavily trafficked roads are considered to be important for the consideration of RR impact with other influencing factors being: high speed, flatness of road and different wearing courses.

Introduction of new parameters (i.e. rolling resistance) into existing management system is thought to be difficult: partially due to systems not being developed in a functional way, the use of a variety of different commercial systems and different administrations in country competent for traffic regulations and road infrastructure. Difficulties also arise from problems with measuring the RR parameter and modelling.

Tyre characteristics are considered most relevant for the quantification of RR while factors like vehicle performance, driver behaviour, tyre condition, mass handling during construction, level of service, network and traffic management were considered as more important than RR in connection with pavement characteristics in 54 % of the responses.

It was also suggested that some negative impacts (water fog, higher construction and maintenance costs, shorter lifetime of roads etc.) as result of introduction of RR need to be appropriately assessed.

More than half of respondents think that the introduction of RR could conflict with other pavement parameters and could reduce safety, mainly as decreased skid resistance, but also as increased smoothness (decreased water drainage, potential increase in vehicle speed).

Some other possible restraints were also listed: with regard to RR it is thought that only typical cases can be modelled due to too many influencing factors. Moreover, only average, approximate results can be modelled since road sections develop differently. An accurate model of pavement deterioration is necessary; an accurate model of inter-dependencies between all pavement parameters and RR is necessary; relation between maintenance procedures and RR needs to be established.

From questionnaire answers it was concluded that in more than 75% of participating countries environmental impacts are not directly considered in management systems although almost all see a need for additional monitoring. The most relevant output would be CO_2 emissions in life cycle of pavement, energy reduction and noise, evolution of GHG in general and air pollution.

Steps that are needed to introduce CO_2 emissions in the maintenance and operation optimization processes are in this MIRIAM report summarized as:

A. Research to determine relevant road surface characteristics, improvement of measurement tools, determine relation between individual characteristics and CO_2 emissions, and several case studies,
B. Formation of models (first model for relevant parameter, then cost and effect models, integrated cost/effect model, introduction of tailored cost/effect model into existing management systems),
C. Convince decision makers; steps A and B should be aimed to produce convincing results through which considerable benefit of rolling resistance (surface parameter) in optimization model in respect to energy savings and lower CO_2e is demonstrated,
D. Formulation of new regulation.

2.5 Review of other literature

Concerning the inclusion of pavement rolling resistance or other parameters related to vehicle energy consumption in pavement and/or asset management systems there is not a lot of literature available. Interesting results can be expected from the Danish project called COOEE (section 2.5.1) and from MIRIAM (discussed above, in section 2.4). Also some papers exist that describe methods for incorporating pavement rolling resistance (associated CO_2 emissions) into life cycle assessment (section 2.5.2).

Only a few literature sources discuss a balance between vehicle energy consumption (defined by rolling resistance) and other requirements for pavement surfaces e.g. safety (section 2.5.3).

2.5.1 Implementation into asset management systems

The COOEE project (CO_2 emission reduction by exploitation of rolling resistance modelling of pavements) is scheduled to run over 4 years (2011–14). It is a result of collaboration between the Danish Road Directorate, Roskilde University, the Technical University of Denmark and NCC Roads [8].

The overall aim of the project is to develop new pavement designs that provide a low rolling resistance in order to reduce fuel consumption. The results will be implemented in the Danish Road Directorates Asset Management System – vejman.dk.

The project addresses the following topics:

- Novel pavements with low rolling resistance,
- Models of rolling resistance,
- Wear and ageing of pavements,
- Measurements of rolling resistance,
- Implementation into asset management system.

The single steps to implementation include:

- Determining the requirements for rolling resistance models,
- Modelling of socio-economic aspects,
- Design of deterioration models,
- Design of optimisation models,
- Design of novel pavement catalogue,
- Performance of cost/benefit analysis based on CO_2 emissions,
- Sensitivity analysis of rolling resistance concepts in asset management systems.

It is expected that rolling resistance will be included in the Danish asset management system by the end of 2014, although this will most likely be a proof of concept.

2.5.2 Life cycle assessment

Some sources describe the way that pavement rolling resistance can be included into life cycle assessment.

VTI report [9] is the outcome of the Swedish studies performed under Sub-project 3 of the MIRIAM project. The objective was to investigate the role of RR on the total energy use and if maintenance treatments can be viable option to reduce the total energy use.

In order to calculate total energy the VETO model and a life cycle approach were used. Two case studies were undertaken where the energy use for traffic and pavement manager induced actions was investigated in detail.

The fuel use for cars and for trucks with and without trailer was estimated with the VETO model. A simulation was performed for each vehicle type and for each of the scenarios in the case studies. The road surface quality and road deterioration regarding IRI (roughness) and MPD (macrotexture) was described according to the historical data that has been gathered from PMS and Väggrafen. The fuel use was estimated on a yearly basis and for the time period equal to the maintenance interval in each scenario. Fuel use was then converted into energy and the total sum of energy use during the time period was divided by the number of years within the same time period. The result was the average yearly energy use that enables comparisons between different scenarios.

The calculations confirmed that least energy is used when MPD and IRI are at the lowest levels.

The paper produced at the University of California Pavement Research Center (UCPRC) [10] describes a Lifecycle Cost Analysis (LCA) model developed to evaluate energy use and GHG emissions from pavement rehabilitation strategies. The LCA model includes the effects of pavement rolling resistance on vehicle operation which was demonstrated on few case studies.

The LCA model presented uses the framework and approach described in the Pavement LCA Guideline, developed. For pavements, the life cycle includes material production, construction, use, maintenance and rehabilitation (M&R), and end-of-life (EOL) phases.

LCA includes an alternative and novel method to evaluate the use phase of pavements, incorporating both roughness (unevenness) and macrotexture (described by IRI and MPD/MTD, respectively) as indications of the pavement surface condition. The rolling resistance is then calculated based on the HDM-4 model and used to estimate the increased engine load experienced by cars and trucks due to additional rolling resistance. The system was recently calibrated to North American vehicles through project NCHRP 1-45 [11].

HDM-4 can also be used to consider the effects on rolling resistance caused by pavement deflection; however, because the calibration from NCHRP 1-45 indicated that pavement deflection was only significant when heavy trucks were moving at slow speeds on hot asphalt it was assumed that energy consumed by deflection would be zero.

In HDM-4, the rolling resistance is calculated based on the following factors: IRI, MTD, deflection, climatic factor, and characteristics of vehicles, tyre type, speed and a set of coefficients.

With this analysis, it is possible to evaluate the cost-effectiveness of maintaining smooth pavements compared to other strategies already underway to reduce GHGs from the highway transportation sector. The models will next be used by the research team to assess smoothness specifications for Caltrans highways with different levels of traffic, and M&R trigger levels for IRI and ravelling (MPD for asphalt) and traffic level based on their impact on GHG emissions and energy consumption.

