REVIEW OF VEHICLE EMISSION MODELLING AND THE ISSUES FOR NEW ZEALAND

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ABSTRACT

This paper[2] briefly reviews key European and American vehicle emission models including NAEI, COPERT, HBEFA, ARTEMIS and MOBILE. Their databases, modelling approaches, strengths, shortcomings and their relevance to New Zealand are discussed. The classification and application of vehicle emission models are also summarised. Some traffic situation models, especially the recently-released ARTEMIS model, seem to have some advantages as they can simulate driving dynamics in a more reliable but relatively simple way. The ARTEMIS database is probably the most comprehensive one developed to date. Two New Zealand models are also reviewed: the Ministry of Transport's VFEM dating from 1998 and the Auckland Regional Council's more recent VEPM. It is believed that these NZ models have significant room for improvement, especially as to the accuracy of emission factors for the unique NZ vehicle fleet. The paper identifies the issues associated with the NZ models and recommends possible ways for improving them. Furthermore, emission data for heavy-duty vehicles are especially scarce for the New Zealand fleet and collection of these data should be given priority.

1 INTRODUCTION

Road motor vehicles are gross energy consumers and considered to be one of the major air pollution sources in urban areas. They can emit a large amount of greenhouse gases and also harmful air pollutants such as carbon monoxide (CO), oxides of nitrogen (NO_x), particulate matter (PM), sulphur dioxide (SO_2) and volatile organic compounds (VOCs). The estimation and projection of air pollutant emissions from motor vehicles are important for transportation planning, air quality modelling, and environmental impact assessment. Vehicle emission models are among the key tools that can be used to fulfil these tasks. A wide variety of vehicle emission models have been developed around the world and several literature reviews have been published (e.g. Esteves-Booth et al., 2002; Boulter et al., 2007; Abo-Qudais and Qdais, 2005). A few models of this kind are also available in New Zealand, including the Ministry of Transport's (MOT) Vehicle Fleet Emissions Model (VFEM) (MOT, 1998a), and the Auckland Regional Council's (ARC) Vehicle Emissions Prediction Model (VEPM) (Kar et al., 2008). The two NZ models have not previously been reviewed in the literature, although they have been widely applied in NZ in a range of

[1] The opinions expressed in this paper are those of the authors, and do not necessarily represent the views of the Ministry of Transport.
[2] The information presented in this paper is primarily taken from an in-house research report prepared for the Ministry of Transport. For more information, including a full list of references, please contact the authors.

situations (e.g. for vehicle fleet emission policy testing, emission inventory development, and providing inputs to air quality dispersion models).

This paper briefly reviews key European and American vehicle emission models, including NAEI (National Atmospheric Emissions Inventory), COPERT (Computer Programme to Calculate Emissions from Road Transport), HBEFA (Handbook Emission Factors for Road Transport), ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems) and MOBILE. Their databases, modelling approaches, strengths, shortcomings and their relevance to New Zealand are discussed. The classification of vehicle emission models and the circumstances of their application are summarised. The two New Zealand models are also reviewed. The issues associated with these NZ models are identified and possible improvements are recommended. The paper also touches on the need to consider Japanese emission models, given the scale of used vehicles imported from Japan in the NZ fleet and their likely differences from European and American vehicles.

2 CLASSIFICATION OF VEHICLE EMISSION MODELS

There are different ways of classifying vehicle emission models in the literature, although there is a considerable degree of overlap between them. Based on the modelling approach and aggregate levels of emission factors, the models can be classified into the following four types:

- ***Aggregated emission factor models.*** Models of this type operate at the simplest level, with a single emission factor being used to represent a particular broad category of vehicle and a general driving condition (e.g. urban roads, rural roads, and motorways). These include NAEI and MOBILE at their normal high level of application, although at a more detailed level these two models also follow the average speed approach.
- ***Average speed models.*** These are the most commonly used models, based on the assumption that average emissions over a trip vary according to the average speed of the trip. A well-known example of this type is COPERT. The ARC's VEPM also belongs to this category.
- ***Traffic situation models.*** This approach incorporates both speed and driving dynamics into emission estimation. Traffic situations are defined qualitatively according to road types and traffic conditions (e.g. urban free flow, urban congested, stop-and-go). Good examples of this type include HBEFA and ARTEMIS. MOT's VFEM also follows this approach.
- ***Instantaneous or modal models.*** Models of this type operate at the highest level of complexity. They no longer attempt to calculate average emissions for a trip, but assign an emission rate to each instantaneous combination of two variables, typically at a one-second interval. One of the variables is instantaneous speed and the other is the acceleration rate, or the product of the speed and acceleration. They are based on the principle that the engine power determines the rate of emission, and that the power required depends on the speed and the acceleration rate. Note that some of the newer instantaneous models follow a power-based approach (Boulter et al., 2007). The PHEM (Passenger car and Heavy duty Emission Model) falls into this

category (PHEM is used in both HBEFA and ARTEMIS for heavy-duty vehicles).

In the literature, emission models are often also placed into two broad categories: macro-scale and micro-scale models (e.g. André et al., 2006; Zachariadis and Samaras 1997). The macro-scale models (including aggregated emission factor models, average speed models and some traffic situation models) estimate emissions in a large area, e.g. an urban or national network (i.e. at the vehicle fleet level), while the micro-scale models come down to the street level. Certainly, the different purposes of their application require different levels of detail and accuracy.

In scenario tests, trends or relative changes are generally more important than absolute emission levels, while in the development of national or regional emission inventories, absolute estimates are arguably more important. In both cases, fine spatial and temporal resolution is not required, and macro-scale models can thus simulate the reality at an acceptable level of accuracy (Joumard, 1999; Esteves-Booth et al., 2002). Macro-scale emission models could also produce inputs for an air quality model applied in an urban region, but additional information would be required to increase the accuracy (Zachariadis and Samaras 1997).

A number of factors have contributed to the widespread use of the average speed approach. For example, the models are relatively easy to use, and there is a reasonably close correspondence between the required model inputs and the data available to users. However, there are some important limitations associated with the models of this type (Boulter et al., 2007; Pronello and André, 2000). The most important concern is that the same average speed may be achieved through very different driving patterns, which could have quite different emission levels. This is particularly true at lower average speeds. In addition, average speed has been found to be a less reliable indicator for the emissions from vehicles of new generations. This is because emissions from the modern vehicles equipped with sophisticated after-treatment devices are more sensitive to vehicle operation (e.g. gear changes and high acceleration). Moreover, average speed models do not allow for detailed spatial resolution in emission estimation. This is an important drawback in dispersion modelling, but less relevant for national or fleet emission estimation.

Instantaneous models are intended to address the drawbacks in average speed models, aiming to provide a more detailed description of vehicle emission behaviour by relating emission rates to vehicle operation during a series of short time periods (often one second). They are suitable for the micro-scale applications (e.g. roadside air quality modelling), where driving behaviour and dynamics are of major interest. However, there are some fundamental problems associated with instantaneous models (Boulter et al., 2007; Zachariadis and Samaras 1997; Joumard, 1999). The models require detailed information on vehicle operation and location, but this type of information is relatively expensive to collect and not always available to users. Its availability is especially limited in New Zealand. Furthermore, it is extremely difficult to measure emissions on a continuous basis with a high degree of precision, and it is possible that the process of averaging the data over many vehicles to obtain representative emission estimates could obscure any improvements in accuracy associated with using a detailed model.

Although most traffic situation models primarily target micro-scale applications, they can be also applied directly to large-scale situations. In the latter case, further aggregation of emission factors can be done if users want to reduce the complexity. Moreover, some traffic situation models, especially the ARTEMIS model, can simulate driving dynamics in a more reliable but relatively simple way (Joumard et al., 2007).

