
# MIRAVEC

# Potential for NRAs to provide energy reducing road infrastructure

Deliverable D3.1

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MIRAVEC

Modelling Infrastructure Influence on RoAd Vehicle Energy Consumption

**MIRAVEC - Modelling Infrastructure Influence on RoAd Vehicle Energy Consumption**

# Deliverable 3.1: Potential for NRAs to provide energy reducing road infrastructure

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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 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 3 (WP3) in MIRAVEC. The objective of this WP is to assess the potential for NRAs to achieve reductions in vehicle energy use, understanding how this is influenced by traffic flow, vehicle characteristics and infrastructure design. It will consider the types of intervention that NRAs can make on their network, for example reduced gradient, improved traffic flow or improved evenness. This information will provide NRAs with an awareness of the 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 saving for different options.

This report details the spreadsheet tool developed to aid NRAs in the assessment of fuel consumption. The tool has brought together a number of different models and studies of fuel consumption and 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 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.

This report also discusses some case studies investigated using the model. From these case studies it was found that the effectiveness of interventions that the NRAs can apply will depend on the condition and traffic levels of the site. For example the introduction of an additional lane can have a large impact on fuel consumption on sites where idle time/congestion is a significant factor. However, this same treatment would have little or no impact on a site with lower traffic densities. It will therefore be necessary to investigate schemes on a case by case basis and this report outlines a suggested methodology for how NRAs could use the spreadsheet tool to achieve this.

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# 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 will investigate the capabilities of available models and tools and evaluate the relative importance of different road infrastructure characteristics for different settings (e.g. topography or network type). 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. The dissemination to the NRAs is planned by using workshops, project presentations and a project website.

## 1.1 Objective of WP3

The main objective of Work Package 3 (WP3) is to assess the potential for NRAs to achieve reductions in vehicle energy use, understanding how this is influenced by the traffic flow, vehicle characteristics and infrastructure design. The types of intervention that can be made by NRAs, for example reduced gradient, improved traffic flow, or improved evenness, have been investigated through calculating the energy reductions achieved during actual improvement schemes (case studies) and also using simulation of improvements. 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 saving for different options.

## 1.2 Structure of WP 3

### 1.2.1 Task 3.1

A spreadsheet has been developed within this work package, which has incorporated the most important relationships identified in 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 the estimates.

### *1.2.2 Task 3.2*

The spreadsheet has been used to assess the capacity for NRAs to provide energy reducing road infrastructure. Since the benefits are dependent on traffic and vehicle characteristics as well as the road infrastructure, available statistical data describing the traffic found on the national road networks for each of the partner organisations, has been used to make the input data realistic. The combinations that lead to particularly high energy use have been identified as: steep uphill gradient, high texture, high levels of roughness, with congestion or high traffic speed. The potential benefits to be gained from making improvements to the infrastructure have been evaluated. This evaluation has considered both specific, isolated interventions to the worst areas of the network and also the introduction of network-wide improvements in standards. A methodology has been developed, in order to compare the effectiveness of different interventions on a common basis. Finally the results have been analysed to draw general conclusions about the effectiveness of different types of intervention in different locations in terms of reducing energy consumption. This has also considered whether future trends, such as higher proportions of electric vehicles and low-energy tyres, will affect the overall length of benefit that could be obtained by making changes to the road infrastructure.

# 2 Summary of previous Work Package findings

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

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. The focus was on models used in other projects such as IERD (2002), ECRPD (2010) and MIRIAM (Hammarström et al., 2012), and to evaluate these projects and identify deficiencies and strengths. The objective was also to analyse factors of major importance identified in WP1, quantitatively or qualitatively depending on the information available and to describe methods for the estimation of uncertainties in model estimations. The results of WP2 will be used as input to both Work Packages 3 and 4.

## *2.1 Work Package 1*

In WP1, factors with a verified or potential influence on road vehicle fuel consumption were analysed, with special attention paid to effects connected with the built road infrastructure.

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)

The effects contributing to road vehicle energy consumption were identified within WP1 to include: Rolling resistance (pavement); Texture; Longitudinal unevenness; Transverse unevenness; Surface defects; Road strength; Vertical alignment (Gradient); Crossfall; Horizontal alignment (Curvature); Road width and lane and carriageway layout; Intersections and roundabouts; Tunnels; Traffic volume and composition; Traffic flow; Traffic speed and speed restriction measures; Traffic lights, road signs, road markings and ITS measures; Driver behaviour; Vehicle type; Tyre type; Air resistance; Temperature; Wind; Water; Snow and ice.

The following effects were not taken into account for the reasons described below:

- *Rolling resistance* is currently not measured as part of standard monitoring. Therefore it is typically not a primary input to the models, but an intermediate result.
- *Surface defects and road strength* are currently not included in the relevant models, but may be considered in the future. They do, however, influence the texture and roughness of the road and can be included when there is a suitable road deterioration model available.
- *Intersections, roundabouts and traffic lights* primarily interact with the traffic flow. Whilst NRAs can sometimes change the layout and capacity of a junction, no generic model exists for junctions. This is because the effect that each junction has on traffic flow is

very dependent on the exact details of each junction and the traffic flow passing through the junction.

- *Tunnels, road signs, road markings and ITS measures* primarily interact with the traffic flow. The level of service is currently not modelled in detail or given as a general level of service. The potential influence by NRAs is of a more indirect nature, influencing the driving behaviour, i.e. speed, acceleration and deceleration.
- *Driver behaviour* is currently not sufficiently covered in the models.
- *Tyre type* is included in some models, however it was assumed to be determined by the vehicle type as a standard tyre for that vehicle.
- *Air resistance and wind*, whilst these have a substantial effect, and are included in some models, it is difficult for NRAs to influence them.
- *Temperature, water, snow and ice* are currently not sufficiently modelled. However, there is on-going work to improve the accuracy of how these variables may affect fuel use. Thus it may be possible for these to be included in the future.

Based on these considerations the effects and parameters shown in Table 1 were retained for analysis in WP2 and inclusion in the WP3 models.

**Table 1: Subset of effects and parameters for analysis in WP2 and inclusion in the WP3 spreadsheet**

| Name of effect or property | Group | NRA influence level (H,M,L) | Parameters |
|---|---|---|---|
| Texture | A | H | MPD, texture spectrum |
| Longitudinal unevenness | A | H | IRI |
| Transverse unevenness | A | H | Rut depth |
| Vertical alignment (Gradient) | B | H | Angle, β, or %, RF |
| Crossfall | B | H | Angle, γ |
| Horizontal alignment (Curvature) | B | H | $R_{curv}$, ADC |
| Road width and lane layout | B | H | $W_{Road}$ |
| Traffic volume and composition | C | L | AADT, % |
| Traffic speed and speed restriction measures | C | M | $V_{average}$, $V_{85}$ |

## 2.2 Work Package 2

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.

A selection of projects that have evaluated road characteristics and the effect on energy use were analysed, including MIRIAM, IERD, and ECRPD. In all of the three projects, the basic model used for traffic energy estimation is VETO, whilst in the MIRIAM project the models FTire/Dymola/Modelica and MOVES are 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 to estimate fuel consumption (Hammarström et al., 2012).

This model took inputs of Rolling resistance, Air resistance, Average degree of curvature (ADC), Gradient and Vehicle velocity. The VETO model was then used to calibrate the model for cars, heavy trucks and for heavy trucks with trailer.

It was felt that, of all the models considered, this model was most appropriate to use within WP3: It accounts for all road characteristics suggested by WP1, 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. 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 was also reviewed in WP2. This model is used by the Swedish transport administration for road planning (object analysis) 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 (http://en.wikipedia.org/wiki/European_emission_standards). 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.

**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 EURO6 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, EURO3 = 1.**

| | 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 |

# 3 Models used in the MIRAVEC tool

## *3.1 Overview*

The main objective of Work Package 3 (WP3) is to assess the potential for NRAs to achieve reductions in vehicle energy use, understanding how this is influenced by the traffic flow, vehicle characteristics and infrastructure design.

To facilitate this assessment, a spreadsheet has been developed, which has incorporated the most important relationships identified in 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 the estimates. This section sets out the models that have been implemented in the spreadsheet developed in Work Package 3.

The fuel consumption models identified within WP2 have been reviewed and the most suitable model (in terms of the feasibility to implement it and also in terms of including all factors identified as important in WP1) has been chosen to use for the MIRAVEC tool. Whilst this model could provide separate fuel consumption estimates for an average car, truck and truck and trailer, it was not able to provide estimates for the vehicle subclasses e.g. there was nothing to distinguish petrol cars from diesel or LPG, nor the different fuel consumption seen due to different engine sizes or the load being carried. Thus, it was necessary to implement an extension to the model, in order for the MIRAVEC tool to be able to estimate differences in fuel consumption due to vehicle fleet changes. The model and the implemented extension are discussed in section 3.2.

Fuel consumption is related to the speed of travel of the vehicle. Whilst each road has a posted speed associated with it, vehicles will not necessarily travel at this speed. For example, average vehicle speed on a narrow, bendy, uphill road is likely to be slower than a wide, straight and flat road of an equivalent class. Similarly, the presence of junctions or congestion may result in the vehicle stopping. Thus, there was a need to estimate the average speed of the vehicles and also the amount of idle time present, in order to calculate fuel consumption within the tool.

Models exist that predict the behaviour of traffic at junctions, however, these are very complicated and require very detailed information such as accurate traffic count, as well as junction design. Thus, it was not possible to include this level of detail in the MIRAVEC tool. It has been possible however, to implement a model that predicts average vehicle speed, based on road capacity, traffic volume and type and geometry of the road, and also give an estimate of the amount of idle time likely to be experienced. This is discussed in section 3.5.

## 3.2 Fuel consumption model for free flow traffic

The following model, developed within the MIRIAM project (Hammarström et al., 2012), and discussed in section 2.2, was implemented in the MIRAVEC spreadsheet:

$$Fcs = c1 \times (1 + k5 \times (Fr + Fair + d1 \times ADC \times v^2 + d2 \times RF + d3 \times RF^2))^{e1} \times v^{e2}$$ **Equation 1**

where $Fcs$: Fuel consumption (L/10km)
$Fr$: Rolling resistance (N)
$Fair$: Air resistance (N)
$ADC$: Average degree of curvature (rad/km)
$RF$: Rise and fall/gradient (m/km)
$v$: Velocity (km/h)
*c1, k5, d1, d2, d3, e1 and e2* are parameters.

The rolling resistance is an input to Equation 1 and is calculated from:

$$Fr = (Cr00 + CrTemp \times (5 - T) + Cr1 \times IRI \times v + Cr2 \times MPD) \times m * 9.81$$ **Equation 2**

where T is the ambient temperature (°C), IRI is the road roughness measure (m/km) and MPD is a measure of macrotexture (mm).

Similarly, air resistance is calculated from:

$$Fair = Cd \times Ayz \times dns \times v^2/2$$ **Equation 3**

where dns is the density of air, and $\mathrm{Cr00}, \mathrm{CrTemp}, \mathrm{Cr1}, \mathrm{Cr2}, \mathrm{m}, \mathrm{Cd}$ and $\mathrm{Ayz}$ are parameters.

The VETO model was used to determine the values of parameters c1, k5, d1, d2, d3, e1, e2, Cr00, CrTemp, Cr1, Cr2, m, Cd and Ayz, for each vehicle type. These are listed in Table 4.

**Table 4: Parameter values used for calculation of fuel consumption**

| Parameter | Car | Truck | Truck with trailer |
|---|---|---|---|
| c1 | 0.286 | 0.684 | 2.33 |
| k5 | 0.00156 | 0.000863 | 0.000466 |
| d1 | 0.0516 | 0.171 | 1.655 |
| d2 | -3.906 | -4.211 | 148.1 |
| d3 | 0.1898 | 1.39 | 1.637 |
| e1 | 1.163 | 1.027 | 1 |
| e2 | 0.056 | -0.04 | -0.266 |
| m | 1492 | 12871 | 41653 |
| Cr00 | 0.00943 | 0.00414 | 0.00365 |
| CrTemp | 0.000104 | 0.00003 | 0.00003 |
| Cr1 | 0.000021 | 0.0000158 | 0.0000158 |
| Cr2 | 0.00172 | 0.00102 | 0.00102 |
| Ayz | 2.06 | 8.07 | 9.53 |
| Cd | 0.32 | 0.6 | 0.72 |

This model enables the fuel consumption to be calculated for three vehicle types given a knowledge of the road geometry (rise and fall of gradient and the curvature), the pavement characteristics (roughness, IRI and texture depth, MPD), the vehicle speed and the temperature. The following sections describe how this model has been extended by the incorporation of additional vehicle classes and how estimates of vehicle speed are made.