2.5.3 Balance of vehicle energy consumption with other requirements

Deliverable D14 of the TYROSAFE project [12] describes interactions of road pavement surface parameters in relation to rolling resistance and includes an interdependency matrix of surface parameters (skid resistance, rolling resistance and noise emission) in connection to aggregate properties, mixture parameters, method of laying/compacting and the finished surface.

The balance between rolling resistance and different pavement properties was presented by MIRIAM partners at the TRB 91st annual meeting in Washington, D.C. (Sandberg [13]). A trade-off between low RR and various functional pavement parameters was assessed in this presentation. The overview of these parameters is seen in Table 1 and summarised in the following paragraphs.

Table 1 Low rolling resistance versus functional pavement parameters (Sandberg, 2012)

Parameter	Effect	+++++ / - - - - -
Fuel (energy) consumption	Very positive relation	+++++
Dry friction	Neutral	0
Wet friction	Serious trade-off, but not for all cases	- - -
Hydroplaning	Positive relation	+++
Interior noise	Positive relation	++
Exterior noise	Weakly positive (exceptions occur)	+
Driving comfort	Positive relation	++
Air pollution	Very positive relation	+++++

Low fuel (or energy) consumption is directly related to low RR. Low macrotexture gives low RR = no trade-off, very positive correlation.

Low dry friction is obtained for low microtexture (polished aggregate). Microtexture not yet shown to influence RR = no trade-off.

Low wet friction is obtained for low macrotexture and high speeds. Macrotexture has very high positive correlation with RR. Macrotexture may be high without negative influence on RR, provided the profile is negative (high skewness). Porous pavements and thin asphalt pavements provide both low RR and high wet friction = serious trade-off, but not for all cases.

Hydroplaning may happen when there is plenty of water on the road. Rolling in water gives much higher RR than on dry pavement = no trade-off, positive correlation.

High interior noise occurs when there is high macro- and megatexture, and is reduced substantially if there is negative skewness in the texture profile = no trade-off, positive correlation.

High exterior noise occurs when there is very high and very low macrotexture and high megatexture, and is considerably reduced if there is high negative skewness in the texture profile. Very low macrotexture is good for RR, but not for noise; apart from that, noise and RR have positive relations. Most low noise pavements are also low RR pavements = no trade-off, except for very smooth pavement texture with no skew.

Poor comfort occurs when there is high roughness/unevenness, including potholes and poor joints between slabs. The same applies to RR = no trade-off, positive correlation.

Air pollution (CO_2 and NO_x) is directly proportional to fuel consumption. Low RR gives low fuel consumption = no trade-off: only very positive correlation.

3 Results of the MIRAVEC survey

WP4 prepared an on-line questionnaire to obtain an overview of existing pavement/asset management systems (PMS/AMS), in particular with regard to road vehicle energy consumption and CO_2 emissions and the opportunities for improving the current practices by introducing new parameters/models. This questionnaire is given in Appendix A.

The questions focused on identification of already existing elements and good practice in pavement/asset management systems connected to CO_2 emission and road vehicle energy consumption; and identification of possible risks and obstacles for the introduction of new parameters and models with the potential for contributing to energy savings and a decrease of CO_2 emissions.

The WP4 questionnaire is structured into four groups of questions:

- Questions of general nature related to CO_2 emissions, the consideration of fuel consumption in the planning phase of construction and maintenance of road infrastructure, and regional particularities that might influence energy consumption in different countries.
- Questions about existing pavement/asset management systems in use, current importance of some specific parameters and difficulties of introducing new parameters into the existing systems.
- A short part of the questionnaire is linked with possible socio-economic impacts due to lowering energy consumption.
- Questions regarding modelling vehicle energy consumption and/or CO_2 emissions, relative importance of parameters, and constraints in introducing new parameters into management systems. This was a core part of the questionnaire.
- Questions focused on the outputs of current management systems and on the steps needed in order to introduce vehicle energy consumption and/or CO_2 emissions in management systems.

3.1 Participating countries

There was a considerable and satisfying response to the WP4 request for collaboration in collecting information through the questionnaire. Answers were sent by 17 experts from 14 different countries, 13 of which were European, with one answer received from USA (California).

Replies were received from Nordic and Baltic countries (Denmark, Sweden and Latvia), western (UK – 3 replies, Ireland, the Netherlands, Germany – 2 replies, and France) and central Europe (Austria, Czech Republic, Slovakia, Hungary and Slovenia).

Figure 1 shows the participating countries, and it can be seen that there is a good regional distribution over Europe.

Figure 1 Countries that provided replies to the MIRAVEC questionnaire

3.2 General view on vehicle fuel consumption savings

In practically all the participating countries there seems to be a general agreement on the three important starting statements:

- Reducing transport CO_2 emissions is an important and urgent issue,
- Vehicle energy consumption is considered to be an important factor for an overall reduction of CO_2 emissions, and
- The improvement of road infrastructure is considered to be an important contributing factor for an overall reduction of CO_2 emissions in road transport.

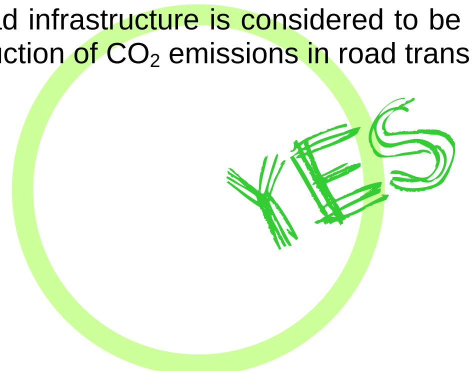

Figure 2 Is reducing transport CO_2 an important and urgent issue?

Such a strong support can only be beneficial for the implementation of new knowledge, models and tools into existing pavement or asset management systems.

But in how many of these participating countries do they actually already consider fuel consumption when planning construction and maintenance of infrastructure?

With 11 negative answers the prevailing situation suggests that still much will need to be done towards achieving national greenhouse gas emission goals. However, in some cases there is an interest to consider fuel consumption or research on eco-design by optimizing road profile vs. consumption and pavement surfaces is going on. It should also be noted that negative answers may have been provided due to the national deficit in budget of some countries restricting current consideration of this issue in prioritization process within PMS/AMS.

In 6 countries different methods/models are in use:

- In Swedish road planning there are many types of effect models used, including fuel consumption. For road maintenance the situation is a bit unclear,
- In the Netherlands CO_2 emissions for construction or maintenance are estimated in the contracting phase with the tool Dubocalc. In the planning phase, an estimate is made with the same tool of traffic CO_2 emissions for different construction alternatives,
- In the USA first the rolling resistance from pavement is calculated and then used to update the related parameters in the vehicle emission model, then the vehicle emission model is used to calculate the energy consumption and CO_2 emissions from vehicles,
- In Czech Republic HDM-4 is used in the planning phase for comparing different variants in combination with national software EXNAD, where 3 topics are considered: noise, air pollution and CO_2 emissions,
- Similarly in Slovakia HDM-4 is used for construction and maintenance as well in combination with national software C 920 for construction,
- In UK a traffic model of change due to an improvement scheme identifies speed, volume and route changes. The resultant change in fuel use is converted to CO_2 and reported in project appraisal and environmental impact assessment (however the calculation is a function of traffic models and does not consider pavement types).