3 KEY EUROPEAN AND AMERICAN EMISSION MODELS

3.1 National Atmospheric Emissions Inventory (NAEI)

The UK's NAEI is essentially an average speed model. It can simulate the hot exhaust emissions and cold-start emissions of key pollutants, as well as the evaporative emissions of hydrocarbons, and PM emissions from brake and tyre wear (Bush et al., 2008). The principal NAEI database of emission factors (Barlow et al., 2001) comprises emission data from some 2,800 vehicles and over 25,000 tests. This database has been used as the primary source of emission factors for passenger cars and light-duty vehicles in the development of ARC's VEPM.

The emission–average speed functions were derived from the hot exhaust emission tests based on European "real-world" driving cycles, with the cycles being developed using different road types (urban, rural, and motorway). Nevertheless, it seems that no separate sets of the emission–average speed functions were developed for different road types. Moreover, the majority of the vehicles tested are old pre-Euro 1 or Euro 1 vehicles (over 1,000 in each group). Based on the sample size of the tested vehicles, it can be concluded that NAEI could provide good average emission factors for pre-Euro 1 and Euro 1 passenger cars, which are representative of the vehicles' emissions under typical European driving conditions. In contrast, caution must be taken with the emission factors for heavy-duty trucks and buses in NAEI, because the number of these vehicles tested is very small.

It is worth noting that NAEI has often been operated as an aggregated emission factor model, where the emission factors are aggregated for different road types for each broad vehicle class (generally based on emission control standards). The aggregated emission factors have been derived from the average speeds based on vehicle fleet composition and traffic data in the UK. Therefore, extreme caution must be exercised when the aggregated emission factors are intended to be used for other countries, because their fleet composition and traffic volume/distribution (e.g. those in NZ) can be quite different from those represented by the UK statistics.

3.2 Computer Programme to Calculate Emissions from Road Transport (COPERT)

COPERT has been developed by the European Environment Agency (EEA). It is an average speed model and has been widely used to estimate road transport emissions for annual official national inventories. Its initial version was COPERT 85 (1989), followed by COPERT 90 (1993), COPERT II (1997) and COPERT III (1999). The most recent version is COPERT 4 (2006), which draws the main elements from several large-scale European projects including MEET[3], the COST[4] 319 action on the Estimation of Emissions from Transport, PARTICULATES[5] and ARTEMIS. The COPERT 4 methodology (Gkatzoflias et al., 2007; EEA, 2007) has formed a part (the Road Transport chapter) of the EMEP[6]/CORINAIR[7] Emission Inventory Guidebook. The COPERT III database has been used in VEPM to develop emission factors for heavy-duty vehicles and for cold-start emissions.

In addition to those for normal vehicle types, COPERT 4 can calculate emission factors for LPG (liquefied petroleum gas) or hybrid passenger cars, conventional petrol heavy-duty vehicles, and CNG (compressed natural gas) buses. It can also provide speciation for NO/NO_2, as well as the elemental carbon and organic carbon components of PM. Hot exhaust emissions are estimated in a similar way to NAEI for different vehicle categories. In the bottom-up approach, however, emission-speed functions can be derived separately for the three road types, i.e. urban, rural and motorway (in this respect, COPERT seems to be superior to NAEI). Moreover, the quality of emission factors for heavy-duty vehicles in COPERT is better than that in NAEI, as they are derived from a much larger number of vehicles tested.

A more advanced approach than NAEI for estimating cold-start emissions has been developed in COPERT, by using a cold-over-hot ratio and considering several parameters such as ambient temperature and vehicle use patterns. This approach has been adopted by NAEI in its recent versions. COPERT has also developed methodologies to correct the baseline hot emission factors for vehicle mileage and fuel characteristics. For heavy-duty vehicles, correction factors have been derived to take account of the effects of vehicle loading and road gradient. There are two methodologies in COPERT for estimating evaporative emissions of VOCs for petrol vehicles. While the calculation of total evaporative emissions using the simple methodology is straightforward, application of the more detailed one could be limited by the availability of detailed data. Like many other emission models, the methodologies for estimating non-exhaust PM emissions in COPERT are associated with large uncertainties. In particular, the emission factors for road surface wear are highly uncertain.