## 3.3 *Incorporation of additional vehicle classes*

Equation 1 and Table 4 allow for the calculation of fuel consumption for three vehicle classes: Cars, trucks and trucks with trailers. There is no scope in the above model to account for the effect of fuel type, nor the range of Euro classes. However, the type of fuel a vehicle uses and its fuel efficiency (represented by the Euro classification) clearly affects the amount of fuel consumed. For example, a diesel car will use a smaller volume of fuel compared with an equivalent petrol car.

This restriction would limit the use of the tool for modelling the effects of future trends in fuel consumption and for modelling regional differences in the types of vehicle. For example, if the proportion of electric cars increases in the future, the model would not be able to reflect the reduction in fuel associated with this evolution, nor would it be able to estimate greater fuel consumption in a country where the vehicles were generally older than the European average, or on roads such as the approaches to ports or rail interchanges where freight vehicles are heavily laden.

To allow a wider range of vehicle sub classes and Euro classifications to be included in the spreadsheet, information about their relative differences in fuel consumption has been incorporated by way of adjustment factors.

Two sources of information have been examined for this purpose. The correction factors provided by WP2 (shown in Table 3), provided a starting point. However, the factors listed in Table 3 cover a small range of vehicles, and there is no way to determine fuel consumption for busses and coaches with only these factors and the parameters in Table 4. Therefore to expand the range of vehicles that can be considered in the model, data collected for use in the UK Highways Agency's model for road works (SCOOT) was used. This dataset contains typical fuel consumption data for a range of vehicle sub classes and Euro classes.

Each of the vehicle sub classes was initially assigned to the most relevant of the three vehicle types defined by the EVA model (car, truck, truck with trailer). This assignment is shown in the "EVA class" column in Table 5 to Table 10, and it determines which set of the parameter values in Table 4 will be used as the basis of the initial fuel consumption calculation.

For each of the EVA vehicle types (car, truck, truck with trailer), the fuel consumption for each of the assigned sub classes and Euro classes was then calculated, relative to a reference, from the SCOOT data. These adjustment factors are shown in Table 5 to Table 10 and they are used to adjust the fuel consumption for each specific vehicle type. The reference was selected on the basis of a judgement of the most representative of the subclasses defined in Table 3. This resulted in the EURO 3 Petrol car with an engine size of 1.4-2l, EURO III 12-14t HGV and EURO III truck with trailer being chosen. These reference vehicles are identified by grey shading and an adjustment value of 1.00 in the following Table 5 to Table 10. In general, the adjustment factors are similar to those in Table 3.

Thus, the fuel consumption for a 28-34 tonne EURO III articulated truck will be calculated using Equation 1 and the truck parameter values given in Table 4. This value is then scaled by a factor of 1.45 to obtain a more realistic fuel consumption value for such a vehicle.

**Table 5: Correction factors derived from SCOOT data for Cars**

| Sub class | EVA Class | Correction factor for sub class | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre-Euro | Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5 | Euro 6 |
| Petrol <1.4l | Car | 1.09 | 0.99 | 0.95 | 0.89 | 0.82 | 0.73 | 0.65 |
| Petrol 1.4-2l | Car | 1.21 | 1.12 | 1.07 | 1.00 | 0.91 | 0.79 | 0.70 |
| Petrol >2l | Car | 1.60 | 1.52 | 1.46 | 1.35 | 1.27 | 1.11 | 0.97 |
| Diesel <1.4l | Car | 0.63 | 0.61 | 0.57 | 0.51 | 0.52 | 0.45 | 0.39 |
| Diesel 1.4-2l | Car | 0.85 | 0.82 | 0.77 | 0.70 | 0.67 | 0.58 | 0.51 |
| Diesel >2l | Car | 1.24 | 1.20 | 1.13 | 1.03 | 0.96 | 0.85 | 0.75 |
| LPG | Car | N/A | 1.28 | 1.28 | 1.28 | 1.28 | 1.28 | 1.28 |

**Table 6: Correction factors derived from SCOOT data for Light Goods Vehicles**

| Sub class | EVA Class | Correction factor for sub class | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre-Euro | Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5 | Euro 6 |
| LGV N1(I) Petrol | Truck | 0.41 | 0.38 | 0.36 | 0.34 | 0.31 | 0.28 | 0.25 |
| LGV N1(I) Diesel | Truck | 0.29 | 0.28 | 0.26 | 0.24 | 0.23 | 0.20 | 0.18 |
| LGV N1(II) Petrol | Truck | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 |
| LGV N1(II) Diesel | Truck | 0.42 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 |
| LGV N1(III) Petrol | Truck | 0.51 | 0.50 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 |
| LGV N1(III) Diesel | Truck | 0.41 | 0.50 | 0.47 | 0.44 | 0.44 | 0.44 | 0.44 |

**Table 7: Correction factors derived from SCOOT data for Rigid Heavy Goods Vehicles**

| Sub class | EVA Class | Correction factor for sub class | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre-Euro | Euro I | Euro II | Euro III | Euro IV | Euro V | Euro VI |
| HGV Rigid Diesel 3.5-7.5t | Truck | 0.82 | 0.67 | 0.68 | 0.67 | 0.65 | 0.65 | 0.65 |
| HGV Rigid Diesel 7.5-12 t | Truck | 1.06 | 0.95 | 0.93 | 0.96 | 0.91 | 0.92 | 0.92 |
| HGV Rigid Diesel 12-14 t | Truck | 1.08 | 1.00 | 0.97 | 1.00 | 0.93 | 0.94 | 0.94 |
| HGV Rigid Diesel 14-20 t | Truck | 1.29 | 1.03 | 1.05 | 1.05 | 0.98 | 1.00 | 1.00 |
| HGV Rigid Diesel 20-26 t | Truck | 1.54 | 1.36 | 1.26 | 1.34 | 1.26 | 1.28 | 1.28 |
| HGV Rigid Diesel 26-28 t | Truck | 1.64 | 1.45 | 1.41 | 1.43 | 1.33 | 1.35 | 1.35 |
| HGV Rigid Diesel 28-32 t | Truck | 1.88 | 1.60 | 1.56 | 1.60 | 1.56 | 1.58 | 1.58 |
| HGV Rigid Diesel >32 t | Truck | 1.85 | 1.66 | 1.63 | 1.63 | 1.52 | 1.55 | 1.55 |

**Table 8: Correction factors derived from SCOOT data for Articulated Heavy Goods Vehicles**

| Sub class | EVA Class | Correction factor for sub class | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre-Euro | Euro I | Euro II | Euro III | Euro IV | Euro V | Euro VI |
| HGV artic Diesel 14-20 t | Truck | 1.22 | 1.06 | 0.98 | 1.02 | 0.99 | 1.00 | 1.00 |
| HGV artic Diesel 20-28 t | Truck | 1.53 | 1.39 | 1.34 | 1.36 | 1.27 | 1.29 | 1.29 |
| HGV artic Diesel 28-34 t | Truck | 1.62 | 1.48 | 1.43 | 1.45 | 1.35 | 1.37 | 1.37 |
| HGV artic Diesel 34-40 t | Truck | 1.87 | 1.68 | 1.64 | 1.65 | 1.54 | 1.56 | 1.56 |
| HGV artic Diesel 40-50 t | Truck | 2.09 | 1.87 | 1.84 | 1.84 | 1.71 | 1.74 | 1.74 |

**Table 9: Correction factors derived from SCOOT data for Motorbikes**

| Sub class | EVA Class | Correction factor for sub class | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre-Euro | Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5 | Euro 6 |
| Moped <50cc | Car | 0.48 | 0.29 | 0.23 | 0.20 | n/a | n/a | n/a |
| M/cycle, 2-stroke Petrol <=150 | Car | 0.64 | 0.59 | 0.59 | 0.59 | n/a | n/a | n/a |
| M/cycle, 2-stroke Petrol 150-250 | Car | 0.61 | 0.61 | 0.61 | 0.61 | n/a | n/a | n/a |
| M/cycle, 4-stroke Petrol <=150 | Car | 0.43 | 0.43 | 0.43 | 0.43 | n/a | n/a | n/a |
| M/cycle, 4-stroke Petrol 150-250 | Car | 0.49 | 0.49 | 0.49 | 0.49 | n/a | n/a | n/a |
| M/cycle, 4-stroke Petrol 250-750 | Car | 0.77 | 0.74 | 0.68 | 0.68 | n/a | n/a | n/a |
| M/cycle, 4-stroke Petrol >750 | Car | 0.88 | 0.79 | 0.80 | 0.80 | n/a | n/a | n/a |

In the SCOOT dataset, there are no data for trucks with trailers (as they are not present on UK roads). Therefore the factors provided by WP2 (shown in Table 3), were used as a basis for this class. In order to provide a factor for pre-Euro vehicles, the average ratio between pre-Euro and Euro 1 for the other vehicle types was calculated and applied to Euro 1 factor from Table 3. These factors can be seen below in Table 10.

**Table 10: Correction factors derived from Table 3 and SCOOT data for trucks with trailers**

| Sub class | EVA Class | Correction factor for sub class | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre-Euro | Euro I | Euro II | Euro III | Euro IV | Euro V | Euro VI |
| Truck with Trailer | Truck with trailer | 1.12 | 1.01 | 1.00 | 1.00 | 0.96 | 0.95 | 0.94 |

## 3.4 Estimation of speed for free flowing vehicles

The speed with which a vehicle is travelling effects the amount of fuel consumed, and this is included in the fuel consumption model implemented in the MIRAVEC tool (Equation 1). Whilst each road has a posted speed limit associated with it, vehicles will not necessarily be able to travel at this speed e.g. due to curves, uphill slopes on the road, or high traffic volume. Therefore equations for estimating the average vehicle speed which take into account both road type and geometry and traffic volume and fleet distribution are needed.

Models that predict average vehicle speed were reviewed and none were found that incorporated all of the effects of road capacity, traffic volume and type and the range of road geometry found on the European road network. We have therefore needed to combine a number of models within the MIRAVEC tool, in order to obtain a speed estimate.

The COBA models, which are specified in the Highways Agency's Design Manual for Roads and Bridges (DMRB, Vol13, Sec1, Pt5), were identified as providing an estimate of vehicle speed for different road classes (rural single carriageway, rural dual carriageway, motorway etc.) based on the road geometry and traffic levels. They also treat light vehicles separately from heavy vehicles. Although these models are focussed on conditions found in the UK, it is expected that driver behaviour in other countries will be broadly similar and, where local variations are known, users of the spreadsheet can input alternative speeds.

The COBA models calculate average speeds for light and heavy vehicles separately. Each follows a linear relationship with traffic, with vehicle speed decreasing as traffic increases, until reaching a break point, above which a second linear relationship is followed with a steeper negative slope. This break point is applied when the traffic level exceeds a certain percentage of the capacity of the road (typically 80%). The capacity of the road is calculated from carriageway width and/or number of lanes.

In order to maintain realistic speeds, each of the COBA models has a minimum speed cut-off. This is 45km/h for motorways and rural roads, and 25k/h and 15km/h for urban non-central roads and urban central roads respectively.

The COBA models do not take account of the effect of road surface characteristics (e.g. rutting, IRI etc.). It is thought that higher levels of IRI, MPD and rutting can reduce the speed at which vehicles travel on a road and the following reductions are used within the EVA model:

For cars: $dv_{car} = -0.11 * rut - 1.33 * IRI$ **Equation 4**

For heavy trucks: $dv_{hgv} = -0.12 * rut - 1.17 * IRI$ **Equation 5**

For trucks + trailers: $dv_{tr+tr} = -0.09 * rut - 2.31 * IRI$ **Equation 6**

Where *rut*=rut depth (mm) and *IRI* is the value of IRI in m/km.

As no road is perfectly flat, with zero IRI and rut depth, the speed estimate will always be reduced by these equations. Indeed, a newly constructed, fairly smooth road has an IRI of around 2m/km. In this case, the above equations would reduce the average vehicle speed by between 2 and 4.5km/h, which does not seem realistic. This is supported by other research that has found that a significant reduction in vehicle speed occurs only when road condition deteriorates beyond some critical level (Parkman et al, 2012). Work in New Zealand and Australia also found that pavement roughness does not affect speeds until it exceeds 4.5m/km IRI (Opus, 1999) or 5m/km for cars and 3m/km IRI for articulated trucks (McLean and Foley 1998). Similarly, shallow ruts are not expected to have an effect on speed.

Thus, the EVA models have been adjusted so that there is no influence on speed below a rut depth of 5mm or below an IRI value of 5m/km for cars or 3 m/km for trucks. In the spreadsheet the following relationships have been used to adjust the estimate of average vehicle speed from the COBA models:

For cars: $dv_{car} = MIN(0,-0.11*(rut-5)) + MIN(0,-1.33*(IRI-5))$ **Equation 7**

For heavy trucks: $dv_{hgv} = MIN(0,-0.12*(rut-5)) + MIN(0,-1.17*(IRI-3))$ **Equation 8**

For trucks + trailers: $dv_{tr+tr} = MIN(0,-0.09*(rut-5)) + MIN(0,-2.31*(IRI-3))$ **Equation 9**

A further assumption has been made that the IRI and rut depths will not reduce the speed below the minimum used in the COBA model (45km/h for motorways and rural roads).