Regional particularities or climatic constraints that influence vehicle energy consumption in specific countries might prevail on savings from infrastructure adaptation/modification through a considerable part of a year. These constraints mainly relate to winter time:

- Use of studded tyres in winter and snow cover that is present in Latvia for about 3 to 5 months each year,
- Winter period of about 4 months with a lot of freeze-thaw cycles which require quite intensive winter maintenance in Central Europe,
- Snow and water on the road surface, air temperature and air resistance wind in Sweden
- Severe snow or wind (storm) can influence traffic demand (often a weather alarm is given on such occasions),
- Heterogeneous topography and microclimate combined with relatively small network and medium traffic could prevail on savings through infrastructure adaptation,
- The rolling resistance from wide-base tires and its impact on the pavement-vehicle interaction hasn't been fully investigated but it may have influence on the fuel consumption and CO_2 emissions.

In general PMS/AMS do not contain information on road infrastructure that is relevant to the fuel consumption. An exception to this can be found in the UK where some information is available on lane classification and inventory (e.g. gradient), and especially in California (USA) where the new PMS from California Department of Transportation contains the AADT, truck percent, lane distribution factors, and emission factors to calculate the approximate energy consumption and CO_2 emissions.

3.3 Existing asset/pavement management systems

The large majority of participating countries have their PMS/AMS developed in-house (see Figure 3).

Figure 3 Is your PMS/AMS developed in-house?

Respondents foresee a number of difficulties in the introduction of new parameters and rule sets for vehicle fuel consumption into the existing system, starting from funding and coming to the technical perspective of such activities:

- It would have to be agreed and integrated correctly, historic data may not be available,
- Vehicle fuel consumption is a relatively new parameter, research is needed to determine the impact on network performances, the users and LCC costs,
- In the current system, the parameters are all inter-dependent to each other. Adding any new parameters, especially those related with pavement performance, can be difficult because of the dependence with other parameters,
- Requires funding which is difficult to approve,
- Sometimes it is hard to go round the existing rules/guidelines/regulation and implement new parameters.

MIRAVEC has prepared an inventory of potential infrastructure effects that contribute to vehicle energy consumption (WP1). These are related to 5 categories: Pavement surface characteristics, Road design and layout, Traffic properties and interaction with the traffic flow, Vehicle and tyre characteristics, and Meteorological effects.

Some of them were selected as the ones that NRAs have high influence on and are also suitable for modelling. These can be seen from the following Table 2.

Table 2 Groups of analysed effects and properties

Group	Name of effect or property
Pavement surface characteristics	Rolling resistance Texture Longitudinal unevenness Transverse unevenness Surface defects Road strength
Road design and layout	Vertical alignment Crossfall Horizontal alignment Road width and lane layout Intersections and roundabouts Tunnels
Traffic properties and interaction with the traffic flow	Traffic volume and composition Traffic flow Traffic speed and speed restriction measures Traffic lights, road signs, road markings and ITS measures Driver behaviour

The most assessed or considered properties within asset/pavement maintenance and operation systems are pavement surface texture and longitudinal evenness and traffic volume. These are followed by transverse evenness, surface defects, vertical alignment and road width (see Figure 4).

Of course, it was not expected that all of the listed properties would already be included in maintenance and operation systems, it was rather thought that there might be specific reasons for difficulties encountered when trying to introduce a new property/parameter in the existing system.

Some common agreement to include new parameter is always needed, at least in the road transport sector, since in general the acceptance of any new (modified) system is always hard.

Rolling resistance is not directly measured and there are only a few countries that routinely measure the parameters needed to calculate a proxy for it. And even with existing measuring equipment, to incorporate a parameter would require that it is measured accurately - availability and cost effectiveness of particular criteria (e.g. road strength) can turn out to be costly for an entire network.

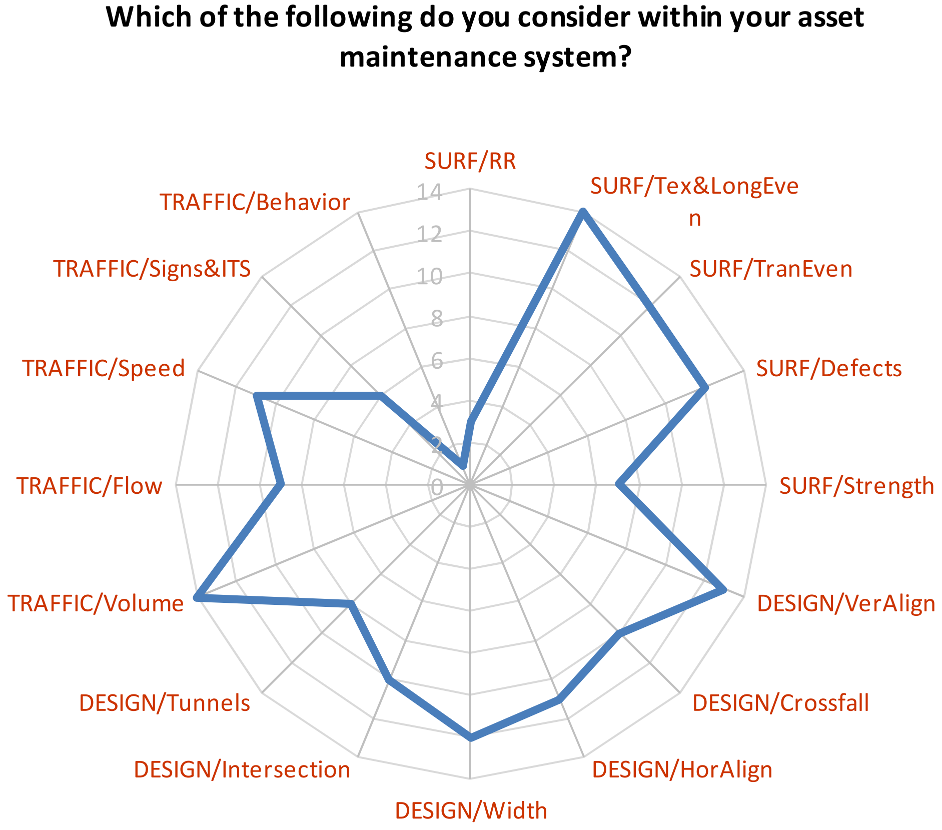

Figure 4 Properties that are considered within pavement management systems

Concerning parameters or properties that could be used as a relevant starting point for quantifying the pavement surface to obtain vehicle energy consumption/CO_2 emissions, the general agreement seems to be that:

- surface texture,
- evenness,
- (horizontal and vertical) alignment,
- rolling resistance,
- skid resistance, and
- chipping size

are those properties which can be used satisfactorily to asses energy consumption and CO_2 emissions.