3.3 Handbook Emission Factors for Road Transport (HBEFA)

The most recent version (2.1) of HBEFA was produced in 2004 (de Haan and Keller, 2004). Although its previous versions used an instantaneous modelling approach based on a matrix of instantaneous speed, and the product of speed and acceleration, the latest version has, in general, become a traffic situation model. A "traffic situation" qualitatively defines the traffic condition on a specific type of road (e.g. "urban highway with a speed limit of 100 km/h, free flow"), which can be applied equally to all vehicle categories (e.g. passenger cars and trucks). But behind the same traffic situation each vehicle category may have its own "driving pattern" that represents a typical driving behaviour and may be expressed as a speed-time curve.

[3] MEET = Methodologies for Estimating Air Pollutant Emissions from Transport.
[4] COST = European Co-operation in the Field of Scientific Research.
[5] PARTICULATES = Characterisation of Exhaust Particulate Emissions from Road Vehicles.
[6] EMEP = The Co-Operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe.
[7] CORINAR = Core Inventory of Air Emissions.

Emission factors are originally derived for these underlying driving patterns based on emission test results. The emission factors for each traffic situation are then calculated by combining and weighting the emission factors of these driving patterns. This has been achieved in HBEFA by using a computer program called “Art.combino” through linear combinations.

Note that the driving patterns and traffic situations in HBEFA have been derived based on the driving characteristics in Germany and Switzerland and the corresponding emission factors are intended to be used mainly in Germany, Switzerland and Austria. Different countries can have quite different traffic situations. Caution should thus be taken when trying to apply the emission factors of individual traffic situations in HBEFA to other countries. Nevertheless, emission factors for the many underlying driving patterns could still provide a good reference for other countries including New Zealand.

The traffic situation approach developed by HBEFA is interesting and potentially very useful for developing a NZ emission model. The ARTEMIS model discussed below has also applied a similar methodology (Keller and Kljun, 2007).

The PHEM model was used in HBEFA to derive emission factors for heavy-duty vehicles based on engine emission maps and vehicle data (Pischinger, 2002). A major problem in deriving the average emission factor for a particular heavy-duty vehicle category is that it is generally difficult to have a sufficient number of engines measured for the fleet segment concerned (a combination of vehicle type, emission control standard and engine size). To help resolve this issue, a normalisation procedure was developed in PHEM to bring emission maps into a standard format. This method ensures that every vehicle category is covered by a proper number of measurements of different engines. In this way, the sample size per vehicle category is improved on average by a factor of nine, which makes the emission factors much more reliable.

3.4 Assessment and Reliability of Transport Emission Models and Inventory Systems (ARTEMIS)

The ARTEMIS model is a joint product of two large scale European projects – ARTEMIS and COST-346. It has also integrated the emission data from other sources including MEET, HBEFA and PARTICULATES (Keller and Kljun, 2007; Joumard et al., 2007). ARTEMIS is probably one of the most comprehensive road vehicle emission models to date in the world. It can be applied at both the macro level (e.g. national inventories) and the micro level (e.g. at the street level, but not for individual vehicles). The ARTEMIS model for light-duty vehicles has been improved greatly in comparison with the approaches used in the COPERT or HBEFA (Joumard et al., 2007).

ARTEMIS contains five sub-models for calculating hot exhaust emissions: the traffic situation model, the average speed model, the kinematic regression model and two instantaneous models, with the last three being for passenger cars and light commercial vehicles only. Although the instantaneous and kinematic models are the best way to take account of driving dynamics, they need complex kinematic data and are generally difficult to use. In contrast, the traffic situation approach is capable of taking into consideration the kinematics in a more reliable but relatively simple way (Joumard et al., 2007). The average speed model in ARTEMIS is very similar to COPERT, but less accurate than the traffic situation model. Therefore, only its main model, the traffic situation model, is discussed in this paper.

