MIRAVEC

Final Report: MIRAVEC - Modelling Infrastructure Influence on RoAd Vehicle Energy Consumption

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Modelling Infrastructure Influence on RoAd Vehicle Energy Consumption

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Deliverable 5.3: Final Report: MIRAVEC - Modelling Infrastructure Influence on RoAd Vehicle Energy Consumption

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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 these interactions and the implementation of results in current pavement and asset management practice.

The objective of MIRAVEC was to build on existing knowledge and models in order to achieve a more holistic view considering a broad variety of effects. The project results are compiled in this final report of MIRAVEC project.

The first part of this final report is a short summary on the findings and outputs of all Work Packages (WP), while the second part is a summary of all recommendations to National Road Administrations (NRAs) on how to implement the findings, models and tools in pavement and asset management systems.

The main findings and recommendations of the project can be summarised as follows:

- Five major groups of parameters influencing road vehicle energy and fuel consumption were identified, of which a subset was selected based on impact, potential for influence by National Roads Administrations and integration into existing fuel consumption models. Further analysis showed that while currently monitored parameters can be used for modelling several effects of the infrastructure influence, knowledge gaps remain with respect to other parameters and the correct modelling of associated effects.

- There is no current model which takes all infrastructure-related effects into account. Most models for fuel consumption and CO_2 emission of road vehicles focus on vehicle and traffic flow characteristics and tend to neglect details of the infrastructure. The Swedish VETO model is one of the most advanced models in this respect and was the basis of many analyses. As the knowledge about the infrastructure influence increases, these models offer the possibility to integrate this knowledge into decision making.

- The spreadsheet tool developed in WP3 allows the comparison of the effects of different infrastructure-related measures on fuel consumption and CO_2 emission. It requires data about the most widely available pavement and road layout parameters and uses information about traffic flow and vehicles as background information. While the tool can be applied even with limited data, the strong influence of these background data found in the analysis may supersede the infrastructure effects in some cases.

- The investigation of the current situation with regard to the occurrence of this topic in pavement and asset management found a growing awareness of its importance with road managers, but so far very limited implementation in the actual systems. While future models based on the more commonly monitored infrastructure parameters will make the integration of vehicle CO_2 emission feasible, acceptance and weight in decision making in the view of limited financial resources for maintenance still remain to be achieved.

Table of contents

List of Tables

List of Figures

Abbreviations

Abbreviation	Meaning
AADT	Annual Average Daily Traffic
ADC	Average Degree of Curvature
AMS	Asset management system
CEN	European Committee for Standardization
CEREAL	"CO_2 Emission REduction in roAd Lifecycles", ENR Energy project
ECRPD	"Energy Conservation in Road Pavement Design, Maintenance and Utilisation", EU Project
ENR	ERANET ROAD
EU	European Union
EURO 1 - 6	Standardized European system of vehicle emission classes
EVA	Swedish road planning tool with traffic model
HBEFA	Handbook Emission Factors for Road Transport (and associated software model)
IERD	"Integration of the Measurements of Energy Usage into Road design", Final report", project title
IRI	International Roughness Index (see CEN 13036 – 5), measure for longitudinal unevenness
ISO	International Organization for Standardization
LICCER	"Life Cycle Considerations in Environmental Impact Assessment of Road Infrastructure", ENR Energy project
MIRIAM	"Models for rolling resistance In Road Infrastructure Asset Management Systems", project title
MOVES	Motor Vehicle Emission Simulator (Emission model of the United States Environmental Protection Agency)
MPD	Mean Profile Depth (see ISO 13473-1), measure for texture depth
NRA	National Roads Administration
PMS	Pavement management system
RF	Rise and Fall (measure for the occurrence of gradients)
RR	Rolling resistance
SUNRA	"Sustainability - National Road Administrations", ENR Energy project
VETO	Swedish model for road vehicle fuel and energy consumption
VTI	Swedish National Road and Transport Research Institute (Statens väg- och transportforskningsinstitut)
WP	Work Package

1 Introduction

"ERA-NET ROAD – Coordination and Implementation of Road Research in Europe" was 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.eranetroad.org). The subject "Energy - Sustainability and Energy Efficient Management of Roads" was part of the 4th call of the joint research programme in 2011. The funding national road administrations (NRA) in the Energy topic were those of Germany, Denmark, Ireland, Norway, Sweden and United Kingdom. The MIRAVEC project was part of the ENR Energy programme together with its sister projects SUNRA (Sustainability - National Road Administrations), CEREAL (CO_2 Emission REduction in roAd Lifecycles), and LICCER (Life Cycle Considerations in EIA of Road Infrastructure).