Different countries might have quite different views on how important are pavement properties and according to these views also “the will” to introduce new parameters may differ significantly.

MIRAVEC (WP1) prepared an inventory of potential infrastructure effects that contribute to vehicle energy consumption, and respondents were asked which of these they asses or consider within asset/pavement maintenance and operation systems. Related to that question they were also asked which parameters (not just limited to those listed by WP1) do they consider to be the most relevant for the quantification of vehicle energy consumption/CO_2 emissions.

The additional parameters are:

- Deceleration and the level of deceleration,
- % of heavy traffic,
- Vehicle characteristics,
- Tyre characteristics,
- Tyre condition and inflation pressure, and
- Meteorological effects.

Although it is possible to model vehicle energy consumption/CO_2 emissions there are some constraints in including new models in pavement/asset management systems. To begin with, acceptance of new models should be assured within established protocols. Next, costs of accurate data acquisition and for developing models can become considerable. Data should be collected and made available in the same format across different countries. And, it is very important when introducing a new parameter in an existing system that the optimization of maintenance strategies does not get jeopardized. Therefore it is of utmost importance that the results and maintenance solutions are carefully checked before the system is brought into operation with the new parameters.

3.4 Socio-economic impacts

Vehicle energy consumption, compared to other influencing factors, is widely considered as having a major influence on CO_2 emissions in the road sector. Therefore, reducing vehicle energy consumption can considerably contribute to national goals of overall reduction of CO_2 emissions and GHG emissions in general.

Lowering of vehicle energy consumption can be, from the road sector perspective, achieved in many ways – by improved construction or maintenance to road infrastructure, by smart and more efficient driving (less stop and go, more fluent driving, the importance of correct tyre pressures etc.). This will, in the longer run, indirectly affect national economies as well: tax on fuel usually forms a significant part of the collected governmental taxes in a country. A reduction in energy use will result in lower fuel consumption and hence lower economic income to the state. On the other hand, it will also contribute to saving of natural resources which in turn is a permanent force to develop more economical vehicles.

There are several vehicle or pavement related parameters which are considered to influence changes of CO_2 emissions with time:

- Vehicles: an increase in production and use of electric vehicles will reduce the fossil fuel consumption; going from an old vehicle fleet with less efficient engines to modern vehicles with high efficient engines will reduce the fuel consumption and hence the CO_2 emission; the higher the truck percent is, the higher the energy consumption and CO_2 emissions are,
- Energy consumption per vehicle can be lowered by new technology (e.g. improved engines and tyres, in-vehicle systems), especially if imposed by stringent EU norms, and can cause a significant decrease in CO_2 emissions with time if the number of vehicles doesn't increase significantly,
- Increase in traffic can happen for different reasons: due to increase of traffic demand or because of political reasons - with new members joining EU, traffic will increase in some “older” members, which may counter any pavement measure implemented to lower CO_2 emissions,
- Decrease of emissions arising from vehicles will make emissions arising from pavement construction and maintenance proportionately more significant (currently these are relatively small),

- Road pavement: a consideration on road alignment will reduce fuel consumption, optimization of pavement texture including unevenness, pavement durability etc. will have an impact on rolling resistance and fuel consumption as well,
- Traffic management: good tracking of the whole vehicle fleet, ITS measures, free flowing road serve to this aim, too.

3.5 Models of energy consumption and CO_2 emissions

All respondents think that it is possible to model vehicle energy consumption/CO_2 emissions due to road traffic. This would make a new parameter to be included in pavement/asset management systems and consequently also to rethink the relative importance of several parameters. This is considered and assessed in many countries and in several ways.

- In Denmark a correlation between pavement surface unevenness and user costs is used. In the user cost model fuel consumption is incorporated. Texture and skid resistance are related to traffic safety, texture and unevenness but on the other hand could also be considered as parameters for rolling resistance,
- In Sweden, special attention is put on surface unevenness and texture (in terms of IRI and MPD) which influences rolling resistance. Rolling resistance is input to total driving resistance and total driving resistance will result into energy use of different types of energy carriers like fuel and diesel,
- In the USA, the rolling resistance from pavement is initially calculated based on the pavement unevenness and macrotexture (in terms of MPD), and then used to update the related parameters in the vehicle emission model. The vehicle emission model is then used to calculate the energy consumption and CO_2 emissions from vehicles,
- In the UK, pavement surface characteristics are considered in the modelling of different maintenance treatment options, and how the different options will lead to different treatment profiles in the future,
- In some other countries weights or multipliers are applied to each parameter.

3.6 Outputs of current systems

In the pavement optimization process, within a PMS/AMS, different solutions of construction or maintenance strategies are compared and optimized in relation to the annual financial resources provided for managing the road network.

What is relevant for pavement optimization slightly differs from country to country although focus is mostly on skid resistance, evenness, surface damage, noise, durability and costs. However, rolling resistance is becoming more and more important as are delays to road users. In the USA only the vehicle energy consumption is considered in the optimization right now. In this context the traffic level of the pavement section is optimized against the level of smoothness the pavement should be maintained to.

Vehicle energy consumption/CO_2 emissions due to road traffic are almost nowhere considered directly in pavement/asset management systems yet. In Denmark it is anticipated that this will be done within few years, whilst in Czech Republic it is considered only in the design phase when different alternatives are compared.

Only in the USA are the energy consumption and CO_2 emissions analyzed in the whole life cycle phases of pavement, including the design phase, material production, construction, and use phase of pavement.

Different parameters are monitored at different stages in different countries and some parameters are not monitored at all in some countries. Therefore respondents were asked if, in their respective countries three parameters, namely vehicle energy consumption, pavement surface skid resistance and noise emissions are monitored, and at which phase: design, construction and/or maintenance. The results are shown in the following Figure.