As mentioned above, the COBA models have been designed for use on the UK trunk road network, where extremes of gradient are unlikely to be encountered. Thus, the model only accounts for gradients of less than about 3%. Since there are many mountainous regions found in mainland Europe, it was thought important to include an adjustment for speed, in the case of vehicles travelling on prolonged slopes.

The Sweden Transport Administration uses the following formula for determining the effect of gradients on vehicle speeds:

Change in vehicle speed, due to gravity = - gravity*section length/speed at start of section. **Equation 10**

It was felt that this model would be appropriate to implement in the MIRAVEC tool. As with the effect of road condition, it has been assumed that gradient will not reduce the speed below the minimum used in the COBA model.

## 3.5 Additional fuel consumption due to idling

Once the volume of traffic has reached a certain level e.g. 80% of the road capacity, traffic will slow to a level where free flow is not possible and start-stop conditions are induced. These conditions are associated with higher fuel consumption than free flow and therefore it was considered important to be able to model such conditions, to enable the MIRAVEC tool to be able to estimate the benefit of changes to road layout such as adding an extra lane.

No models have been found for the estimation of idle time. Therefore a simplistic approach has been developed for use in the MIRAVEC tool. The speed is initially calculated as described above, ignoring the minimum speed cut off. This represents an estimate of the average speed over the section and is used to estimate the time taken to transit the section. It is then assumed that the transit time is made up of the time travelling at the minimum speed specified by the COBA model, plus the time spent at zero speed with the engine idling. This enables an estimate to be made for the idle time as follows (the maximum function in the equation is to avoid errors and negative values):

$$\textit{Idle time} = \frac{\textit{Length of site}}{\textit{Minimum speed}} - \frac{\textit{Length of site}}{\textit{max(Calculated speed,5km/h)}}$$ **Equation 11**

The input data for the EVA model for fuel use due to idling was used in the MIRAVEC spreadsheet. This EVA model data has two values for each of the given vehicle types, one for when auxiliary equipment is used and one for when it is not. This data was expanded to cover the range of vehicle subclasses using the SCOOT data in a similar way to that applied to the free flow traffic calculation (section 3.2). The values used in the MIRAVEC spreadsheet are given below, and the cells corresponding to the EVA model data are highlighted with grey shading.

**Table 11: Fuel consumption due to idling based on EVA model data and SCOOT for cars**

| Sub class | AUX | Fuel consumption due to idling ($dm^3/h$) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre-Euro | Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5 | Euro 6 |
| Petrol <1.4l | N | 0.691 | 0.631 | 0.603 | 0.564 | 0.523 | 0.465 | 0.415 |
| | Y | 0.691 | 0.631 | 0.603 | 0.564 | 0.523 | 0.465 | 0.415 |
| Petrol 1.4-2l | N | 0.769 | 0.710 | 0.679 | 0.635 | 0.577 | 0.504 | 0.444 |
| | Y | 0.769 | 0.710 | 0.679 | 0.635 | 0.577 | 0.504 | 0.444 |
| Petrol >2l | N | 1.012 | 0.962 | 0.924 | 0.854 | 0.808 | 0.704 | 0.615 |
| | Y | 1.012 | 0.962 | 0.924 | 0.854 | 0.808 | 0.704 | 0.615 |
| Diesel <1.4l | N | 0.177 | 0.171 | 0.159 | 0.143 | 0.144 | 0.125 | 0.109 |
| | Y | 0.177 | 0.171 | 0.159 | 0.143 | 0.144 | 0.125 | 0.109 |
| Diesel 1.4-2l | N | 0.238 | 0.230 | 0.215 | 0.195 | 0.186 | 0.162 | 0.142 |
| | Y | 0.238 | 0.230 | 0.215 | 0.195 | 0.186 | 0.162 | 0.142 |
| Diesel >2l | N | 0.346 | 0.336 | 0.315 | 0.289 | 0.269 | 0.237 | 0.209 |
| | Y | 0.346 | 0.336 | 0.315 | 0.289 | 0.269 | 0.237 | 0.209 |
| LPG | N | N/A | 0.813 | 0.812 | 0.811 | 0.810 | 0.810 | 0.810 |
| | Y | N/A | 0.813 | 0.812 | 0.811 | 0.810 | 0.810 | 0.810 |

**Table 12: Fuel consumption due to idling based on EVA model data and SCOOT for Light Goods Vehicles**

| Sub class | AUX | Fuel consumption due to idling ($dm^3/h$) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre-Euro | Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5 | Euro 6 |
| LGV N1(I) Petrol | N | 0.494 | 0.455 | 0.435 | 0.407 | 0.371 | 0.330 | 0.296 |
| | Y | 0.910 | 0.839 | 0.803 | 0.750 | 0.685 | 0.610 | 0.546 |
| LGV N1(I) Diesel | N | 0.346 | 0.334 | 0.312 | 0.283 | 0.271 | 0.241 | 0.214 |
| | Y | 0.637 | 0.616 | 0.575 | 0.522 | 0.501 | 0.444 | 0.395 |
| LGV N1(II) Petrol | N | 0.442 | 0.442 | 0.442 | 0.442 | 0.442 | 0.442 | 0.442 |
| | Y | 0.816 | 0.816 | 0.816 | 0.816 | 0.816 | 0.816 | 0.816 |
| LGV N1(II) Diesel | N | 0.502 | 0.444 | 0.444 | 0.444 | 0.444 | 0.444 | 0.444 |
| | Y | 0.927 | 0.819 | 0.819 | 0.819 | 0.819 | 0.819 | 0.819 |
| LGV N1(III) Petrol | N | 0.612 | 0.604 | 0.542 | 0.542 | 0.542 | 0.542 | 0.542 |
| | Y | 1.129 | 1.114 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| LGV N1(III) Diesel | N | 0.495 | 0.605 | 0.565 | 0.524 | 0.524 | 0.524 | 0.524 |
| | Y | 0.912 | 1.115 | 1.042 | 0.967 | 0.967 | 0.967 | 0.967 |

**Table 13: Fuel consumption due to idling based on EVA model data and SCOOT for Rigid Heavy Goods Vehicles**

| Sub class | AUX | Fuel consumption due to idling (dm³/h) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre-Euro | Euro I | Euro II | Euro III | Euro IV | Euro V | Euro VI |
| HGV Rigid Diesel 3.5-7.5t | N | 0.986 | 0.803 | 0.809 | 0.803 | 0.774 | 0.784 | 0.784 |
| | Y | 1.818 | 1.481 | 1.493 | 1.482 | 1.428 | 1.445 | 1.445 |
| HGV Rigid Diesel 7.5-12 t | N | 1.264 | 1.142 | 1.114 | 1.152 | 1.089 | 1.099 | 1.099 |
| | Y | 2.331 | 2.106 | 2.055 | 2.125 | 2.008 | 2.027 | 2.027 |
| HGV Rigid Diesel 12-14 t | N | 1.298 | 1.193 | 1.160 | 1.198 | 1.117 | 1.130 | 1.130 |
| | Y | 2.394 | 2.200 | 2.139 | 2.210 | 2.060 | 2.084 | 2.084 |
| HGV Rigid Diesel 14-20 t | N | 1.548 | 1.253 | 1.253 | 1.253 | 1.174 | 1.192 | 1.192 |
| | Y | 2.855 | 2.311 | 2.311 | 2.311 | 2.165 | 2.199 | 2.199 |
| HGV Rigid Diesel 20-26 t | N | 1.844 | 1.635 | 1.509 | 1.605 | 1.506 | 1.529 | 1.529 |
| | Y | 3.401 | 3.015 | 2.783 | 2.961 | 2.778 | 2.820 | 2.820 |
| HGV Rigid Diesel 26-28 t | N | 1.964 | 1.737 | 1.690 | 1.710 | 1.598 | 1.623 | 1.623 |
| | Y | 3.622 | 3.205 | 3.116 | 3.153 | 2.948 | 2.994 | 2.994 |
| HGV Rigid Diesel 28-32 t | N | 2.254 | 1.917 | 1.867 | 1.912 | 1.866 | 1.888 | 1.888 |
| | Y | 4.157 | 3.536 | 3.443 | 3.527 | 3.442 | 3.482 | 3.482 |
| HGV Rigid Diesel >32 t | N | 2.221 | 1.989 | 1.947 | 1.955 | 1.826 | 1.853 | 1.853 |
| | Y | 4.097 | 3.669 | 3.591 | 3.606 | 3.368 | 3.418 | 3.418 |

**Table 14: Fuel consumption due to idling based on EVA model data and SCOOT for Articulated Heavy Goods Vehicles**

| Sub class | AUX | Fuel consumption due to idling (dm³/h) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre-Euro | Euro I | Euro II | Euro III | Euro IV | Euro V | Euro VI |
| HGV artic Diesel 14-20 t | N | 1.463 | 1.267 | 1.170 | 1.221 | 1.183 | 1.201 | 1.201 |
| | Y | 2.699 | 2.337 | 2.157 | 2.251 | 2.182 | 2.216 | 2.216 |
| HGV artic Diesel 20-28 t | N | 1.835 | 1.663 | 1.610 | 1.631 | 1.523 | 1.549 | 1.549 |
| | Y | 3.384 | 3.066 | 2.969 | 3.008 | 2.809 | 2.857 | 2.857 |
| HGV artic Diesel 28-34 t | N | 1.945 | 1.768 | 1.716 | 1.734 | 1.614 | 1.640 | 1.640 |
| | Y | 3.586 | 3.262 | 3.164 | 3.198 | 2.977 | 3.024 | 3.024 |
| HGV artic Diesel 34-40 t | N | 2.239 | 2.007 | 1.970 | 1.977 | 1.843 | 1.864 | 1.864 |
| | Y | 4.130 | 3.702 | 3.633 | 3.647 | 3.399 | 3.438 | 3.438 |
| HGV artic Diesel 40-50 t | N | 2.509 | 2.236 | 2.202 | 2.208 | 2.052 | 2.086 | 2.086 |
| | Y | 4.627 | 4.124 | 4.061 | 4.072 | 3.785 | 3.847 | 3.847 |

**Table 15: Fuel consumption due to idling based on EVA model data and SCOOT for Motorbikes**

| Sub class | AUX | Fuel consumption due to idling ($dm^3/h$) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre-Euro | Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5 | Euro 6 |
| Moped <50cc | N | 0.306 | 0.184 | 0.148 | 0.129 | n/a | n/a | n/a |
| | Y | 0.306 | 0.184 | 0.148 | 0.129 | n/a | n/a | n/a |
| M/cycle, 2-stroke Petrol <=150 | N | 0.408 | 0.377 | 0.377 | 0.377 | n/a | n/a | n/a |
| | Y | 0.408 | 0.377 | 0.377 | 0.377 | n/a | n/a | n/a |
| M/cycle, 2-stroke Petrol 150-250 | N | 0.389 | 0.389 | 0.389 | 0.389 | n/a | n/a | n/a |
| | Y | 0.389 | 0.389 | 0.389 | 0.389 | n/a | n/a | n/a |
| M/cycle, 4-stroke Petrol <=150 | N | 0.271 | 0.271 | 0.271 | 0.271 | n/a | n/a | n/a |
| | Y | 0.271 | 0.271 | 0.271 | 0.271 | n/a | n/a | n/a |
| M/cycle, 4-stroke Petrol 150-250 | N | 0.311 | 0.311 | 0.311 | 0.311 | n/a | n/a | n/a |
| | Y | 0.311 | 0.311 | 0.311 | 0.311 | n/a | n/a | n/a |
| M/cycle, 4-stroke Petrol 250-750 | N | 0.486 | 0.469 | 0.433 | 0.433 | n/a | n/a | n/a |
| | Y | 0.486 | 0.469 | 0.433 | 0.433 | n/a | n/a | n/a |
| M/cycle, 4-stroke Petrol >750 | N | 0.556 | 0.502 | 0.509 | 0.509 | n/a | n/a | n/a |
| | Y | 0.556 | 0.502 | 0.509 | 0.509 | n/a | n/a | n/a |

## 3.6 Calculation of overall fuel consumption for a road section

The previous sections describe the method adopted for the calculation of fuel consumption for individual vehicles. This depends on the road geometry (gradient and curvature), the pavement characteristics (roughness, IRI and texture depth, MPD) and the temperature, which must be input by the spreadsheet user. It also depends on the vehicle speed, for which an estimate is made following the approach described above; this can be overwritten if desired by the spreadsheet user. In addition, an estimate is made of the additional fuel consumption resulting from vehicle idling in conditions where stop-start traffic flow might be expected because the traffic is approaching the road capacity. This requires the user to input details of the road layout (number of lanes) and traffic flow (annual average daily total, AADT).