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.

The objective of MIRAVEC was to build on existing knowledge and models to achieve a holistic view considering a broad variety of effects beyond only traffic flow characteristics or tyre-pavement interaction (e.g. the interaction between road design and traffic flow). MIRAVEC has investigated the capabilities of available models and tools and evaluated the relative importance of different road infrastructure characteristics in 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.

2 Summary of MIRAVEC work packages and literature review

MIRAVEC was performed in four scientific work packages (WP) and one work package dealing with dissemination and project management, as can be seen in Figure 1. In WP1 the most important effects contributing to road vehicle energy consumption, which are governed by interaction with the infrastructure and their associated parameters, were identified. From these parameters a subset which can be influenced by NRA decisions and which is part of the available models was selected. This WP gave input to WP2, WP3 and WP4.

WP2 evaluated the available modelling tools for the effects defined in WP1. This included the currently available tools and their capabilities, the potential for further developments to improve their performance and scope, the possibilities for integration of different tools and the remaining gaps. WP2 provided its results to WP3 and WP4.

WP3 considered and assessed the relative importance of the effects defined in WP1 in different contexts and settings and evaluated the potential savings in vehicle energy use that could be achieved by NRAs by making changes to the road infrastructure. WP3 also considered the effects of changing vehicle fleets, including greater uptake of electric vehicles on the estimated savings. It delivered its findings to WP4.

WP4 was built upon the output of Work Packages 1-3. Its first task was to investigate the current role of road vehicle energy consumption in road pavement and asset management systems. Based on this specific recommendations how to implement the available knowledge and/or models were done. This will support energy efficiency considerations in the decision making processes of NRAs while also maintaining high levels of safety and low noise emissions.