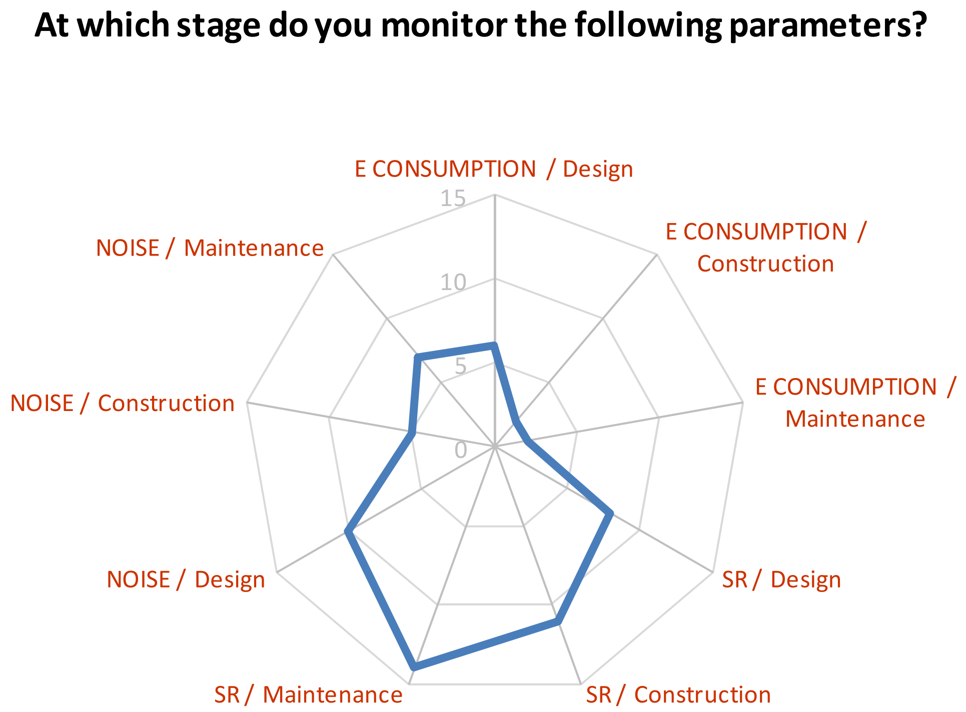

Figure 5 At which phase parameters are being monitored

Without doubt skid resistance is the most monitored parameter (at all three phases: design, construction and maintenance), followed by noise emissions (at the design phase, rarely at construction and maintenance). Vehicle energy consumption is considered practically only at the design phase.

Before implementing new parameter(s) into a management system it is very important to decide what should be the outcome of this management system in relation to the new parameter. In other words, which kind of output, in terms of vehicle energy consumption/CO_2 emissions, would be relevant for road network managers?

Respondents though that the most favourable way to present results would be as prognoses of evolution of CO_2 emission over time, based on different budget levels for the different maintenance treatments modelled. Apart from the smoothness level that a pavement should be maintained at to achieve the highest amount of CO_2 reduction, the total CO_2 reduction from the whole network would be of interest, too.

3.7 Balancing low energy consumption with other requirements

When introducing new parameter(s) into PMS/AMS one should be aware that this parameter can easily come in conflict with others. So, what are possible conflicts or side effects that might occur with the introduction of vehicle energy consumption/CO_2 emissions due to road traffic in connection with other pavement parameters in the optimization process? There can be several of them and the questionnaire respondents identified the following:

- Lower texture positively affects rolling resistance,
- A conflict with friction: a decrease in texture (e.g. MPD) can reduce the pavement surface friction and increase the risk of aquaplaning,
- Changes in texture affect noise emissions,
- A smooth surface can cause drivers to drive quicker.

A way to look at optimisation can be that going too far in one direction - reducing energy consumption - would unavoidably lead to unacceptable levels of traffic safety. From this point of view optimisation should be based on risk analysis. However, a careful optimisation of different parameters is needed.

In the end, another conflict which is of more "political" nature might also frequently occur. Firstly, to accept a new concept and then to define the parameter thresholds can be a great challenge.

In the questionnaire survey consideration was also given to how important vehicle energy consumption, pavement surface skid resistance and noise emissions (balancing of them) are to respondents.

In general, skid resistance is given the highest importance followed by noise emissions. Energy consumption comes third, sometimes being ranked at the same level as noise emissions.

Practical difference or variation to this general rule are seen in the answers from Sweden, Germany (here two different rankings were received which were simply averaged) and Hungary (see Figure 6). They rate energy consumption highest, followed by skidding resistance and noise emissions.

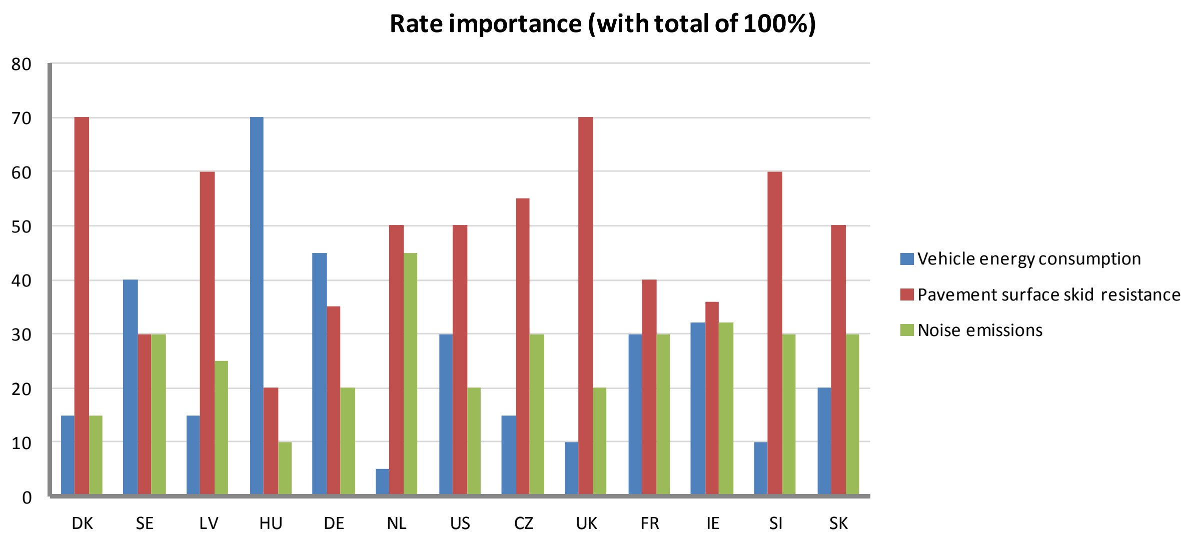

Figure 6 Relative importance of energy consumption, skid resistance and noise emissions

The view of respondents was not exactly the same and they used different arguments. It is possible to compare these opinions with view of experts from MIRIAM group (see Chapter 2.5.3).

Skid resistance

Skid resistance is a more important parameter of the pavement surface than RR and noise emissions and this parameter has the biggest trade-off with RR. Therefore the balance between these two parameters must be very well defined. Drainage surfaces and surfaces with negative skewness in the texture profile seem to have less problems here.

Noise emission

Importance of this parameter depends on the specific situation. In some locations there are not high requirements concerning it. Exterior noise is reduced very much if there is high negative skewness in the texture profile. Most low noise pavements are also low RR pavements. That means that there is no significant trade-off, except for very smooth pavement texture with no skew.

3.8 Steps to upgrade optimization process

The introduction of vehicle energy consumption/CO_2 emissions is considered economically feasible in practically all responding countries. In the few countries where this is not the case, energy and emissions are not considered yet mainly because of economic restraints. The low budget available is used for solving the highest priority issues only.