The spreadsheet allows for the definition of flow groups so that the daily average vehicle count can be split unevenly over the day to account for peaks in the traffic flow. The overall, annual fuel consumption, *FC*, is calculated by combining the fuel consumption for each of these flow groups, $FC_{FG}$, as shown below:

$$FC = \sum_{Flow\ groups} FC_{FG} * Annual\ traffic\ for\ flow\ group$$ **Equation 12**

Where the annual traffic for the flow group is calculated by dividing the daily traffic flow (AADT) between the flow groups, based on the user's values for relative traffic densities between flow groups and proportions of the day for each flow group, and then multiplying by the number of days in the year.

The fuel consumption in each flow group is calculated by summing the fuel consumption, *FC,* within that flow group for each of the vehicle classes.

$$FC_{FG} = \sum_{Vehicle\ class} FC_{Class,FG}$$ **Equation 13**

The fuel consumption for each vehicle class comprises the sum of the fuel consumption for the subclasses within the vehicle class and is calculated using the formulae below.

$$FC_{Class,FG} = \sum_{subclass} \%\ of\ traffic_{subclass,FG} * FC_{subclass,FG}$$ **Equation 14**

$$FC_{sub\ class,FG} = Freeflow\ FC_{sub\ class,FG} + Idle\ time\ FC_{sub\ class,FG}$$ **Equation 15**

Where:

$$Freeflow\ FC_{subclass,FG} = Free\ flow\ FC_{std\ Vehicle,FG} * subclass\ modification\ factor$$ **Equation 16**

$$Free\ flow\ FC_{std\ Vehicle,FG} = \sum_{sub-lengths} Freeflow\ FC\ per\ sub\ length_{FG} * length$$ **Equation 17**

$$Idle\ time\ FC_{subclass,FG} = Idle\ time_{FG} * FC\ during\ idling_{subclass}$$ **Equation 18**

While it is recognised that there are limitations in the accuracy of many of these estimates, this approach brings together the current state of knowledge in relation to the effect of road infrastructure on vehicle fuel consumption for the purposes of allowing NRAs to understand the most important effects. The tool can be updated as necessary as further research leads to better models becoming available.

# 4 MIRAVEC tool for estimating vehicle fuel consumption

## 4.1 Overview of the spreadsheet

The MIRAVEC tool 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. It has been implemented using a spreadsheet package and is split into three main sections, which are further divided into separate worksheets. These sections are colour coded to help users to easily identify the structure of the workbook. The first section (with sheets tabs colour coded red) allows the user to enter global variables e.g. the distribution of vehicle types, typical air temperature etc. The second section (with blue sheet tabs) is used to enter the details of the road route being assessed. The third section (with green sheet tabs) provides the output data from the tool, including breakdowns of fuel consumption and $CO_2$ emissions by vehicle type and changes in fuel consumption and $CO_2$ emissions along the length of the road routes.

## 4.2 Input data needed

There are two main types of data required for the MIRAVEC tool: Global data and local data.

### 4.2.1 Global data

The global data is entered on the sheets with red tabs and is split into three subsections, each with an individual work sheet:

1. Traffic breakdown
2. Traffic flow distribution
3. Default values.

In the traffic breakdown sheet, the user is asked to provide the distribution of traffic by vehicle sub-classes and Euro class. This is entered as percentage of the overall traffic within each of the class combinations and should be entered in the yellow cells. After entry of the data the user should check that the total percentage distribution equals 100%; this sum is shown on the sheet in cell B9. If traffic data are not readily available to the user at the levels of granularity shown in the table, they can enter their data grouped together appropriately. For example if their traffic is 60% cars but they do not know how this is split by Euro class or vehicle size, then they should enter 60% in the cell which they think best represents the average car for their traffic. This process can then be applied to the other vehicle types. If a vehicle type is not typically present in their traffic then the associated table can be left blank (as long as total percentage distribution equals 100%).

The traffic breakdown sheet also allows the user to enter traffic into a user-defined fuel efficiency class. The level of fuel consumption for this class is defined by the percentage fuel used relative to class 3, in cell D6. A value less than 100 equates to a more fuel efficient vehicle than class 3. A screen shot of this sheet can be seen in Figure 1, below.

Fuel consumption for user defined vehicle class equals 50 % of Euro 3 for same vehicle type.

| | |
|---|---|
| Total of percentage distribution | 100.0% |
| Percentage heavy vehicles | 19.0% |

| | Percentage distirbution | | | | | | | | Vehicle type ty | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre-Euro 1 | Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5 | Euro 6 | User | Pre-Euro 1 | Euro 1 | E |
| **Cars** | | | | | | | | | | | |
| Petrol <1400cc | | 5.0% | | | | | | | No | No | |
| Petrol 1400-2000cc | | | 5.0% | 5.0% | 5.0% | 5.0% | 5.0% | | No | No | |
| Petrol >2000cc | | | | 5.0% | 5.0% | | | | No | No | |
| Diesel <1400cc | | 2.0% | 2.0% | 2.0% | 2.0% | 1.0% | 1.0% | | No | No | |
| Diesel 1400-2000cc | | | 2.0% | 2.0% | 2.0% | 2.0% | 2.0% | | No | No | |
| Diesel >2000cc | | | | | | | | | No | No | |
| LPG | N/A | | 1.0% | 2.0% | 1.0% | | | | N/A | No | |

| | Petrol | Diesel | Total |
|---|---|---|---|
| Total Car percentage | 40.0% | 24.0% | 64.0% |

| | Pre-Euro 1 | Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5 | Euro 6 | User | Pre-Euro 1 | Euro 1 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Light Goods Vehicles** | | | | | | | | | | |
| LGV N1(I) Petrol | | | 1.0% | | | | | | No | No |

**Figure 1 Screen shot of part of the traffic breakdown sheet**

The traffic flow distribution sheet gives the user the opportunity to define peak / off peak times of the day for traffic. These periods are referred to as flow groups, and the user is asked to specify how the overall traffic level varies between these periods. The sheet is designed to allow for eight flow groups, four for weekdays, and four for weekends. A screen shot of this sheet can be seen in Figure 2 below.

| | Hourly Flow group (HFG) | Description | Percentage increase in traffic per hour releative to flow group 2 | |
|---|---|---|---|---|
| Weekdays | 1 | Low weekday traffic periods | -50 | % |
| | 2 | Typical weekday traffic levels | 0 | % |
| | 3 | higher weekday traffic periods | 200 | % |
| | 4 | Peak weekday traffic periods | 500 | % |
| Weekends | 5 | Low weekend traffic periods | -80 | % |
| | 6 | Typical weekend traffic levels | -50 | % |
| | 7 | higher weekend traffic periods | 100 | % |
| | 8 | Peak weekend traffic periods | 150 | % |

| | | Flow group asignment | | | |
|---|---|---|---|---|---|
| From | To | Mon-Thurs | Frid | Sat | Sun |
| 00:00 | 01:00 | 1 | 1 | 5 | 5 |
| 01:00 | 02:00 | 1 | 1 | 5 | 5 |
| 02:00 | 03:00 | 1 | 1 | 5 | 5 |
| 03:00 | 04:00 | 1 | 1 | 5 | 5 |
| 04:00 | 05:00 | 1 | 1 | 5 | 5 |
| 05:00 | 06:00 | 1 | 1 | 5 | 5 |
| 06:00 | 07:00 | 1 | 1 | 5 | 5 |
| 07:00 | 08:00 | 2 | 2 | 5 | 5 |
| 08:00 | 09:00 | 2 | 2 | 6 | 5 |
| 09:00 | 10:00 | 2 | 2 | 6 | 6 |
| 10:00 | 11:00 | 2 | 2 | 7 | 6 |
| 11:00 | 12:00 | 2 | 2 | 8 | 6 |
| 12:00 | 13:00 | 2 | 3 | 8 | 6 |
| 13:00 | 14:00 | 2 | 3 | 8 | 6 |
| 14:00 | 15:00 | 2 | 3 | 7 | 6 |
| 15:00 | 16:00 | 2 | 3 | 6 | 6 |
| 16:00 | 17:00 | 3 | 3 | 6 | 7 |
| 17:00 | 18:00 | 4 | 4 | 6 | 8 |
| 18:00 | 19:00 | 2 | 3 | 6 | 7 |
| 19:00 | 20:00 | 1 | 1 | 6 | 6 |
| 20:00 | 21:00 | 1 | 1 | 5 | 6 |
| 21:00 | 22:00 | 1 | 1 | 5 | 5 |
| 22:00 | 23:00 | 1 | 1 | 5 | 5 |
| 23:00 | 00:00 | 1 | 1 | 5 | 5 |

**Figure 2 Screen shot of the traffic flow distribution sheet**

The third sheet for the global data section is for default values. This sheet details the default values that will be used if any of the cells are left blank on the local data sheets (sheets with the blue tabs, discussed below). These default values were calculated by taking the average values from the UK and Austria. However, there is also an option on this sheet for the user to enter their own default values, which enables them to define values specific to their country that will be used whenever detailed information about a specific route is not available.

The user can also enter values for the uncertainty of the survey measurements, which are used to calculate the expected error on the output sheet (discussed in section 4.3).This sheet is also where the typical air temperature and pressure are entered.

### 4.2.2 Local data

There are two blue-coloured sheets for the entry of local data in the MIRAVEC tool. The first of these sheets allows the user to enter the details of a road route and obtain an estimate of the fuel consumption and $CO_2$ emissions for that route. The second of the local data sheets can be optionally used to enter the same road route but with slight modifications, for example to show the changes that will result from planned maintenance.  This allows an estimate of the effects of various policies or maintenance actions on fuel consumption to be calculated.

In the entry tables on these sheets, each row represents a sub-length of the route. These sub-lengths:

- Should be of a homogenous nature (i.e. the properties of the sub length should be similar along its whole length, for all of the parameters entered e.g. similar condition, alignment, traffic density and distribution)
- Should be contiguous with the lengths entered in the rows above and below
- Can be of any length (and can vary within the route) but it is expected that they will typically range in length between 50m and 2km.

The first column of the data table can be used to enter a section reference. The entry of this data is optional, as it is only used in the tool to add dotted lines to the graphs in the output statistics to show where section changes are, to aid reading of the data. The next four columns are used to enter the start and end points (in m) for each of the sub lengths and to define the road type (e.g. rural single carriageway, motorway etc.). The start and end points are used to determine the extent of the sub-length. The road type is used in the determination of the average vehicle speed (see section 3.4). These three columns (start and end points, and the definition of road type) are compulsory for all lengths which are entered into the tool. A screen shot of the first 5 columns of this sheet can be seen in Figure 3 below.

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | Length of route: | 3.230 | km | | |
| 2 | Average daily CO2 for route: | 5.971 | Tonnes | | |
| 3 | Route CO2 due to idling: | 0.022 | Tonnes | | |
| 4 | | | | | |
| 5 | Average daily CO2 per km: | 1.849 | Tonnes/km | | |
| 6–17 | | | | | |
| 18 | Location inforamtion | | | | |
| 19 | Section Reference | Start Chainage (m) | End chainage (m) | Motorway, Single or Dual carriageway | Urban or Rural |
| 20 | 9000M90/123 | 0 | 100 | Single | Rural |
| 21 | 9000M90/123 | 100 | 150 | Single | Rural |
| 22 | 9000M90/123 | 150 | 200 | Single | Rural |
| 23 | 9000M90/123 | 200 | 300 | Single | Rural |
| 24 | 9000M90/123 | 300 | 400 | Single | Rural |
| 25 | 9000M90/123 | 400 | 500 | Single | Rural |
| 26 | 9000M90/123 | 500 | 600 | Single | Rural |
| 27 | 9000M90/123 | 600 | 700 | Single | Rural |
| 28 | 9000M90/123 | 700 | 800 | Single | Rural |
| 29 | 9000M90/123 | 800 | 900 | Single | Rural |
| 30 | 9000M90/123 | 900 | 1000 | Single | Rural |

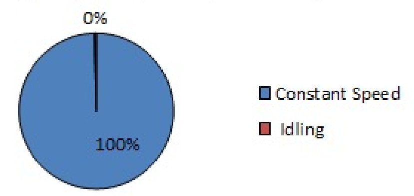



**Figure 3 Screen shot of the first 5 columns of the route sheet**

The remaining columns are split into six groups:

1. Road layout (8 columns)
2. Speed limits (6 columns)
3. Pavement characteristics (5 columns)
4. Traffic (1 column)
5. Traffic speed, for all flow groups (96 columns)
6. Fuel consumption output (6 columns).

If any of the columns in the first 4 groups are left blank, the default values, given in the global data, will be used. Groups 5 and 6 are populated by the tool based on the input values supplied by the user.

The road layout group covers parameters used in the speed calculation models and includes carriageway width, number of lanes and whether a junction is present. The presence of a junction is currently only used in the estimation of speed for urban roads. This is a very simple implementation of the presence of a feature and takes no account of the complexities in traffic flow caused by varying features. It is therefore recommended that for future developments of this tool the effect of junctions on speed is strengthened, both for the urban roads and for the rural roads.