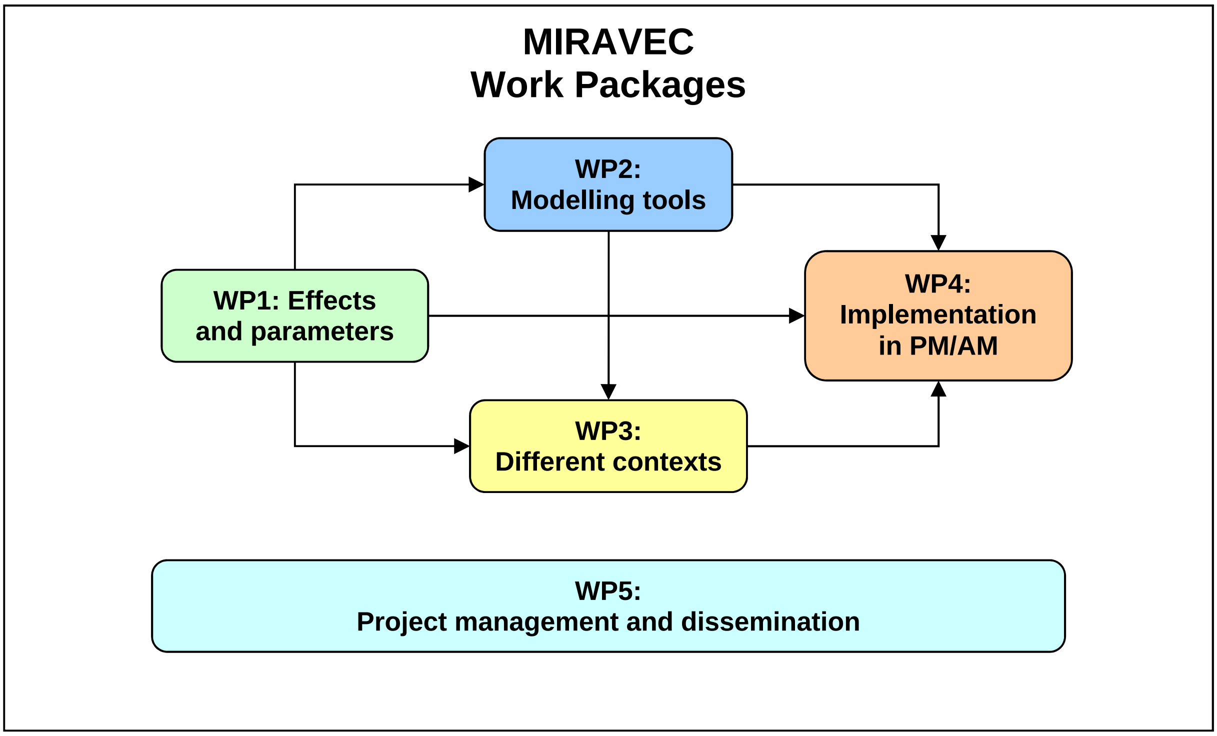

Figure 1: MIRAVEC Work Packages and their interactions

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 served as a basis for the detailed work plans of Work Packages 2 and 3.

2.1.1 Task 1.1: Infrastructure effects contributing to vehicle energy consumption

This task aimed at evaluating the different contributions to the overall road vehicle energy consumption with a view to extracting those which can be influenced by infrastructure design. Special attention was given to the following groups of effects:

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

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

C. Traffic properties and interaction with the traffic flow (tolerance of congestion, speed limits, access restrictions)

D. Potential effects of current trends in vehicle and tyre development (as far as interaction with the infrastructure is concerned)

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

Interactions and synergies between different effects that can occur were described as well. NRAs typically have a larger influence on the effects contributing to road vehicle energy consumption identified within groups A to C, and these were included in some questions of the WP4 questionnaire.

2.1.2 Task 1.2: Parameters describing road infrastructure effects

Using the results of task 1.1 the governing parameters for each of the described effects have been determined to enable quantitative evaluations. The existing knowledge on those parameters was evaluated along with the available measurement methods. The proposed parameters need to be relevant for the effects to be described, which may in some cases entail a choice between different parameter sets.

2.1.3 Task 1.3: Compilation of a comprehensive overview

The results of Tasks 1.1 and 1.2 were used to compile a report on the effects and parameters that need to be considered in order to determine the influence of road infrastructure on road vehicle energy consumption. This report includes an investigation of the phenomena, a list of requirements for the models of WP2 as well as a description of knowledge gaps.

2.1.4 Conclusions of WP1

The key recommendations for further analysis in WP2 of this project can be summarized as followed:

- The review of existing models in WP2 should investigate for all effects and parameters analysed in WP1 which subset of these parameters was already included in models and in which way they are integrated into the models.
- The proposals for the addition of new parameters currently not included in the models was then based on the parameters from WP1, taking the quality of the available quantitative description and data availability into account.

- Quantitative analysis may not be possible or not sufficiently accurate at this time. However, even a rough description (e.g. by introducing classes) helps to take new effects into account.
- WP1 focused on providing a complete view of all possible influencing factors. However the analysis in WP2 showed that some of them either had a low impact, were not sufficiently well quantitatively described in models, or that the influence of NRAs on these factors was rather low. Such effects were omitted from the further stages of the analysis. This could already be indicated in WP1 for some effects where pertinent information was available.
- Consequently, for the evaluation of uncertainties in the predictions of existing models, it was proposed to use the subset of effects and parameters shown in table 1.