Having this in mind it is important to set an agenda for upgrading optimization process with the new parameter. So, what steps need to be considered in order to introduce vehicle energy consumption/CO_2 emissions in maintenance and operation optimization processes? From received answers the following steps would form a unified approach:

A. Prepare clear policy goals and rules; this would be the most important first step and it should include acceptance of who is responsible for any associated costs (e.g. road agency or society). Presumably it should be driven by central government.
B. Perform theoretical investigation; we need appropriate vehicle/pavement models, deterioration models and optimization models. E.g. research should be done on relation between CO_2 emissions and vehicle speed, CO_2 emission and rolling resistance, vehicle type and road alignment vs. energy consumption data.
C. Perform practical investigation; good experience in different EU countries is important, verify models, set adequate form for proper input data. Verification should include investigation of impact of upgrading optimization process.
D. Prepare implementation process; part of preparation efforts should be put on calculation strategy. E.g. a suggestion coming from the USA is to divide the network based on the traffic level (AADT and truck percent) on each segment in the network, then based on the traffic level on each pavement segment, and then to calculate the optimized unevenness level (in terms of IRI) at which the life cycle energy consumption saving/CO_2 emissions reduction can be maximized. This procedure includes the energy consumption/CO_2 emissions at material production, construction, and use phase.
E. Finally, start employment.

In most participating countries it is thought that authorisation would be required at the highest level to go ahead with implementation. Such authorisation would be provided by the Ministry (of Transport), central government/federal government or even by the European Parliament. In some countries approval by the national Road Administration governing body would be enough since it is expected that the first application would be on national roads network.

The prevailing opinion is that this authorisation would be achieved but with some hindrance in at least some countries. The outcome is not certain, and depends a lot on results of current research on this issue and on priorities given under current budget restrictions. Works costs are the main driver in the current economic climate and limited budget might not allow for including any additional costs at the moment.

4 Recommendations

For this WP an on-line questionnaire has been prepared to assess the current level of integration of vehicle energy consumption considerations into pavement/asset management systems across Europe. Questionnaire answers together with the information generated in previous MIRAVEC project WPs, with information found in literature and information obtained during consultations with experts from different countries, served as a basis to give recommendations for the implementation of models, tools and gathered knowledge into existing pavement/asset management systems.

4.1 On influencing parameters and investigating schemes

WP1 identified a number of effects and parameters, contributing and influencing the energy consumption of road vehicles, with a special focus on the effects of road infrastructure; these were retained by WP2 for analysis of the capabilities of existing modelling tools. The additional sensitivity analysis, carried out in the same WP, showed that there is a close to linear relationship between relative changes in the analysed road variables and the relative change in fuel use. This relationship makes it less complicated to estimate the effect of changes. The heavier the vehicle the larger relative changes are. Passenger cars, being the majority of vehicles travelling on the roads, will most likely be responsible for the largest change in fuel use, when changes are made to the road variables.

Parameters that are recommended by WP1 are also in line with results of WP4 survey:

- Group of parameters on which NRAs have high influence: texture, longitudinal and transversal unevenness, vertical alignment (gradient), horizontal alignment (curvature), crossfall, road width and lane layout,
- NRAs have less influence on these parameters: traffic volume and composition, traffic speed and speed restriction measures.

WP2 found that in general, among road variables rise and fall/gradient leads to the largest impact on fuel use, followed by MPD and average degree of curvature.

WP3 has developed a spreadsheet tool (the MIRAVEC tool) to aid NRAs in the assessment of fuel consumption and CO_2 emissions. This tool has been used to assess the potential benefits to be gained from making improvements to the infrastructure.

With multiple intervention options available to NRAs the effectiveness of each intervention depends on the condition and traffic levels of the site.

Recommendation is to investigate schemes on a case by case basis and to provide input data, particularly traffic flow, appropriate to the case being considered. The MIRAVEC spreadsheet tool can be used for such investigation and WP3 recommended that the following methodology should be used:

A. Populate route 1 with the current condition of the route, with either current or future traffic levels.
B. Populate route 2 with the condition of the proposed intervention, with the same traffic data used in route 1. Note, depending on the intervention this may be a longer or shorter route than route 1 (e.g. due to a bypass)
C. Examine the fuel consumption statistics in the output stats sheet. If the routes are of different lengths then the fuel consumption per km (shown on the route sheets) should also be investigated.
D. Consider the differences in fuel consumption found from step C in relation to other factors, e.g. journey time, road surface condition, cost of works, noise etc.
E. Repeat for any additional proposed interventions.

4.2 On considering CO_2 emissions and other effects

There is a general agreement that reducing transport CO_2 emissions is an important and urgent issue, and that the improvement of road infrastructure is considered to be an important contributing factor for an overall reduction of CO_2 emissions.

However, only a few countries actually already consider fuel consumption/CO_2 emissions when planning construction and maintenance of infrastructure, which suggests that still much will need to be done towards achieving national greenhouse gas emission goals.

The recommendation, which is based on results of the MIRAVEC survey, is to investigate schemes on a case by case basis, since there are a number of regional particularities or climatic constraints that influence vehicle energy consumption and these might prevail on savings from infrastructure adaptation/modification through a considerable part of a year. These constraints mainly relate to winter time (studded tyres, long winter period with many freeze-thaw cycles, snow water on the road surface etc.).

There are several other vehicle or pavement related parameters which are considered to influence changes of CO_2 emissions with time:

- An increase in production and use of electric vehicles will reduce the fossil fuel consumption (here we leave apart discussion on how electricity is produced),
- Energy consumption per vehicle can be lowered by new technology (e.g. improved engines and tyres, in-vehicle systems), especially if imposed by stringent EU norms,
- Decrease of emissions arising from vehicles will make emissions arising from pavement construction and maintenance proportionately more significant,
- Good tracking of the whole vehicle fleet, ITS measures, free flowing road will also reduce fuel consumption/CO_2 emissions.

4.3 On modelling and optimization with other parameters

In general, PMS/AMS do not contain information on road infrastructure that is directly relevant to the fuel consumption. The most assessed or considered properties within pavement maintenance and operation systems are pavement surface texture, longitudinal evenness and traffic volume. These are followed by transverse evenness, surface defects, vertical alignment and road width.

When analysing the influence of road variables on traffic fuel consumption, a microscopic model that simulates individual vehicles is the most appropriate one, since it has a possibility to use the input data in great detail.

There is currently no single model that takes all of the relevant aspects into consideration and is able to perform a complete analysis of the effect of fuel use and traffic emission due to road measures. Therefore, it is necessary to use several different models that describe different aspects such as traffic assignment including induced traffic, driving patterns, driving resistance and fuel consumption (WP2).