The speed limits group allows the user to enter speed limits for each of the vehicle classes.

The pavement characteristics group is where the user enters details on gradient, curvature, road roughness, macrotexture and rut depth.

Traffic volume is entered as AADT (Annual Average Daily Traffic). AADT is calculated by taking the total volume of traffic for a year and dividing by the number of days in the year.

The next group shows the average speeds and idle time calculated by the speed model, for all flow groups, and allows the user the option to enter their own values to override the values generated by the tool. As use of this functionality is optional and unlikely to be used by the majority of users, the tool has been set up to allow these columns to be hidden. To change whether these columns are shown the user should click on the +/- sign and/or on the black line shown above the column letters.

The last group shows the fuel consumption calculation for each of the sub-lengths.

## *4.3 Output data*

The output of the MIRAVEC tool is shown on the sheet with the green-coloured tab. This sheet shows the estimated fuel consumption and $CO_2$ output for one year of traffic, and fuel consumption for a single pass. In addition the expected error (based on the uncertainty of the road condition parameters) is displayed here. This data is split by vehicle type, and the user can select (using the dropdown boxes) whether to look at all flow groups, or for an individual flow group (e.g. peak weekday traffic).

This sheet also has graphs showing how the $CO_2$ emissions vary over the length of the route. Screen shots of this sheet can be seen in Figure 4, Figure 5 and Figure 6.

All Flow groups

Selection acounts for 100.00% of the year
Selection acounts for 100.00% of the AADT

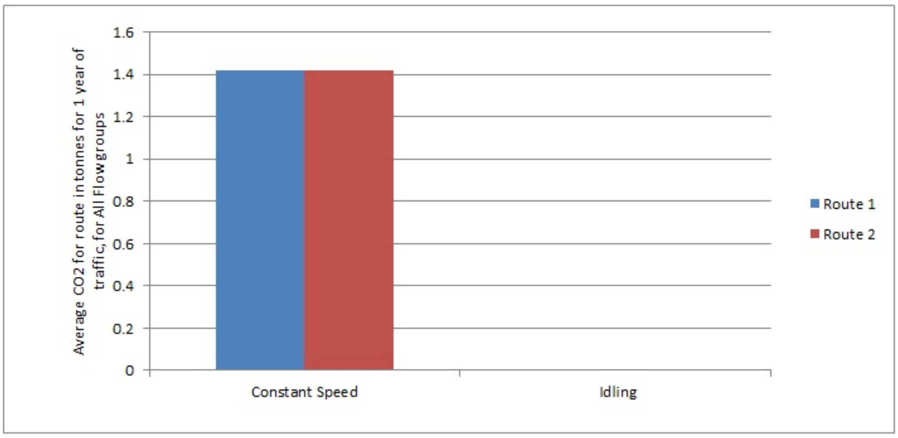
| | Average Fuel Consumption for route in litres for 1 year of traffic, for All Flow groups | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | All | Car (Petrol) | Car (Diesel) | LGV (Petrol) | LGV (Diesel) | HGV | Truck and Trailer | Bus / Coach | Motorbike |
| Route 1 Constant speed | 555,258 | 194,453 | 80,837 | 11,448 | 25,785 | 191,511 | - | 33,169 | 18,056 |
| Route 1 expected error | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| Route 2 Constant speed | 555,258 | 194,453 | 80,837 | 11,448 | 25,785 | 191,511 | - | 33,169 | 18,056 |
| Route 2 expected error | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| Route 1 Idling | 3,168 | 1,149 | 292 | 117 | 264 | 891 | - | 348 | 107 |
| Route 2 Idling | 3,168 | 1,149 | 292 | 117 | 264 | 891 | - | 348 | 107 |
| Route 1 Total | 558,426 | 195,602 | 81,129 | 11,565 | 26,049 | 192,401 | - | 33,517 | 18,163 |
| Route 2 Total | 558,426 | 195,602 | 81,129 | 11,565 | 26,049 | 192,401 | - | 33,517 | 18,163 |

| | Fuel Consumption for route in litres (single pass), average of All Flow groups | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Car (Petrol) | Car (Diesel) | LGV (Petrol) | LGV (Diesel) | HGV | Truck and Trailer | Bus / Coach | Motorbike |
| Route 1 Constant speed | 0.22 | 0.15 | 0.17 | 0.16 | 0.55 | 0.00 | 0.50 | 0.13 |
| Route 2 Constant speed | 0.22 | 0.15 | 0.17 | 0.16 | 0.55 | 0.00 | 0.50 | 0.13 |
| Route 1 Idling | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |
| Route 2 Idling | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |
| Route 1 Total | 0.22 | 0.15 | 0.18 | 0.16 | 0.55 | 0.00 | 0.51 | 0.13 |
| Route 2 Total | 0.22 | 0.15 | 0.18 | 0.16 | 0.55 | 0.00 | 0.51 | 0.13 |

**Figure 4 Screen shot of the outputs sheet part 1**

All Flow groups

Selection acounts for 100.00% of the year
Selection acounts for 100.00% of the AADT




| | Average CO2 for route in tonnes for 1 year of traffic, for All Flow groups | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | All | Car (Petrol) | Car (Diesel) | LGV (Petrol) | LGV (Diesel) | HGV | Truck and Trailer | Bus / Coach | Motorbike |
| Route 1 Constant speed | 1,416.72 | 456.58 | 217.37 | 26.88 | 69.34 | 514.97 | - | 89.19 | 42.40 |
| Route 2 Constant speed | 1,416.72 | 456.58 | 217.37 | 26.88 | 69.34 | 514.97 | - | 89.19 | 42.40 |
| Route 1 Idling | 8.05 | 2.70 | 0.78 | 0.28 | 0.71 | 2.39 | - | 0.94 | 0.25 |
| Route 2 Idling | 8.05 | 2.70 | 0.78 | 0.28 | 0.71 | 2.39 | - | 0.94 | 0.25 |
| Route 1 Total | 1,424.77 | 459.27 | 218.16 | 27.15 | 70.05 | 517.37 | - | 90.13 | 42.65 |
| Route 2 Total | 1,424.77 | 459.27 | 218.16 | 27.15 | 70.05 | 517.37 | - | 90.13 | 42.65 |

**Figure 5 Screen shot of the outputs sheet part 2**

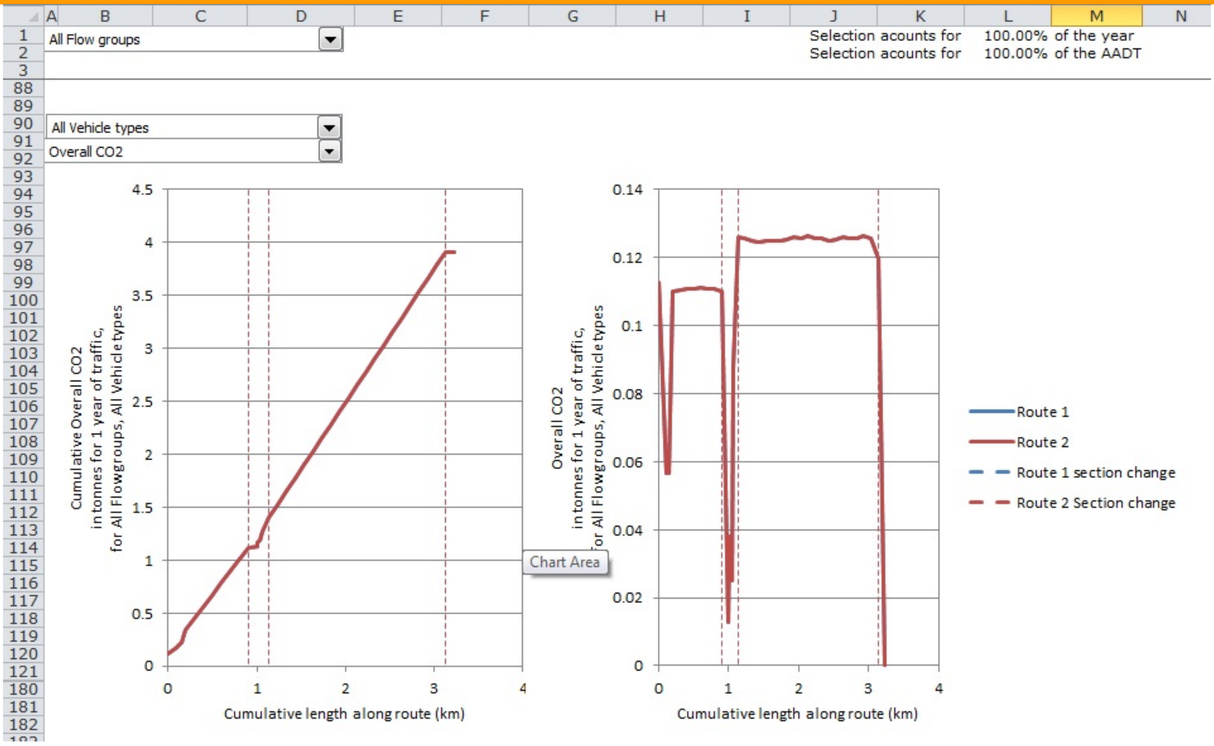



**Figure 6 Screen shot of the outputs sheet part 3**

# 5 Case Studies and Scenarios

The spreadsheet described in chapter 4 has been used to assess the capacity for NRAs to provide energy reducing road infrastructure. This has been achieved by considering different scenarios and then using statistical data available from national road networks to determine the potential benefits to be gained from making improvements to the infrastructure.

It was possible that the results obtained may differ on networks with different geometry, or between main, strategic roads and more minor ones. Therefore, data has been used that represents flat road networks with only small gradients present, data that represents road networks in mountainous regions and also road networks where such extremes of gradient are not seen. Also, local or minor roads have been considered separately to motorways and main or strategic roads. Thus, the networks detailed in Table 16 were used for the general scenarios.

Data from specific lengths were used for the case studies and these are detailed in the relevant sections. The data for these case studies were obtained from a number of selected sites in the appropriate countries. The traffic distributions are based on average values for the networks and can be seen in Appendix A.

**Table 16: Networks used for scenarios**

| Country | Road Type | Local geometry | Length |
|---|---|---|---|
| Austria | Motorway | Mountainous | 105.0 km |
| Austria | Motorway | Non-mountainous | 123.45 km |
| UK | Motorway and strategic roads | Hilly | 204.8 km |
| UK | Motorway and strategic roads | Flat | 163.2 km |
| UK | Local roads | Hilly | 172.1km |
| UK | Local roads | Flat | 93.1km |

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.

## *5.1 Effect of changes to road layout*

### 5.1.1 Scenarios

The number of lanes available to traffic affects the capacity of the road and thus the likelihood that congestion will occur. Thus, the effect of providing an extra lane on congested lengths has been considered.

*Case study*: The hard shoulder has been opened to traffic during peak hours on some congested lengths of UK motorways under the Managed Motorways programme. Data from the M42, which was the first length of road where the Managed Motorway programme was implemented, has been used to calculate the amount of fuel consumed per day if only the 3 lanes in the main carriageway are available and also the fuel consumed if a 4th lane (the hard shoulder) is available. Note, as a simplification, the calculation has been carried out assuming that the additional lane is available at all times whereas, in reality, the use of the additional lane is only allowed during peak times. The route considered consisted of 31km of data.

### 5.1.2 Results

**Table 17: Effect of road layout on $CO_2$ production**

| Number of lanes | Yearly $CO_2$ production per km (in tonnes) | $CO_2$ per km and average vehicle (in kg) |
|---|---|---|
| 3 | 10863 | 0.288 |
| 4 | 9330 | 0.247 |

From this table we can see that increasing the number of lanes has caused a 14% reduction in the $CO_2$ production due to a decrease in the amount of idle time experienced. On routes with lower levels of traffic per lane the addition of a lane would result in reduced or no reduction in fuel consumption.

## 5.2 Effect of regional variations

### 5.2.1 Scenarios

The effect of changing road condition parameters in countries with a different average yearly temperature (0 and 15˚C) has been considered, along with the effect of extreme cold or heat on the fuel consumption (seasonal temperatures). Specifically, the fuel consumption has been calculated for temperatures of 0 and 15 ˚C and also -15, -10, 35 and 45 ˚C for the current road condition parameters on the UK hilly motorway network. The UK hilly network was chosen over the flat network due to the higher traffic levels.

The effect of differing local topology has been considered by calculating fuel consumption for flat, mountainous and moderate networks and the results of this are given in section 5.6.

### 5.2.2 Results

**Table 18: Temperature effects on $CO_2$ production for UK hilly motorway**

| Temperature | Tonnes of $CO_2$ produced per year per km (kg of $CO_2$ produced per average vehicle per km) | Percentage change |
|---|---|---|
| -15 | 1791 (0.256) | +4.43% |
| -10 | 1765 (0.252) | +2.92% |
| 0 | 1715 (0.245) | - |
| 15 | 1644 (0.235) | -4.13% |
| 35 | 1556 (0.222) | -9.26% |
| 45 | 1535 (0.219) | -10.48% |

The table above illustrates that the fuel consumption is linearly related to temperature in the model. This is to be expected after examination of the equations given in section 3.2.