Table 1: Proposed subset of effects and parameters for uncertainty modelling in WP2

No.	Name of effect or property	Group	NRA influence level (H,M,L)[1]	Parameters
2	Texture	A	H	MPD, texture spectrum
3	Longitudinal unevenness	A	H	IRI
4	Transversal unevenness	A	H	Rut depth
7	Vertical alignment (Gradient)	B	H	Angle β or %, RF
8	Crossfall	B	H	Angle γ
9	Horizontal alignment	B	H	$R_{Curv,}$ ADC
10	Road width and lane layout	B	H	w_{Road}
13	Traffic volume and composition	C	L	AADT, %
15	Traffic speed and speed restriction measures	C	M	$v_{average}$, v_{85}

Air temperature was not part of the originally proposed subset for WP2 due to the low potential influence of NRAs, but was included as a necessary background parameter in WP2 and in the final model used in WP3.

[1] H=high, M=medium, L=low

2.2 Work Package 2

This work package focused on describing and evaluating models used in research linking traffic energy use and road infrastructure. WP2 was divided into 4 tasks, which are described below.

2.2.1 Task 2.1: Description of models used in other projects

A selection of projects that have evaluated the link between road characteristics and energy use were analysed in this task. These were IERD [5], ECRPD [6] and MIRIAM [7]. IERD primarily evaluated the road alignment and the effect on energy use of different alignment options. The results could be used to include the energy aspect when building a new road. ECRPD complemented IERD in the sense that the operation and maintenance stage of a road life cycle was included in the evaluation. This made it possible to also consider the rehabilitation stages. In MIRIAM, the main focus was on the importance of rolling resistance and how the effect of improvement of road surface characteristics (IRI and MPD) would influence traffic energy, both on a large network and on a specific road section. In all three projects the Swedish VETO model was used to analyse the impact of all these parameters on energy consumption. The evaluation of these models showed that there are possibilities to achieve energy savings in traffic fuel use by taking this into consideration when planning construction of a road or a rehabilitation measure of pavements.

2.2.2 Task 2.2: Evaluation of these projects in order to identify deficiencies and strengths

Based on the evaluation of the different projects it was possible to examine which parameters from WP1 were included and treated in their models. These models were identified and qualitatively analysed. However, a significant number of effects identified in WP1 are currently not adequately described via quantitative models.

2.2.3 Task 2.3: Evaluation of the most important factors identified in WP1

Based on the assessment work and model inventory and depending on the available information, the influencing parameters were evaluated in a sensitivity analysis. In general, changes in the gradient lead to the largest impact, followed by macro texture and horizontal curvature.

2.2.4 Task 2.4: Methods for estimation of uncertainties in model estimations

One of the most important tasks in model applications was to quantify the uncertainty in estimated values. Such uncertainty estimation was performed for the VETO model. The results show a close to linear relationship between relative changes in the analysed road variables and the relative change in fuel use, which means that uncertainties in the output are linearly linked to the input parameters.

2.2.5 Conclusions of WP2

The review carried out in WP2 [2] found that there are numerous traffic models that can be used to simulate traffic at different levels of aggregation. It was found that a microscopic model that simulates individual vehicles was the most appropriate one for analysing the influence of road infrastructure variables on traffic fuel consumption, since this allows the description of detailed input data which can also describe the infrastructure effects omitted in more general models. However, most microscopic traffic simulation models strongly simplify infrastructure effects and focus on the vehicles, the overall traffic flow, the effects of road traffic management systems, and some specific traffic problems such as the traffic flow at junctions. Therefore only a small number of models are available which can describe the influence of road infrastructure in detail.

A selection of projects that have evaluated road characteristics and their effect on energy use were analysed, including MIRIAM, IERD, and ECRPD. In all of these three projects, the basic model used for traffic energy estimation is VETO, while in the MIRIAM project a model based on tyre dynamics modelling and the MOVES [8] model were also used. Within sub-project 2 of MIRIAM, VTI derived a rolling resistance function based on IRI, MPD and speed and integrated this into a larger simulation model based on VETO to estimate fuel consumption [9].

The VETO model with the extension developed in MIRIAM took rolling resistance, air resistance, average degree of curvature (ADC), gradient and vehicle velocity into account. The effects of texture and longitudinal evenness were accounted for in the rolling resistance partial model. The VETO model was then used to calibrate the model for cars, heavy trucks and for heavy trucks with a trailer.