The basic approach used in the ARTEMIS model follows the notion of traffic situation used in the HBEFA, although the methodology has been refined. Traffic situations have been developed taking into account the following parameters: the area (urban, rural), the road type, the speed limit and the level of service (in four levels: “free flow”, “heavy traffic”, “saturated traffic” and “stop-and-go”). In total, more than 200 traffic situations have been defined according to typical driving in Europe. Clearly, some of the defined traffic situations are not applicable to NZ (e.g. those relevant to motorways having a speed limit significantly greater than 100 km/h).

As discussed in the HBEFA section, caution must be taken when using the average emission factors of the traffic situations in ARTEMIS for regions outside the European countries, because these traffic situations were developed based on European driving characteristics. On the other hand, the emission factors of its many defined driving patterns may still be very useful for other regions including New Zealand, since these driving patterns could potentially be used to develop other traffic situations by linear combinations. The “Art.combino” program may be used for this purpose. Given that the majority of the NZ vehicle fleet is imported Japanese vehicles, one issue for NZ is that we do not know whether or not the Japanese and European vehicles have similar emission behaviours on average when they are driving in the same patterns. The Japanese and European vehicle emission standards have different limit values, are introduced in different years and based on different test driving cycles. Even where a correspondence can be obtained between these standards, there is no guarantee that “real-world” (off-cycle) emissions will be equivalent for the corresponding vehicles. This discrepancy may result from the different vehicle design standards and possible differences in the fuelling operation and emission control systems (Boulter and McCrae, 2007).

3.5 MOBILE

MOBILE is the USEPA’s model for estimating air pollutants and fuel consumption for all types of road vehicle in the US. It was first developed as MOBILE1 in 1978, and has been upgraded periodically since then. Its latest main version is MOBILE6, which was released in 2002, with some further minor upgrades being integrated later on (USEPA, 2001a; 2002). Note that the USEPA is developing a new modelling system termed the Motor Vehicle Emission Simulator (MOVES). This new system will estimate emissions for both on-road and non-road sources, and allow multiple-scale analysis, from fine-scale analysis to national inventory estimation. The draft MOVES2009 is now available. When fully implemented, MOVES will serve as the replacement for MOBILE6 and NONROAD (the current model for off-road vehicle emissions) for all official analyses (http://www.epa.gov/otaq/models/moves/index.htm).

MOBILE6 is an aggregated emission factor model although it, in principle, also follows the average speed approach. It is largely based on the base emission rates (BERs), which are a function of vehicle type, model year and technology. These

BERs were developed from FTP (federal test procedure) emission test data for 28 vehicle classes. Two emitter categories (normal and high emitters) were defined and two altitude (high and low) regions were simulated. To account for the “off-cycle” effects, MOBILE6 allows the users to adjust the BERs for many parameters such as driving behaviour, ambient conditions, fuel characteristics, air conditioner usage and emission control programs.

It is worth noting that MOBILE6 estimates vehicle emissions on freeway ramps separately from those on freeways (the other two road types simulated are arterials/collectors and local roads). Research has found that, at the same average speed, vehicles driving on the ramps (often associated with hard accelerations) emit a greater quantity of pollutants than those on freeways (USEPA, 2001b). MOBILE6 assumes that 8% of all freeway vehicle miles travelled in the US occur on the ramps (USEPA, 2001a). Traffic data from the New Zealand Transport Agency (NZTA) suggest that 10% – 11% of all motorway vehicle kilometres travelled in Auckland and Wellington occur on the ramps (personal communication, 2009). It is therefore likely that modelling vehicle emissions on motorways and those on the ramps together, based on the driving cycles derived solely from motorways, could significantly underestimate the emissions in urban centres.

The MOBILE6 modelling methodology is rather simple and straightforward. Its methodology for hydrocarbon evaporative emissions is quite detailed (including hot soak, diurnal, resting loss, running loss, crankcase and refuelling emissions). It can also take into account the effects of gross emitters. However, it should be noted that MOBILE models all passenger cars in one class without any engine size break-down. Furthermore, all the BERs were derived based on FTP emission data rather than “real-world” driving cycles. If we wanted to apply these BERs to NZ we would need to conduct research to assess the applicability to NZ of the correction factors derived in MOBILE6. Given the large differences between the New Zealand and US vehicle fleets, as well as between driving conditions in these two countries, it is unlikely to be productive to expend much effort to consider their emission factors, but the model’s approach may merit further consideration.