There are some models available where the interaction of the vehicle and road can be described in detail, such as VETO. It considers speed, vehicle type and emission concepts, sight class of rural roads with ADC and RF and urban roads. VETO model was used for traffic energy estimation in projects MIRIAM, IERD, and ECRPD.

For the first time, the MIRAVEC tool has brought together a number of different models and studies of fuel consumption, and it incorporates:

- The effect of road roughness on fuel consumption (measured using IRI),
- The effect of macro texture depth on fuel consumption (measured using MPD),
- The effect of road geometry on fuel consumption (measured using the degree ofcurvature and rise and fall/gradient),
- The effect of vehicle speed on fuel consumption,
- The effect of vehicle fleet composition on fuel consumption.

The final decision concerning the model used is on each administrator and depends on their experience, possibilities, tradition …

A number of difficulties are foreseen in the introduction of new parameters/models and rule sets for vehicle fuel consumption into the existing systems:

- It would have to be agreed and integrated correctly,
- Historic data may not be available,
- Research is needed to determine the impact of this relatively new parameter on network performances, the users and Life cycle costs,
- Research is also needed to determine inter-dependencies between vehicle fuel consumption and other parameters, included in PMS/AMS,
- Requires additional funding which is often difficult to approve,
- Sometimes it is simply hard to get around the existing rules/guidelines/regulations and implement new parameters.

When introducing new parameter(s) into PMS/AMS one should be aware that this parameter can easily come into conflict with other(s) and a careful optimisation of different parameters is needed. Several possible conflicts or side effects might occur with the introduction of vehicle energy consumption/CO_2 emissions in the optimization process:

- Lower texture positively affects rolling resistance,
- Decrease in texture (e.g. MPD) is expected to reduce the pavement surface friction and increase the risk of aquaplaning,
- Changes in texture affects noise emissions,
- Smooth surfaces can cause drivers to drive quicker.

4.4 On implementation

Before implementing new parameter(s) into a management system it is very important to decide what the outcome should be of this management system in relation to the new parameter. In other words, which kind of output in terms of vehicle energy consumption/CO_2 emissions would be relevant for road network managers?

According to the survey replies the most expected way to present results would be prognoses of evolution of CO_2 emission over time, based on different budget levels for the different maintenance treatments/measures modelled. Apart from the smoothness level that a pavement should be maintained at to achieve the highest amount of CO_2 reduction, the total CO_2 reduction from the whole network would be of interest, too.

Some constraints in including new models in pavement/asset management systems exist. To start, acceptance of new models should be assured within established protocols. Next, costs of accurate data acquisition and for developing models can become considerable. It is of utmost importance that the results and maintenance solutions are carefully checked before the system is brought into operation with the new parameters. At least these steps should be included in an agenda for upgrading optimisation process.

In order to introduce vehicle energy consumption/CO_2 emissions in maintenance and operation optimization processes the following steps are recommended:

A. Prepare clear policy goals and rules through e.g. road agency or central government.
B. Perform theoretical studies concerning appropriate vehicle/pavement models, deterioration models and optimization models. E.g. research should be done on relation between CO_2 emissions and vehicle speed, CO_2 emission and rolling resistance, vehicle type and road alignment vs. energy consumption data.
C. Perform and evaluate practical studies; good experience in different EU countries is important, verify models, set adequate form for proper input data.
D. Prepare implementation process.
E. Finally, start employment.

Authorisation at the highest level e.g. by Ministry (of Transport), central government/federal government or even by European Parliament will be most probably required to go ahead with implementation. In some countries approval by national Road Administration governing body would be enough since it is expected that the first application would be on national roads network.

The prevailing opinion is that this authorisation would be achieved but with some hindrance in at least some countries as well. The outcome is not certain, and depends a lot on results of current research on this issue and on priorities given under current budget restrictions.

Sources

[1] Haider, M and Conter, M: “Report on the road infrastructure effects contributing to road vehicle energy consumption and their governing parameters”. MIRAVEC Deliverable D1.1, July 2012.

[2] Carlson, A, Hammarström ,U and Eriksson, O: “Models and methods for the estimation of fuel consumption due to infrastructure parameters”. MIRAVEC Deliverable D2.1, April 2013.

[3] IERD “Integration of the Measurements of Energy Usage into Road design”, Final report, Contract No:4.1060/Z/02-091/2002. 2002

[4] ECRPD “Energy Conservation in Road Pavement Design, Maintenance and Utilisation, Final report, Grant Agreement EIE/06/039/SI2.448265, February 2010

[5] http://miriam-co2.net/index.htm

[6] Benbow, E, Brittain, S and Viner, H: “Potential for NRAs to provide energy reducing road infrastructure”. MIRAVEC Deliverable D3.1, August 2013.

[7] Mauko, A, Schmidt, B, Der-Stepanian, A and Kokot, D: “Constraints and requirements to implementation: Questionnaire report”. MIRIAM Subproject SP4, November 2011.

[8] Schmidt, B and Dyre, J.C.: “CO2 emission reduction by exploitation of RR modelling of pavements”. Procedia – Social and Behavioral Sciences 48 (2012), p. 311 – 320.

[9] Karlsson, R., Carlson, A., Dolk, E.: Energy use generated by traffic and pavement maintenance, Decision support for optimization of low rolling resistance maintenance treatments, VTI notat 36A–2012, Swedish National Road and Transport Research Institute, 2012.

[10] Wang T, Lee, I-S, Kendall, A, Harvey, J, Lee, E-B and Kim C: »Life cycle energy consumption and GHG emission from pavement rehabilitation with different rolling resistance”. Journal of Cleaner Production 33 (2012), p. 86 – 96.

[11] Project NCHRP 1-45: Models for Estimating the Effects of Pavement Condition on Vehicle Operating Costs, Michigan State University, 2006 – 2012. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=231

[12] Scharnigg, K, Schwalbe, G: Interdependencies of parameters influencing skid resistance, rolling resistance and noise emission, TYROSAFE Deliverable D14, March 2010.

[13] Sandberg, U: “Trade-offs Between Rolling Resistance and Other Pavement Properties.” Presented at the TRB 91st Annual Meeting, Transportation Research Board, January 22–26, 2012.

Appendix A. MIRAVEC Questionnaire

The following questionnaire has been prepared to obtain information to fulfil the WP4 objectives.

MIRAVEC - Modelling Infrastructure influence on RoAd Vehicle Energy Consumption

Questionnaire on implementation in pavement/asset management

Dear Madam or Sir!

CO_2 emissions from road transport represent an important part of the overall greenhouse gas emissions. The improvement of road infrastructure characteristics related to fuel consumption can contribute to an overall reduction of these emissions and consequently to mitigation of the ongoing climate change. National Road Administrations can take a deliberate decision towards improving the design and maintenance of the road infrastructure to affect CO_2 emissions. This decision requires both a thorough understanding of interactions and the implementation of results in current pavement and asset management practice.