It was felt that, of all the models considered, this extended model was most appropriate to use within WP3, as it accounts for the subset of road characteristics suggested by WP1 for quantitative modelling, except for rutting. The omission of this factor can be justified, since the effect of rutting on fuel consumption is unclear: It is likely that any effect is due to the longitudinal roughness found in the bottom of the ruts, rather than the rutting itself, which is already contained in the rolling resistance model. Also, whilst crossfall is not a variable within the model, it has been included in the VETO calibration. Crossfall is generally set when the road is constructed and it is not something that NRAs would necessarily want to change, due to the safety implications of reducing crossfall i.e. potential adverse impacts on surface water drainage and super-elevation on bends.

The EVA traffic model [9] was also reviewed in WP2 and used for WP3. This model is used by the Swedish transport administration for road planning to calculate effects and socio-economic costs and benefits of individual objects or traffic systems within the road transport system. Calculations of fuel consumption for different vehicle categories, road width and speed limits, based on estimates generated by VETO are implemented within EVA. The vehicle categories included are passenger cars (diesel and petrol), trucks, trucks with trailer, urban buses and coaches.

All vehicles sold in EU member states are subject to European emission standards, which define the acceptable limits for exhaust emissions[2]. Thus the vehicle types are further split into emission classes, which are either different year model classes (for pre-EURO classification vehicles) or EURO classes. These are listed in Table 2.

[2] http://en.wikipedia.org/wiki/European_emission_standards

Table 2: Vehicle types and emission classes used in EVA

Vehicle type	Emission classification*					
	A	B	C	D	E	F
Car, petrol	*–1987*	*1988–1995 A12*	*1996-2000 (94/12EG)*	2001-2005 (98/69/EG)	2005 98/69/EG+ACEA	2008 98/69/EG+ACEA
Car, diesel	*–1988*	*1989–1995*	1996–2000	2001–2005		
Truck	*–1992*	*1993–1995 A30*	1997 A31	Euro III	Euro IV	Euro V
Truck + trailer	*–1992*	*1993–1995 A30*	1997 A31	Euro III	Euro IV	Euro V
Urban bus	*–1992*	*1993–1995 A30*	1997 A31	Euro III	Euro IV	Euro V
Coach	*–1992*	*1993–1995 A30*	1997 A31	Euro III	Euro IV	Euro V

*At present only classes with italic letters have separate models in EVA. Other classes are estimated based on average fuel factors in each class.

To facilitate taking newer EURO classes into consideration, correction factors have been estimated for vehicle categories described in Table 2. These figures use EURO3 as reference and EURO1-2 and EURO4-6 have been related to that emission class. The estimations are based on the information in HBEFA 3.1 of the Swedish vehicle fleet in 2010 and the result is presented in Table 3. There was no information about emissions for EURO 6 in 2010 for petrol and diesel passenger cars, so information from the prognosis in 2014 is used for this emission class instead.

Table 3: Correction factors for different emission classes

	Passenger car (petrol)	**Passenger car (diesel)**	**Trucks**	**Trucks+ trailer**	**Urban bus**	**Coach**
EURO-1	1.06	0.94	0.96	1.01	0.93	1.00
EURO-2	1.02	0.92	0.98	1.00	0.96	0.99
EURO-3	1.00	1.00	1.00	1.00	1.00	1.00
EURO-4	0.93	0.86	1.03	0.96	0.84	0.86
EURO-5	0.73	0.73	1.06	0.95	0.93	0.95
EURO-6	0.70	0.68	1.06	0.94	0.92	0.99

Comparisons between emission factors currently used in emission standards and emission models and real-life emission measurements have in some cases shown differences which need to be accounted for by using correction factors when newer or more accurate data become available (see [10]). The MIRAVEC tool developed in WP3 provides the user with the option to enter updated and user-defined emission factors.

2.3 Work Package 3

The objective of this WP was to assess the potential for NRAs to achieve reductions in vehicle energy use, and to understand how this is influenced by the traffic flow, vehicle characteristics and infrastructure design. It considered the types of intervention that NRAs can perform on their network, for example reducing gradient, improving traffic flow or improving evenness. This information will provide NRAs with an awareness of where the greatest potential energy savings are to be found and a methodology that can be used on their network to evaluate the potential energy savings for different options.