4 NEW ZEALAND EMISSION MODELS

4.1 Vehicle Fleet Emissions Model (VFEM)

The Ministry of Transport’s VFEM was developed in the late 1990s by an external consultant (MOT, 1998a). The emission rates from the VFEM were also packaged in a program called “NZ-TER”. In the absence of any other publicly available data, NZ-TER has been widely deployed by NZ users in a range of transport modelling situations. However, the VFEM has a number of drawbacks. The chief among these are that the underlying data are poorly documented and that many of the emission values appear to be the “best guesses” rather than based on actual testing. The emission factors in the model have also not been updated since it was developed over ten years ago, and therefore do not reflect the current fleet well.

Like HBEFA and ARTEMIS, the VFEM is a traffic situation model in which twelve traffic situations are defined based on four road types (central urban, suburban, motorway and rural) and three levels of service (congested traffic, interrupted flow and free flow). Another limiting factor for the VFEM is that, in defining the 12 traffic situations, speed limits are not considered and only three levels of service are used. In comparison, more than 200 traffic situations are defined in the ARTEMIS model.

There are three sub-models in the VFEM: a fleet model, a traffic activity model and an emission factor model. In the past two years the MOT has worked to update the fleet and traffic parts of the VFEM and these sub-models are now generally considered to be acceptable. ARC's VEPM has used this newly-developed fleet model to generate fleet profiles. Note that initially there were only three engine size categories (<1350cc, 1350cc-2000cc, and >2000cc) in the VFEM. To better fit the NZ fleet, the MOT has split the fleet into five bands in the newer versions of VFEM (<1350cc, 1350cc-1600cc, 1600cc–2000cc, 2000cc–3000cc, and >3000cc). The change to the range of engine sizes in the model reflects primarily an increased interest in emissions of greenhouse gases (primarily carbon dioxide (CO_2)). The emission of CO_2 is far more closely linked to engine size (and vehicle mass) than it is for harmful exhaust gases.

As noted, the emission and fuel consumption factors in the VFEM are poorly documented, but are thought to be derived from overseas databases and "calibrated" using the results of a NZ vehicle emission testing program in the late 1990s. The testing program was conducted under the MOT's Vehicle Fleet Emission Control Strategy (VFECS) and funded partly by the Ministry for the Environment's Sustainable Management Funds (MOT, 1998b). In total, 23 light-duty petrol vehicles, eleven light-duty diesel vehicles and four heavy-duty diesel trucks were tested. Most of the tests were conducted based on NZ "real world" driving cycles developed in the VFECS program (most light-duty vehicles were tested over more then ten driving cycles).

In order to improve the VFEM's emission factors, it appears that the very comprehensive ARTEMIS database should be investigated. However, as the vast majority of the NZ fleet is sourced from Japan, with about half being so-called "used vehicles" originally built to Japanese domestic specifications (which are known to be different from European standards), vehicle emission data from Japan will also be vital to ensuring the accuracy of any New Zealand-based models.

4.2 Vehicle Emissions Prediction Model (VEPM)

Recognising the shortcomings of the VFEM, the Auckland Regional Council has developed its own emissions model: the VEPM (its most recent version is 3.0; Kar et al., 2008). Unlike the VFEM, the VEPM is an average speed model. It was developed largely using data derived from the UK's NAEI database (for light-duty vehicles) and EEA's COPERT III database (for heavy-duty vehicles). In addition to the European data, the database from the first stage (1997 – 2001) of JCAP (Japan Clean Air Program) was used for the development of "equivalencies" for the vehicles of Japanese origin.

In 2004 another NZ vehicle emission testing program was conducted for the MOT, in which 61 petrol light-duty vehicles, 22 light-duty diesel vehicles and four diesel heavy-duty vehicles were tested on dynamometers using a few driving cycles (three driving cycles for each light-duty vehicle) (Campbell et al., 2006a; Campbell et al., 2006b). The resulting emission database was used for the development of "equivalencies" for NZ origin vehicles in the VEPM.