## 5.3 Effect of changes to road alignment

### 5.3.1 Scenarios

Road alignment is not something that can readily be changed, once a road has been constructed. Crossfall is generally set for safety and curvature is often dictated by local topography, landmarks, or the need to connect with other roads. Therefore, only changes to gradient have been considered, specifically:

- The effect on fuel consumption of building a road over the top of a hill, or round the side (i.e. shorter & steeper vs. longer but shallower). [*Note: We have not included the option of using a tunnel here. It is known that there is air resistance is different when driving through a tunnel but this is dependent on the size, length, design and shape of the tunnel. A suitable generic model was not found for this and thus, it was not possible to include this effect in the MIRAVEC tool. If the MIRAVEC tool were to be used to compare a tunnel with a hill/mountain, the fuel savings would be overestimated*].
- The effect of fuel consumption of having a steady gentle slope versus a flat section followed by a steeper slope (same length).
- Using a cutting to reduce gradient.

Case study: A by-pass has been built on a main road in the UK, to avoid a pinch point caused by the presence of traffic lights at a crossroads. The path of the original road is over the top of the hill and this route is 11.8km long, whilst the bypass goes around the side and is 16.0km long.

Case study: There is a large cutting on the M40 motorway near London. The fuel consumption has been calculated for the 7.1km section containing this cutting. The gradient has then been artificially changed so that:

- the slope is uniform for the whole section
- the road is shallower for the first half of the section and then has a steeper slope in the second half.

### 5.3.2 Results

**Table 19: Effect of bypass to avoid hill**

| Scenario | Length | Yearly $CO_2$ production (in tonnes) | | $CO_2$ per km and average vehicle |
|---|---|---|---|---|
| | | Total | Per km | |
| Original route | 11.753 | 21828 | 1857 | 0.191 |
| By-pass | 15.986 | 29492 | 1845 | 0.189 |

We can see from this case study that implementing the by-pass around the hill has caused a 0.65% decrease in the $CO_2$ per km. However because the route is longer, it results in an overall increase in $CO_2$ production (35%).

**Table 20: Effect of change in gradient**

| Scenario | Yearly $CO_2$ production per km (in tonnes) | $CO_2$ per km and average vehicle |
|---|---|---|
| Uniform slope for whole route | 4257 | 0.233 |
| Shallower slope for first half, steeper slope for second half | 4244 | 0.233 |

The case study investigating the effect of changing the gradient found that it did not result in a significant change in the production of $CO_2$. However, it is possible that more extreme changes in gradient or other variations of slope may cause differences in fuel consumption.

## 5.4 *Effect of changes to posted speed limits*

### 5.4.1 Scenarios

The following scenarios have been considered:

- The effect of changing the posted speed limit.
- The effect of changing the maximum speed at which HGVs can travel.
- Reducing speed limit on congested roads at peak times.

At the time of the study, an increase in the UK motorway speed limit from 70 to 80mph (112 to 129km/h) was being discussed, thus the fuel consumption on the UK hilly motorway network has been calculated.

The effect of reducing the speed of HGVs from 96km/h to 80km/h has also been calculated on the UK hilly motorway network.

Case study: The M25 (the London orbital motorway) in the UK is subject to one of the highest volume of traffic in Europe. Many widening schemes have been undertaken, to attempt to cope with this, however, further measures have been needed to try to limit the congestion, including implementation of variable speed limits. To simulate this effect, the fuel consumption for part of the M25 (97.4km between junctions 8 and 16) has been calculated, allowing traffic to travel at the national speed limit (112 km/h for cars, 96 km/h for HGV) and then calculated with a speed limit of 80km/h for all vehicles.

### 5.4.2 Results

**Table 21: Effect of change in posted speed limits for UK hilly motorway**

| Scenario | Yearly $CO_2$ production per km (in tonnes) | $CO_2$ per km and average vehicle | % change in $CO_2$ |
|---|---|---|---|
| Current speed limits (112 km/h for cars, 96 km/h for HGV) | 1677 | 0.239 | - |
| Car speed limit raised to 129km/h | 1695 | 0.242 | +1.11% |
| HGVs speed limits reduced from 96km/h to 80km/h | 1604 | 0.229 | -4.36% |

**Table 22: Effect of change in posted speed limits for part of M25**

| Scenario | Yearly $CO_2$ production per km (in tonnes) | $CO_2$ per km and average vehicle | % change in $CO_2$ |
|---|---|---|---|
| Current speed limits (112 km/h for cars, 96 km/h for HGV) | 6725 | 0.230 | - |
| Speed limit of 80km/h for all vehicles | 5620 | 0.193 | -16.43% |

The model used for the calculation of fuel consumption results in higher values for higher vehicle speeds. This is reflected in the results in the case studies investigating the effects of changing the posted speed limit. However it is worth noting that in both of the case studies in Table 21 the speed differential between the cars/light vehicles and the HGVs is greater in comparison to the initial condition. This is also likely to cause a decrease in speeds attained by the light vehicles due to these vehicles navigating around slower moving vehicles. This effect is not modelled in the spreadsheet, and may be a consideration for future development.

## 5.5 Effect of changes to pavement condition

### 5.5.1 Scenarios

The effect of improving road condition by reducing the maintenance threshold for IRI has been considered by calculating the fuel consumed when all values of IRI >3m/km are replaced with 1m/km (a value that might be expected when a road is maintained for ride quality) in the UK hilly motorway network data. Fuel consumption has also been calculated when all values >2.5m/km are replaced with 1m/km.

A coarse surface texture, represented by a high value of MPD is usually associated with good skid resistance. Thus, roads can be resurfaced if the texture depth falls below a defined threshold. This has been simulated using the UK hilly motorway network and replacing all MPD values <1 mm with 1.2 mm (These values have been chosen based on typical values of MPD found in the UK but may not be appropriate for all countries).

In some cases, coarse textured surfaces can be replaced by newer surfacing materials with smoother textures that still deliver acceptable skid resistance and, furthermore, produce lower tyre-road noise. The UK is a good example, with a significant amount of Hot Rolled Asphalt surfacing present on the trunk road network, which has higher MPD values compared with newer surfacing materials. If the lower textured surfacing were to be used when maintaining the road network, it would result in the overall texture of the network being within a small range. This scenario has been modelled by replacing all MPD values below 1mm or greater than 1.5mm with 1.2mm for the UK hilly motorway network.

### 5.5.2 Results

**Table 23: Effect of maintenance for UK hilly motorway**

| Scenario | Length maintained (in km) | Yearly $CO_2$ production per km (in tonnes) | $CO_2$ per km and average vehicle | % change in $CO_2$ |
|---|---|---|---|---|
| Current condition | n/a | 1677 | 0.239 | - |
| IRI >3.0m/km replaced with 1.0m/km | 1.2 (1%) | 1677 | 0.239 | -0.01% |
| IRI >2.5m/km replaced with 1.0m/km | 6.3 (3%) | 1676 | 0.239 | -0.06% |
| MPD <1.0mm replaced with 1.2mm | 3.9 (2%) | 1677 | 0.239 | +0.01% |
| MPD <1.0mm and >1.5mm replaced with 1.2mm | 124.1 (61%) | 1653 | 0.236 | -1.39% |

It can be seen from Table 23 that changing the maintenance thresholds for of IRI and MPD has a negligible effect on fuel consumption in the UK because the length of the road network that is affected by the change is a low percentage of the overall length. In the final scenario where a more significant proportion of the overall length is affected, we see a larger change in the fuel consumption.

## 5.6 Effect of changes to traffic volume and type

NRAs have little direct control over the volume and type of traffic that uses their networks. Therefore, the extent to which they can influence vehicle energy consumption by changes to the road infrastructure needs to be considered against the affects from differences in the traffic distribution.

### 5.6.1 Scenarios

To illustrate the scale of these changes, we have considered:

- The effect of older vehicles, with higher emissions

- The effect of only allowing HGV to travel overnight, i.e. between 8pm and 6am. This will affect the congestion levels at peak hours.
- The effect of a larger percentage of HGVs.
- The effect of increasing traffic volumes.
- The effect of larger percentage of cars being electric powered.

To achieve this, we have carried out the following on the UK and Austrian motorway networks (detailed in Table 16):

- Calculated the fuel consumed on the road network for the current traffic volume and fleet distribution.
- Calculated the fuel consumed on the road network if all <EURO2/II vehicles are replaced by EURO 2/II vehicles.
- Calculated the fuel consumed on the road network if all <EURO3/III vehicles are replaced by EURO 3/III vehicles.
- Calculated the fuel consumed if all HGVs travel between 8pm and 6am
- Calculated the fuel consumed if 10% more of the vehicle fleet consisted of HGVs
- Calculated the fuel consumed in there was 50% more traffic
- Calculated the fuel consumed if 10% of all cars were electric.
- Calculated the fuel consumed if the MPD or IRI increased by 10% for the current traffic volume and fleet distribution, for the current traffic volume and 10% more HGVs, for increased traffic volume and if 10% of the cars were electric.

### 5.6.2 Results

The results for these scenarios are given in Table 24 for all motorway networks considered, whilst the results of the effects of increasing the MPD by 10% are given in Table 25 and those for increasing IRI by 10% are given in Table 26 for these networks. The same results for the UK local road networks are given in Table 27, Table 28 and Table 29.

On examination of Table 24 to Table 29 we can see a mixture of effects. The majority of the trends seen follow the expected patterns, for example replacing old vehicle classes with newer classes results in a modest reduction in the fuel consumption. There is however two instances, which on initial inspection, appear to be counter to expectations. Firstly the scenario of a 50% increase in traffic flow which, as expected, causes the overall $CO_2$ per year to increase. However in most cases the $CO_2$ per vehicle (the value in the brackets) *decreases*. This is because the increase in traffic has caused a decrease in traffic speed (reducing fuel consumption), but the traffic has not increased to a level which produces significant idle time (which would increase fuel consumption). Secondly, the general decrease in $CO_2$ per km seen when IRI is increased by 10% on the local roads. This is again due to the decrease in traffic speed, due to the rougher surface.

In addition it can be seen that $CO_2$ per vehicle is in general higher for the UK case studies in comparison to the Austrian case studies. This is due, in part, to the differences in the traffic distribution used for these case studies. The traffic distributions used can be seen in Appendix A.

**Table 24: $CO_2$ production for scenarios for Motorway networks for current condition**

| Network | UK flat motorway | | UK hilly motorway | | Austrian motorway | | Austrian mountainous motorway | |
|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Tonnes of $CO_2$ produced per year per km (kg of $CO_2$ produced per average vehicle per km*) and % change** | | | | | | | |
| Current traffic volume and fleet distribution. | 3818 (0.208) | - | 1677 (0.239) | - | 2791 (0.144) | - | 954 (0.148) | - |
| Current traffic volume but <EURO2/II vehicles replaced by EURO 2/II vehicles. | 3814 (0.207) | -0.10% | 1675 (0.239) | -0.10% | 2749 (0.141) | -1.52% | 940 (0.146) | -1.52% |
| Current traffic volume but <EURO3/III vehicles replaced by EURO 3/III vehicles. | 3806 (0.207) | -0.30% | 1672 (0.239) | -0.30% | 2702 (0.139) | -3.20% | 924 (0.144) | -3.17% |
| HGVs restricted to travel between 8pm and 6am | 2701 (0.161) | -29.24% | 1183 (0.188) | -29.42% | 2356 (0.13) | -15.57% | 897 (0.15) | -6.01% |
| 10% more of the vehicle fleet consisting of HGVs | 4881 (0.265) | +27.85% | 2022 (0.289) | +20.59% | 3668 (0.189) | +31.42% | 1264 (0.197) | +32.52% |
| A 50% increase in traffic | 5390 (0.195) | +41.19% | 2507 (0.239) | +49.52% | 4241 (0.146) | +51.94% | 1381 (0.143) | +44.69% |
| 10% of cars powered by electricity** | 3642 (0.198) | -4.60% | 1600 (0.228) | -4.58% | 2609 (0.134) | -6.53% | 893 (0.139) | -6.43% |

* The spreadsheet calculates the amount of $CO_2$ produced for all vehicles. The figure presented here is this value divided by the average AADT*365 on the site

** To calculate $CO_2$ production for electric cars is very difficult, since the electricity can be obtained from a number of sources, some of which have large $CO_2$ output, some having none. Thus we have needed to make an assumption for these vehicles within this scenario and this was that these vehicles have no $CO_2$ associated with them.