2.3.1 Task 3.1: Development of a methodology for estimating vehicle energy use

A spreadsheet tool was developed, incorporating the most important relationships from WP1 and WP2 to describe the influence of traffic, vehicle characteristics and infrastructure design on vehicle energy use. The spreadsheet enables vehicle energy use to be estimated for different situations, given appropriate input data, and displays the uncertainty associated with these estimates. Among other parameters, the input to the spreadsheet includes the following parameters:

- 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.

2.3.2 Task 3.2: Assess capacity for NRAs to provide energy reducing road infrastructure

The spreadsheet can be used to assess the capacity for NRAs to provide energy reducing road infrastructure, e.g. by improving or optimizing vertical alignment, horizontal alignment, number and width of lanes, junction layout, or pavement characteristics and condition. Since the benefits depend on the traffic and vehicle characteristics as well as the road infrastructure, all statistical data available for the national road networks for each of the partner organisations were taken to make the input data realistic. The combinations that lead to particularly high energy use were identified and the potential benefits from making improvements to the infrastructure were evaluated. This considered both isolated interventions to specific parts of the network and also the introduction of network-wide improvements in standards. A methodology was developed to compare the effectiveness of different interventions on a common basis, for example considering the length, lifetime and cost of the intervention. Finally, these results were analysed to draw general conclusions about the effectiveness of different types of intervention in different locations in terms of reducing vehicle energy consumption. This also considered whether future trends such as a higher proportion of electric vehicles and low-energy tyres will affect the overall level of benefit that could be obtained by making changes to the road infrastructure.

2.3.3 Conclusions of WP3

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. The reduction of texture depth measured as MPD across the network helps to reduce fuel consumption by lowering the rolling resistance. However, reducing texture depth is only possible in those parts of the network where the current texture depth is above the minimum required for safety. The possible improvements concerning longitudinal unevenness (e.g. measured as IRI) are also strongly dependent on the pre-existing pavement condition. Another example 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.

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, a 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 [5] 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 considering 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 by NRAs.

The MIRAVEC spreadsheet tool can be used for such investigations 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 both the fuel consumption per km and for the whole stretch of the route (shown on the route sheets) should 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 Work Package 4

The main objective of Work Package 4 (WP4) was 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 performed several 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 could be assessed. Different levels of implementation of existing energy and CO_2 emission considerations or models were asked 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 integration of new parameters.

Additional activities to gather relevant information included 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.

2.4.1 Task 4.1 Identification of the current role of road vehicle energy consumption and CO_2 emissions in existing systems and of opportunities for improvement

In this task the work comprised 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 [5].

2.4.2 Task 4.2 Potential implications of optimizing for low energy consumption for other objectives

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.

2.4.3 Task 4.3 Preparation of recommendations on implementation

Recommendations for the implementation of new models and elements in pavement and asset management systems were 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.

2.4.4 Conclusions of WP4

The on-line questionnaire was answered by 14 countries in Europe and showed that reducing CO_2 emissions from transports was considered important and urgent. Road infrastructure influence of vehicle energy consumption is seen as an important contributing factor to an overall reduction of CO_2 emissions. While the use of PMS/AMS systems is widespread, the number and type of parameters considered in these systems varies. However, only a small number contain environment-related methods/models and parameters with an influence on decision making. While monitoring energy use within the existing pavement/asset management (PMS/AMS) is not common today, several parameters are routinely monitored which could be used as input for energy consumption modelling in the future.

According to the responses such new models would be used for prognosis of the effects of the different maintenance treatments/measures and the development of CO_2 emission over time, based on different budget levels. Despite the awareness for the importance of monitoring or modelling energy use of traffic, the introduction of additional parameters and models will likely meet some difficulties connected with acceptance, funds, availability of input data and the need to further develop measuring and modelling methods.