This questionnaire is part of the MIRAVEC (Modelling Infrastructure influence on RoAd Vehicle Energy Consumption) project and is intended for the identification of possibilities and opportunities for implementation of vehicle energy consumption considerations into existing pavement/asset management systems. The resulting information will be used to facilitate decision making regarding new investments and maintenance of road infrastructure and will help to assemble information that is important to achieve national greenhouse gas emission goals for 2020.

For further information regarding the project please visit the web-site: http://www.fehrl.org/?m=321

We would kindly ask you to complete the form, and thus contribute significantly to a broader view on this topic in different countries.

Thank you very much for your cooperation. Your contribution is greatly appreciated.

Yours sincerely,

MIRAVEC group

Name:

Affiliation:

Your role in affiliation:

Country:

E-mail:

Type of affiliation:

(Answers to be chosen among:) State/Public authority/Academic/Private

(group) GENERAL INFORMATION ON THE TOPIC

About CO_2 emissions

1. Do you agree that reducing transport CO_2 is an important and urgent issue?

(Answers to be chosen among:) Yes/No

2. Do you consider vehicle energy consumption to be an important factor for an overall reduction of CO_2 emissions?

(Answers to be chosen among:) Yes/No

3. Do you consider the improvement of road infrastructure to be an important contributing factor for an overall reduction of CO_2 emissions in road transport?

(Answers to be chosen among:) Yes/No

4. Do you already consider fuel consumption when planning construction and maintenance of infrastructure?

(Answers to be chosen among:)

If so, how is it taken into account?

If not, do you have an interest in considering it in future?

Regional specificities, climate

5. Are you aware of any specificities or climatic constraints that would influence vehicle energy consumption in your country (e.g. studded tyres, mountainous region, snow over large part of year...)?

(Answers to be chosen among:) Yes/No

If yes, please specify which:

Road and traffic information

6. What are the road classes in your country (if possible, please name and specify them)?

7. How do you classify the traffic amount in your country (for example: according to equivalent single axle loading, annual average daily traffic, specific loading …)? Please specify.

8. Does your pavement management system contain information such as provision of truck lanes etc. that are relevant to the fuel consumption?

(group) IMPLEMENTATION WITHIN EXISTING ASSET MANAGEMENT SYSTEMS

9. Is your asset/pavement management system developed in-house?

(Answers to be chosen among:) Yes/No

10. Do you foresee any difficulties in the introduction of new parameters and rule sets for vehicle fuel consumption in the existing system?

(Answers to be chosen among:) Yes/No

If yes, please specify which:

11. MIRAVEC has prepared an inventory of potential infrastructure effects that contribute to vehicle energy consumption. These are related to 5 categories: Pavement surface characteristics, Road design and layout, Traffic properties and interaction with the traffic flow, Vehicle and tyre characteristics, and Meteorological effects. Some of them were selected as the ones that NRAs have high influence on and are also suitable for modelling. Which of the following do you asses/consider within your asset maintenance and operation system?

(Parameters will form a list from which to be checked, multiple options)

A. Pavement surface characteristics (Rolling resistance/Texture/Longitudinal unevenness/Transverse unevenness/Surface defects/Road strength)

B. Road design and layout (Vertical alignment/Cross fall/Horizontal alignment/Road width and lane layout/Intersections and roundabouts/Tunnels)

C. Traffic properties and interaction with the traffic flow (Traffic volume and composition/Traffic flow/Traffic speed and speed restriction measures/Traffic lights, road signs, road markings and ITS measures/Driver behaviour)

12. Do you foresee any difficulties in the introduction of the above listed parameters in the existing system (if not already included)?

(Answers to be chosen among:) Yes/No

If yes, please specify which:

13. How would you rate importance of the following parameters (with a total of 100%)

Vehicle energy consumption (%):

Pavement surface skid resistance (%):

Noise emissions (%):

14. What pavement performance data would you consider could be used as a relevant start for quantifying vehicle energy consumption/CO_2 emissions due to road traffic?

15. Which parameters do you consider to be the most relevant for the quantification of vehicle energy consumption/CO_2 emissions due to road traffic (apart the selected ones in question 11)?

Please specify which:

16. Do you foresee any conflicts or side effects that might occur with the introduction of vehicle energy consumption/CO_2 emissions due to road traffic in connection with other pavement parameters in the optimization process (e.g. excessive loss of skid resistance resulting from materials with low texture depth)?

(Answers to be chosen among:) Yes/No

If yes, please specify which:

(group) SOCIO-ECONOMIC IMPACTS AND ROLLING RESISTANCE

17. Do you consider vehicle energy consumption to have a major influence on CO_2 emissions in the road sector, if it is compared to other influencing factors?

(Answers to be chosen among:) Yes/No

If no, please name the other influencing parameters:

18. Do you have any information about other possible socio-economic impacts by lowering energy consumption?

(Answers to be chosen among:) Yes/No

If yes, please name some of these:

(group) MODELS OF ENERGY CONSUMPTION / CO_2 EMISSIONS

19. How might CO_2 emissions change with time, and what vehicle or pavement related parameters would you consider could influence such changes?

20. Do you think is it possible to model vehicle energy consumption/CO_2 emissions due to road traffic?

(Answers to be chosen among:) Yes/No

21. Do you consider and assess the relative importance of parameters (see question 10) in your management system?

(Answers to be chosen among:) Yes/No/If yes, please specify how:

22. How does the vehicle energy consumption/CO_2 emissions change with changing vehicle fleets?

23. Which constraints do you see in including models for vehicle energy consumption/CO_2 emissions due to road traffic in your management system?

(group) OUTPUTS OF CURRENT SYSTEMS

24. What results are relevant for your pavement optimization at the moment?

25. At which stage do you monitor the following parameters.

Vehicle energy consumption: *(Select)* Design/Construction/Maintenance

Pavement surface skid resistance: *(Select)* Design/Construction/Maintenance

Noise emissions: *(Select)* Design/Construction/Maintenance

26. Do you consider vehicle energy consumption/CO_2 emissions due to road traffic directly in your management system and at which stage?

(Answers to be chosen among:) Yes/No

If yes, please specify how:

(Select) Design/Construction/Maintenance

27. Which kind of output in terms of vehicle energy consumption/CO_2 emissions would be relevant for your affiliation (e.g. the evolution of CO_2 emissions over time, based on different budget levels?,...)

28. What steps need to be considered in order to introduce vehicle energy consumption/CO_2 emissions in your maintenance and operation optimization processes?

29. What level of authorisation would be required to go ahead with implementation?

30. Is it likely that this authorisation would be achieved and, if not, what are the main reasons?

(Answers to be chosen among:) Yes/No

If no, please specify why:

31. Do you consider the introduction of vehicle energy consumption/CO_2 emissions economically feasible?

(Answers to be chosen among:) Yes/No

32. Would you like to comment on anything else?