**Table 25: $CO_2$ production for scenarios for Motorway networks with MPD increased by 10%**

| Network | UK flat motorway | | UK hilly motorway | | Austrian motorway | | Austrian mountainous motorway | |
|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Tonnes of $CO_2$ produced per year per km (kg of $CO_2$ produced per average vehicle per km*) and % change** | | | | | | | |
| Current traffic volume and fleet distribution. | 3835 (0.209) | - | 1685 (0.242) | - | 2796 (0.144) | - | 956 (0.149) | - |
| 10% more of the vehicle fleet consisting of HGVs | 4904 (0.267) | +27.88% | 2032 (0.292) | +20.62% | 3675 (0.189) | +31.45% | 1267 (0.197) | +32.55% |
| A 50% increase in traffic | 5415 (0.196) | +41.22% | 2519 (0.24) | +49.52% | 4248 (0.146) | +51.94% | 1383 (0.143) | +44.70% |
| 10% of cars powered by electricity | 3658 (0.199) | -4.60% | 1608 (0.231) | -4.58% | 2613 (0.135) | -6.53% | 894 (0.139) | -6.43% |

**Table 26: $CO_2$ production for scenarios for Motorway networks with IRI increased by 10%**

| Network | UK flat motorway | | UK hilly motorway | | Austrian motorway | | Austrian mountainous motorway | |
|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Tonnes of $CO_2$ produced per year per km (kg of $CO_2$ produced per average vehicle per km*) and % change** | | | | | | | |
| Current traffic volume and fleet distribution. | 3867 (0.21) | - | 1680 (0.242) | - | 2794 (0.144) | - | 956 (0.149) | - |
| 10% more of the vehicle fleet consisting of HGVs | 4927 (0.268) | +27.88% | 2026 (0.291) | +20.62% | 3673 (0.189) | +31.45% | 1267 (0.197) | +32.55% |
| A 50% increase in traffic | 5454 (0.198) | +41.22% | 2511 (0.239) | +49.52% | 4245 (0.146) | +51.94% | 1383 (0.143) | +44.70% |
| 10% of cars powered by electricity | 3688 (0.201) | -4.60% | 1603 (0.23) | -4.58% | 2612 (0.134) | -6.53% | 894 (0.139) | -6.43% |

**Table 27: $CO_2$ production for scenarios for local road networks for current condition**

| Network | UK flat local roads | | UK hilly local roads | |
|---|---|---|---|---|
| Scenario | Tonnes of $CO_2$ produced per year per km (kg of $CO_2$ produced per average vehicle per km*) and % change | | | |
| Current traffic volume and fleet distribution. | 397 (0.055) | - | 389 (0.055) | - |
| 10% more of the vehicle fleet consisting of HGVs | 500 (0.07) | +25.94% | 490 (0.07) | +25.96% |
| A 50% increase in traffic | 694 (0.048) | +74.81% | 682 (0.049) | +75.32% |
| 10% of cars powered by electricity | 373 (0.052) | -6.05% | 375 (0.054) | -3.60% |

* The spreadsheet calculates the amount of $CO_2$ produced for all vehicles. The figure presented here is this value divided by the average AADT*365 on the site

**Table 28: $CO_2$ production for scenarios for local road networks with MPD increased by 10%**

| Network | UK flat local roads | | UK hilly local roads | |
|---|---|---|---|---|
| Scenario | Tonnes of $CO_2$ produced per year per km (kg of $CO_2$ produced per average vehicle per km*) and % change | | | |
| Current traffic volume and fleet distribution. | 398 (0.056) | - | 390 (0.056) | - |
| 10% more of the vehicle fleet consisting of HGVs | 502 (0.07) | +26.13% | 493 (0.07) | +26.41% |
| A 50% increase in traffic | 697 (0.049) | +75.13% | 685 (0.049) | +75.64% |
| 10% of cars powered by electricity | 385 (0.054) | -3.27% | 377 (0.054) | -3.33% |

**Table 29: $CO_2$ production for scenarios for local road networks with IRI increased by 10%**

| Network | UK flat local roads | | UK hilly local roads | |
|---|---|---|---|---|
| Scenario | Tonnes of $CO_2$ produced per year per km (kg of $CO_2$ produced per average vehicle per km*) and % change | | | |
| Current traffic volume and fleet distribution. | 395 (0.055) | - | 387 (0.055) | - |
| 10% more of the vehicle fleet consisting of HGVs | 499 (0.07) | +26.33% | 489 (0.07) | +26.36% |
| A 50% increase in traffic | 692 (0.048) | +75.19% | 681 (0.049) | +75.97% |
| 10% of cars powered by electricity | 382 (0.053) | -3.29% | 374 (0.053) | -3.36% |

## 5.7 *Ability of NRAs to provide energy reducing infrastructure*

The preceding case studies in this section have shown a variety of ways in which NRAs can potentially modify their infrastructure in order to reduce fuel consumption. 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.

There are multiple intervention options available to NRAs and the effectiveness of each intervention will depend on the condition and traffic levels of the site. For example the introduction of an additional lane can have a large impact on fuel consumption on sites where idle time/congestion is a significant factor (section 5.1 showed an annual saving of 1500 tonnes of $CO_2$ as a result of adding an extra lane to 31km of motorway). However, this same treatment would have little or no impact on a site with lower traffic densities. Also, the NRA would need to consider whether increasing the capacity would lead to increased traffic volume in the long term, leading to future congestion problems.

It is expected that achieving a better standard of roughness or lower texture depth would reduce vehicle fuel consumption. Section 5.5 shows that for the UK network, eliminating the roughest areas on the motorway network has a negligible effect, whereas a saving of 24 tonnes $CO_2$ per year could be achieved by introducing surfaces that were less textured but still delivered acceptable friction performance. However, further examination of Table 24, Table 25 and Table 26 shows that the reduction of fuel consumption varies from site to site. For example reducing IRI by 10% results in a reduction in $CO_2$ of 49 tonnes per km per year on the UK flat motorway route and 3 tonnes per km per year on the hilly route. This is mainly due to the differences in traffic levels on these two routes as the $CO_2$ per vehicle drops by 0.002 and 0.003 respectively. However it is also influenced by the initial condition of the sites. A similar scenario can be seen when reducing MPD by 10%, which results in drop of 5 tonnes and 2 tonnes of $CO_2$ for the Austrian motorway and Austrian mountainous motorway, respectively.

Reducing the gradient of a route can significantly affect the fuel consumption per km. However if the new route is sufficiently longer than the original then it can increase the overall fuel consumption. The case study in section 5.3 showed that the bypass that avoided a hill may have reduced the $CO_2$ production by an estimated 12 tonnes per km per year, but as the route was 4km longer, the net effect was an increase of over 7500 tonnes per year.

The analysis did not find any strong combination effects, with the values of fuel consumption increasing by a similar percentage as a result of changing one parameter, regardless of the values of the other parameters. For example, Table 24, Table 25 and Table 26, in section 5.6, show that the fuel consumption per vehicle changes by a similar value due to a 10% increase in MPD in each of the four traffic scenarios. This is also replicated in for the case of a 10% increase in IRI.

The nature of the models implemented within the spreadsheet means that 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 have the converse effect, meaning that the impact of interventions that the NRA carries out will increase. As noted in section 5.6, there can be significant differences between NRAs for similar classes of road as a result of the different distribution of traffic using the road.

Therefore to assess the potential to reduce fuel consumption by the vehicles using their networks, NRAs will need to investigate schemes on a case by case basis and provide input data, particularly traffic flow, appropriate to the case being considered. The MIRAVEC spreadsheet tool can be used for this purpose and it is recommended that the following methodology be used:

1. Populate route 1 with the current condition of the route, with either current or future traffic levels.
2. 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)
3. 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.
4. Consider the differences in fuel consumption found from step 3 in relation to other factors, e.g. journey time, road surface condition, cost of works, noise etc.
5. Repeat for any additional proposed interventions.

# 6 Compatibility with other projects in the "Energy – Sustainability and Energy Efficient Management of Roads" call

This section explores how the MIRAVEC tool can be used in conjunction with the outputs from the other projects within the same funding round.

## 6.1 CEREAL

The aim of the CEREAL project was to build a model that can easily calculate the most important contributions of $CO_2$ emission and consequently guide a reduction strategy in road constructions.

The CEREAL model focuses on the $CO_2$ emissions from maintenance and rehabilitation of in-service roads (90% of most road works) and also new road construction. Included in the calculation of $CO_2$ emissions for a project are estimates for the emissions emanating from vehicles transporting materials to the site.

One of the outputs of the MIRAVEC model is a calculation of how much fuel an individual vehicle would consume when travelling over the route entered by the user. This is split into vehicle category (car, LGV, HGV, truck and trailer, bus/coach and motorbike) and can also be specified for the day and time of day that the vehicle is likely to travel.

A user could input data into the MIRAVEC model, for the routes that vehicles transporting materials to site are likely to take. Then the appropriate fuel consumption could be obtained from and this figure converted into $CO_2$ emissions, using the formula 2689g/litre of diesel (http://www.epa.gov/otaq/climate/documents/420f11041.pdf).

## 6.2 LICCER

The aim of the LICCER study was to develop an easy to use model, including a framework and guidelines, based on existing tools and methodologies for Life Cycle Assessment of road infrastructure that can be used within an EIA process in the early stage of transport planning. The model includes site-dependent aspects of the planning such as the choice of a plain road, bridge or tunnel. The life-cycle model will focus on energy use and contribution to climate change. By using an LCA model there will however be an option to include also other environmental impacts.

The model has been based on already existing models and tools and includes guidelines on how to use them. Recommendations on how to use the model within the EIA processes has also been provided.

The LICCER model calculates fuel consumption over the lifetime of a road, including fuel use by traffic travelling over the road whilst it is in service. Fuel consumption is calculated for the whole site being considered using consumption values for diesel trucks with trailer, diesel trucks with no trailer, light diesel vehicles, and light petrol vehicles.

These fuel consumption values could be obtained from the MIRAVEC model, if the user were to input the average condition data for the pavement lifetime being considered (this would need to be predicted using deterioration models and knowledge of likely maintenance).

# 7 Summary

For this work package a spreadsheet tool has been developed to help NRAs to assess and achieve reductions in energy use by the vehicles using their network. For the first time, this tool has brought together a number of different models and studies of fuel consumption and 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 effect of vehicle fleet composition on fuel consumption.

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 a reduced fuel consumption in situations where this is accompanied by a reduction in vehicle speed.

This tool can also be used to provide inputs for the CEREAL and LICCER tools, as discussed in section 6.

# Sources

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# Nomenclature

| | |
|---|---|
| *Ayz* | Projected frontal area of the vehicle ($m^2$) |
| $C_A$ | Tyre stiffness parameter (N/rad) |
| $C_b$ | Parameter for bearing resistance |
| $C_d$ | Air dynamic coefficient (dimensionless) |
| *crf* | Crossfall (%) |
| $C_{r0}$, $C_{r1}$, $C_{r2}$ | Rolling resistance parameters |
| $C_{r3}$ | Estimated parameter for the stiffness inverse (rad/N) |
| *dns* | Density of air ($kg/m^3$) |
| *dv/dt* | Acceleration level (m/s2) |
| $F_{acc}$ | Acceleration resistance from vehicle mass (N) |
| $F_{air}$ | Air resistance (N) |
| $F_b$ | Wheel bearing resistance (N) |
| *Fc* | Fuel consumption |
| $F_{gr}$ | Gradient resistance (N) |
| $F_r$ | Rolling resistance (N) |
| $F_{side}$ | Resistance caused by the side force (N) |
| $F_x$ | Total driving resistance |
| $F_y$ | Side force acting on the vehicle (N) |
| $F_z$ | Vertical load per tyre (N) |
| *gr* | Longitudinal slope (rad) |
| *IRI* | Road roughness measure (m/km) |
| *J* | Inertial moment per wheel ($kgm^2$) |
| *KJ* | Correction factor of J to include moving parts in the transmission system |
| *m* | Total mass of the vehicle (kg) |
| *MPD* | Mean Profile Depth, macrotexture measure (mm) |
| *MW* | Motorway |
| $P_{air}$ | Air pressure (mbar) |
| *R* | Radius of the road curvature (m) |
| *rwh* | Wheel radius (m) |
| *T* | Ambient temperature (°C) |
| *TS* | Traffic situation |
| *v* | Vehicle velocity (m/s) |