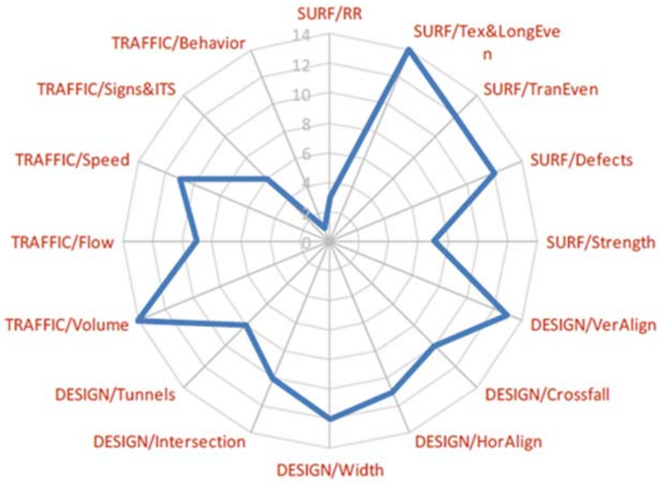

Figure 2: Properties currently considered within pavement management systems

The following steps are recommended for implementing vehicle energy use and CO2 emissions in PMS/AMS:

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 usage of vehicle energy consumption/CO_2 emissions as performance indicator.

3 Recommendations

In this section all main recommendations for National Road Authorities (NRA) are summed up and presented. They are compiled and summed up thematically, starting with the input parameter, where the finding and other considerations are discussed. The next topic is the MIRAVEC model itself and its implementation. Finally the output of the spreadsheet tool and its results are presented.

3.1 Input parameters for the MIRAVEC tool

In deliverable D1.1 [5] an analysis of the contributing effects and influencing factors for energy consumption of road vehicles was performed. Special emphasis was put on the effects of road infrastructure. All these possible effects were put into five categories. The five chosen groups of effects and properties showed clear differences in the level of possible NRA influence. Groups A (pavement surface characteristics) and B (road design and layout) comprised effects where there is a clear impact of infrastructure and which are governed by parameters typically under the control of NRAs. Group A contains effects which could be monitored and influenced by pavement-related measures during the working life of the road. The effects in Group B should be considered in the planning and construction stages of the road, ideally with a tool like the one to be developed by the sister project LICCER. Groups C (traffic flow properties), D (vehicle and tyre properties) and E (meteorological effects) in general contain effects with lower chances or more indirect ways for NRA influence.

The parameters used for describing the different effects in modelling are listed up in table. They show a variety in terms of their descriptive value and data availability:

- Some parameters like MPD, IRI, RF, ADC, or v_{Wind} can already be used directly in models. Some of these may in the future be superseded by more advanced parameters which are more suitable for the development of models, like e.g. the enveloped MPD for texture or the weighted longitudinal profile for unevenness.
- Other parameters, notably the ones describing traffic flow and driver behaviour need to be classified into e.g. typical driving cycles as they are too complex to be described by single numbers.
- The parameters connected with the details of vehicle and tyre type are very numerous. For an analysis focused on road infrastructure effects, they need to be combined into very simplified composite parameters. This is effectively equivalent to choosing an average vehicle and average tyres for each vehicle category to be able to focus on the infrastructure-related effects.
- There are parameters whose effects are difficult to isolate. The prime examples are vehicle speed which is influenced by many other phenomena, and temperature, which can substantially modify other effects.
- The data availability for pavement and road properties which are part of regular monitoring by NRAs is already quite high. This is the case for longitudinal and transversal unevenness, texture, road strength, surface defects, data for traffic volume and composition, and meteorological data. Road design parameters from group B like gradients or crossfall are available to NRAs from the planning and construction phases. Data on the specifics of vehicle and tyre type as well as details of driver behaviour are more difficult to obtain.