# Appendix A. Traffic data used for case studies

**Table 30: Traffic distribution used for Austrian motorways**

| | | Pre-Euro 1 | Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5 | Euro 6 |
|---|---|---|---|---|---|---|---|---|
| Cars | Petrol <1400cc | 1.8% | 0.7% | 0.7% | 1.5% | 1.8% | 1.2% | |
| | Petrol 1400-2000cc | 2.3% | 1.1% | 2.2% | 3.6% | 3.6% | 3.6% | 1.5% |
| | Petrol >2000cc | | | 0.1% | 0.7% | 3.6% | 1.5% | |
| | Diesel <1400cc | 2.0% | 0.9% | 1.5% | 3.6% | 2.9% | 1.2% | |
| | Diesel 1400-2000cc | 3.2% | 1.5% | 2.2% | 3.6% | 5.8% | 4.4% | 2.3% |
| | Diesel >2000cc | | | 0.2% | 0.2% | 2.9% | 2.9% | |
| | LPG | N/A | | | | | | |
| Light goods Vehicles | LGV N1(I) Petrol | | | | | | | |
| | LGV N1(I) Diesel | 0.2% | 0.1% | 0.2% | 0.3% | 0.3% | 0.4% | 0.4% |
| | LGV N1(II) Petrol | | | | | | | |
| | LGV N1(II) Diesel | 0.2% | 0.1% | 0.2% | 0.3% | 0.3% | 0.4% | 0.4% |
| | LGV N1(III) Petrol | | | | | | | |
| | LGV N1(III) Diesel | 0.2% | 0.1% | 0.2% | 0.3% | 0.3% | 0.4% | 0.4% |
| Heavy goods vehicles | HGV Rigid Diesel 3.5-7.5t | 0.4% | 0.1% | 1.0% | 2.8% | 0.4% | 0.5% | 2.8% |
| | HGV Rigid Diesel 7.5-12 t | | | | | | | |
| | HGV Rigid Diesel 12-14 t | | | | | | | |
| | HGV Rigid Diesel 14-20 t | | | | | | | |
| | HGV Rigid Diesel 20-26 t | | | | | | | |
| | HGV Rigid Diesel 26-28 t | | | | | | | |
| | HGV Rigid Diesel 28-32 t | | | | | | | |
| | HGV Rigid Diesel >32 t | | | | | | | |
| | HGV artic Diesel 14-20 t | | | 0.1% | 0.1% | | 0.1% | 0.1% |
| | HGV artic Diesel 20-28 t | | | | | | | |
| | HGV artic Diesel 28-34 t | | | | | | | |
| | HGV artic Diesel 34-40 t | | | | | | | |
| | HGV artic Diesel 40-50 t | | | | | | | |
| | Truck and Trailer | | | | | | 0.1% | 0.1% |
| Bus and coach | Bus Diesel <15t | | | | 0.1% | | 0.1% | 0.1% |
| | Bus Diesel 15-18t | | | | | | | |
| | Bus Diesel >18t | | | | | | | |
| | Coach Diesel 15-18t | | | | | | 0.1% | |
| | Coach Diesel >18t | | | | | | | |
| Motorbikes | Moped <50cc | | 0.5% | 1.1% | | N/A | N/A | N/A |
| | M/cycle, 2-stroke Petrol <=150 | | | | 1.1% | N/A | N/A | N/A |
| | M/cycle, 2-stroke Petrol 150-250 | | | | 1.1% | N/A | N/A | N/A |
| | M/cycle, 4-stroke Petrol <=150 | | | 1.1% | 1.1% | N/A | N/A | N/A |
| | M/cycle, 4-stroke Petrol 150-250 | | | 1.1% | 1.1% | N/A | N/A | N/A |
| | M/cycle, 4-stroke Petrol 250-750 | | | 1.1% | 2.1% | N/A | N/A | N/A |
| | M/cycle, 4-stroke Petrol >750 | | | | 1.1% | N/A | N/A | N/A |
| Summary | | 10.3% | 5.1% | 13.0% | 24.7% | 21.9% | 16.9% | 8.1% |

**Table 31: Traffic distribution used for UK motorways**

| | | Pre-Euro 1 | Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5 | Euro 6 |
|---|---|---|---|---|---|---|---|---|
| Cars | Petrol <1400cc | 0.4% | 0.1% | 0.8% | 4.9% | 5.3% | 4.4% | |
| | Petrol 1400-2000cc | 0.3% | 0.1% | 0.7% | 4.1% | 4.5% | 3.7% | |
| | Petrol >2000cc | 0.1% | | 0.1% | 0.8% | 0.9% | 0.8% | |
| | Diesel <1400cc | | | 0.1% | 0.9% | 1.7% | 1.9% | |
| | Diesel 1400-2000cc | | 0.1% | 0.5% | 5.5% | 10.2% | 12.0% | |
| | Diesel >2000cc | | | 0.2% | 2.0% | 3.6% | 4.3% | |
| | LPG | N/A | | | | | | |
| Light goods Vehicles | LGV N1(I) Petrol | | | | | | | |
| | LGV N1(I) Diesel | | | 0.1% | 0.4% | 1.3% | 1.1% | |
| | LGV N1(II) Petrol | | | | | | | |
| | LGV N1(II) Diesel | | | 0.1% | 0.4% | 1.2% | 1.0% | |
| | LGV N1(III) Petrol | | | | 0.1% | 0.1% | | |
| | LGV N1(III) Diesel | | | 0.1% | 0.9% | 3.0% | 2.6% | |
| Heavy goods vehicles | HGV Rigid Diesel 3.5-7.5t | | | 0.1% | 0.4% | 0.3% | 0.7% | 0.1% |
| | HGV Rigid Diesel 7.5-12 t | | | | 0.1% | 0.1% | 0.1% | |
| | HGV Rigid Diesel 12-14 t | | | | | | 0.1% | |
| | HGV Rigid Diesel 14-20 t | | | | 0.1% | 0.1% | 0.3% | |
| | HGV Rigid Diesel 20-26 t | | | | 0.2% | 0.1% | 0.3% | |
| | HGV Rigid Diesel 26-28 t | | | | 0.1% | 0.1% | 0.2% | |
| | HGV Rigid Diesel 28-32 t | | | | 0.2% | 0.2% | 0.4% | 0.1% |
| | HGV Rigid Diesel >32 t | | | | | | 0.1% | |
| | HGV artic Diesel 14-20 t | | | | | | 0.1% | |
| | HGV artic Diesel 20-28 t | | | | | | 0.1% | |
| | HGV artic Diesel 28-34 t | | | | | | 0.1% | |
| | HGV artic Diesel 34-40 t | | | | 0.2% | 0.3% | 1.6% | 0.3% |
| | HGV artic Diesel 40-50 t | | | | 0.4% | 0.5% | 2.6% | 0.4% |
| | Truck and Trailer | | | | | | | |
| Bus and coach | Bus Diesel <15t | | | | | | | |
| | Bus Diesel 15-18t | | | | | | | |
| | Bus Diesel >18t | | | | | | | |
| | Coach Diesel 15-18t | | | | 0.1% | | 0.1% | |
| | Coach Diesel >18t | | | | 0.1% | | 0.1% | |
| Motorbikes | Moped <50cc | | | | | N/A | N/A | N/A |
| | M/cycle, 2-stroke Petrol <=150 | | | | | N/A | N/A | N/A |
| | M/cycle, 2-stroke Petrol 150-250 | | | | | N/A | N/A | N/A |
| | M/cycle, 4-stroke Petrol <=150 | | | | | N/A | N/A | N/A |
| | M/cycle, 4-stroke Petrol 150-250 | | | | | N/A | N/A | N/A |
| | M/cycle, 4-stroke Petrol 250-750 | | | | | N/A | N/A | N/A |
| | M/cycle, 4-stroke Petrol >750 | 0.1% | 0.2% | 0.1% | 0.4% | N/A | N/A | N/A |
| Summary | | 0.9% | 0.5% | 3.1% | 22.1% | 33.5% | 38.8% | 1.1% |

**Table 32: Traffic distribution used for UK local roads**

| | | Pre-Euro 1 | Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5 | Euro 6 |
|---|---|---|---|---|---|---|---|---|
| Cars | Petrol <1400cc | 0.40% | 0.11% | 0.91% | 5.26% | 5.67% | 4.74% | 0.00% |
| | Petrol 1400-2000cc | 0.45% | 0.13% | 1.01% | 5.82% | 6.27% | 5.25% | 0.00% |
| | Petrol >2000cc | 0.13% | 0.04% | 0.29% | 1.66% | 1.79% | 1.50% | 0.00% |
| | Diesel <1400cc | 0.00% | 0.01% | 0.05% | 0.54% | 1.00% | 1.18% | 0.00% |
| | Diesel 1400-2000cc | 0.00% | 0.07% | 0.37% | 4.32% | 8.02% | 9.46% | 0.00% |
| | Diesel >2000cc | 0.00% | 0.03% | 0.18% | 2.12% | 3.93% | 4.63% | 0.00% |
| | LPG | N/A | | | | | | |
| Light goods Vehicles | LGV N1(I) Petrol | 0.00% | 0.00% | 0.01% | 0.01% | 0.01% | 0.00% | 0.00% |
| | LGV N1(I) Diesel | 0.00% | 0.01% | 0.08% | 0.50% | 1.72% | 1.49% | 0.00% |
| | LGV N1(II) Petrol | 0.04% | 0.01% | 0.06% | 0.08% | 0.08% | 0.05% | 0.00% |
| | LGV N1(II) Diesel | 0.00% | 0.00% | 0.02% | 0.12% | 0.41% | 0.36% | 0.00% |
| | LGV N1(III) Petrol | 0.02% | 0.00% | 0.02% | 0.03% | 0.03% | 0.02% | 0.00% |
| | LGV N1(III) Diesel | 0.01% | 0.02% | 0.22% | 1.32% | 4.56% | 3.95% | 0.00% |
| Heavy goods vehicles | HGV Rigid Diesel 3.5-7.5t | 0.00% | 0.00% | 0.04% | 0.27% | 0.22% | 0.53% | 0.08% |
| | HGV Rigid Diesel 7.5-12 t | 0.00% | 0.00% | 0.01% | 0.05% | 0.04% | 0.10% | 0.01% |
| | HGV Rigid Diesel 12-14 t | 0.00% | 0.00% | 0.00% | 0.02% | 0.02% | 0.04% | 0.01% |
| | HGV Rigid Diesel 14-20 t | 0.00% | 0.00% | 0.01% | 0.09% | 0.08% | 0.18% | 0.03% |
| | HGV Rigid Diesel 20-26 t | 0.00% | 0.00% | 0.02% | 0.13% | 0.11% | 0.25% | 0.04% |
| | HGV Rigid Diesel 26-28 t | 0.00% | 0.00% | 0.01% | 0.07% | 0.06% | 0.14% | 0.02% |
| | HGV Rigid Diesel 28-32 t | 0.00% | 0.00% | 0.02% | 0.14% | 0.12% | 0.28% | 0.04% |
| | HGV Rigid Diesel >32 t | 0.00% | 0.00% | 0.01% | 0.04% | 0.03% | 0.07% | 0.01% |
| | HGV artic Diesel 14-20 t | 0.00% | 0.00% | 0.00% | 0.00% | 0.01% | 0.03% | 0.01% |
| | HGV artic Diesel 20-28 t | 0.00% | 0.00% | 0.00% | 0.01% | 0.01% | 0.04% | 0.01% |
| | HGV artic Diesel 28-34 t | 0.00% | 0.00% | 0.00% | 0.00% | 0.01% | 0.03% | 0.01% |
| | HGV artic Diesel 34-40 t | 0.00% | 0.00% | 0.00% | 0.07% | 0.11% | 0.52% | 0.08% |
| | HGV artic Diesel 40-50 t | 0.00% | 0.00% | 0.01% | 0.12% | 0.18% | 0.85% | 0.14% |
| | Truck and Trailer | | | | | | | |
| Bus and coach | Bus Diesel <15t | 0.00% | 0.00% | 0.01% | 0.05% | 0.03% | 0.06% | 0.01% |
| | Bus Diesel 15-18t | 0.00% | 0.00% | 0.03% | 0.10% | 0.06% | 0.13% | 0.01% |
| | Bus Diesel >18t | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| | Coach Diesel 15-18t | 0.00% | 0.00% | 0.01% | 0.03% | 0.02% | 0.04% | 0.00% |
| | Coach Diesel >18t | 0.00% | 0.00% | 0.01% | 0.03% | 0.02% | 0.04% | 0.00% |
| Motorbikes | Moped <50cc | | | | | N/A | N/A | N/A |
| | M/cycle, 2-stroke Petrol <=150 | | | | | N/A | N/A | N/A |
| | M/cycle, 2-stroke Petrol 150-250 | | | | | N/A | N/A | N/A |
| | M/cycle, 4-stroke Petrol <=150 | 0.01% | 0.04% | 0.02% | 0.17% | N/A | N/A | N/A |
| | M/cycle, 4-stroke Petrol 150-250 | 0.01% | 0.01% | 0.01% | 0.04% | N/A | N/A | N/A |
| | M/cycle, 4-stroke Petrol 250-750 | 0.08% | 0.10% | 0.04% | 0.21% | N/A | N/A | N/A |
| | M/cycle, 4-stroke Petrol >750 | 0.05% | 0.08% | 0.04% | 0.20% | N/A | N/A | N/A |
| Summary | | 1.21% | 0.65% | 3.50% | 23.59% | 34.59% | 35.97% | 0.50% |