Among the variety of possible parameters a selection was made to reduce the complexity of the model. However this reduction also creates a simplification, which makes it necessary to discuss the short-comings:

- Modelling of the pavement contribution to rolling resistance is mainly based on texture and unevenness. It is currently unclear if the contribution of surface defects is sufficiently captured by these other parameters. There is an on-going discussion about the magnitude of the effect of road strength and the advantages of choosing rigid over flexible pavements for fuel consumption.
- The effects of gradients, crossfall and curvature can be described in technical terms as forces acting on the vehicle. The effects of road width and layout, intersections, roundabouts and tunnels are more indirect and act on the driving speed and driving behaviour in general. These effects are small and more difficult to quantify.
- The effect of ITS measures on the traffic flow and vehicle energy consumption needs to be determined individually for each measure. While this analysis has been performed for several measures, this and the classification of driver behaviour are on-going research topics.
- The developments in vehicle and tyre technology will have a major impact on vehicle fuel consumption. The response of the market to the new fuel efficiency requirements for tyres still remains an open question. For vehicles the future degree of market penetration of electric vehicles cannot be predicted accurately.
- There are still considerable knowledge gaps about the quantitative effects of the presence of precipitation like water, snow and ice on the pavement on fuel consumption.

3.2 Known limitations of the MIRAVEC-Spreadsheet

The tool estimates the average vehicle speed from the road geometry, 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. Although generically referred to as “fuel consumption”, the results are reported as CO_2 emissions to avoid a distinction between petrol and diesel fuelled vehicles, which was judged to be of little relevance to NRAs.

The tool is implemented in Microsoft Excel and provides a straightforward and flexible way for NRAs to estimate the overall fuel consumption for parts of their road network and to explore the effect of a wide range of scenarios, including changes to the traffic flow and type, changes of road layout or alignment, speed limits and pavement condition.

It should be noted that the effect of junctions, roundabouts and other features on traffic flow are not included because there are currently no models that are sufficiently general to have been incorporated within the MIRAVEC spreadsheet. In addition the model does not calculate fuel consumption for dynamic changes in vehicle speeds due to traffic flow under stop-start conditions. These aspects should be considered along with improvements to the calculation of idle time for future developments of the tool to improve its accuracy.

A number of case studies have been carried out to illustrate the use of the tool and it was found that significant differences in fuel consumption can occur between NRAs due to differences in the traffic distribution supplied to the tool. It is therefore important that the input values are as accurate as possible, particularly if comparisons between NRAs are being carried out.

Users of the tool should note that it is important to consider the overall fuel consumption in addition to the fuel consumption per km and the fuel consumption per vehicle per km, because, for example, a longer but more fuel efficient route could result in either an increase or decrease in total fuel consumption, depending on whether the fuel used to traverse the additional length outweighs the improved efficiency. Also, increases in traffic volumes can paradoxically result in reduced fuel consumption in situations where this is accompanied by a reduction in vehicle speed.

3.3 Sensitivity to parameter changes

The sensitivity analysis, carried out in WP 2, 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.

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

It is recommended to investigate schemes on a case by case basis and to provide input data, particularly traffic flow, appropriate to the case being considered.

3.3.1 Effects on CO_2 emissions not related to infrastructure

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 effort is necessary to achieve 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 exist 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 (depending 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 and free flowing road traffic will also reduce fuel consumption/CO_2 emissions.

3.3.2 Modelling and optimization

In general, PMS/AMS do not contain information on road infrastructure that is directly relevant to the fuel consumption. The most commonly 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.

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 interdependencies between vehicle fuel consumption and other parameters included in PMS/AMS,
- Requires additional funding,
- Reluctance to introduce new parameters in existing rules/guidelines/regulations.

When introducing a new parameter into PMS/AMS one should be aware that this parameter can easily come into conflict with others 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.

3.3.3 Implementation

Before implementing new parameters into a management system it is very important to ensure that the output in terms of vehicle energy consumption/CO_2 emissions is relevant for road network managers and decisions can be based on it.

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 is 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.

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

[1] Prepare clear policy goals and rules through e.g. road agency or central government.
[2] 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.
[3] Perform and evaluate practical studies; good experience in different EU countries is important, verify models, set adequate form for proper input data.
[4] Prepare implementation process.
[5] Finally, start employment.

Authorisation at the highest level e.g. by the 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 the national governing body of the Road Administration 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.

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