Unlike the VFEM, the VEPM's methodologies have been well documented, with about 150 vehicle categories being modelled. The model aims to estimate tailpipe emissions from the motor vehicles of all countries of origin operating within normal traffic conditions on NZ road networks. The key parameters catered for by the model include: cold-start emissions, rate of catalytic converter removal, fuel properties and emission performance degradation due to vehicle's accumulated distance travelled (petrol vehicles only). Similar to the VFEM, the VEPM is best suited for scenario tests with grid sizes of one km or more, and for time periods of one hour or more. In scenario tests or impact assessments, relative changes or trends are more important than absolute values. Caution should thus be taken when trying to use the VEPM in a situation where absolute emission estimates are important.

As discussed above, the VEPM has been developed based on European databases, and equivalencies have been required to be generated for non-European vehicles in the NZ fleet. Although this is clearly an improvement over the older VFEM, the use of such equivalencies has introduced errors that are difficult to quantify. Moreover, the relevant overseas databases on which its emission factors are based have been updated since the model was developed (e.g. COPERT 4 has been available and the second stage of JCAP has been finished (http://www.pecj.or.jp/english/jcap/jcap2/index_jcap2.html)). In addition, ARTEMIS, a recently completed European program, has produced a database that is probably the most comprehensive one to date in the world. These databases can be very useful for improving the VEPM, especially for newer vehicles.

5 SUMMARY AND RECOMMENDATIONS

Different types of vehicle emission model vary in their modelling approaches, and in the levels of detail required for their input data. They are best suited to different applications and situations regarding spatial and temporal scales, and depending on whether the models are being used to test relative changes from different scenarios or to predict absolute levels of emissions at a given time or place. Some traffic situation models, especially the recently released ARTEMIS model, seem to have clear advantages as they can simulate driving dynamics in a more reliable but relatively simple way.

Both NZ models which are discussed here (VFEM and VEPM) have significant room for improvement, especially as to the accuracy of emission factors for the unique NZ vehicle fleet. The above-mentioned two vehicle emission testing programs conducted for the NZ fleet have provided a valuable database for "calibrating" overseas data when applied to NZ vehicles. However, the number of vehicles tested remains small. This is especially true for heavy-duty vehicles. Even worse, these heavy-duty vehicles have not been tested with internationally-recognised test procedures because of the practical limitations of the testing equipment.

These existing datasets are unlikely to form an emission factor database robust enough to allow us to rely solely on it to develop a satisfactory emission model for the NZ fleet. This is because the NZ fleet, though small, has quite diverse origins and a complex composition. We have Japanese domestic-sourced vehicles that are likely to behave differently under the same conditions from European vehicles. Possibly a greater concern for modelling purpose could be the large group of “New Zealand-new” vehicles which were imported prior to the introduction of NZ legal requirements for vehicle manufacturing standards. Large uncertainties exist about their likely emission characteristics as their manufacturing standards are reported to have varied with each shipment depending on the source.

This means that, if we were to develop our own emission factors, the number of vehicles to be tested would need to be quite large in order to be representative of the fleet as a whole. It is unlikely that we will have the resources to carry out this level of testing for the foreseeable future. Overseas emission databases will therefore continue to be needed to model the vehicle emissions in NZ. We may be better advised to continue to “cherry pick” information from these global databases.

In addition to concerns over the emission factors, differences in the “real-world” driving dynamics and traffic conditions need to be taken into consideration when using the overseas data for NZ. It appears that the “Art.combino” software can be useful for this purpose, as long as the average emission factor for a driving cycle is known in the overseas datasets. In principle, any NZ “real-world” driving cycles could be simulated using the “Art.combino” from overseas driving cycles (normally by linear combinations). The corresponding emission factors for the NZ driving cycles could then be derived in the same way.

Furthermore, emission data for heavy-duty vehicles are relatively limited worldwide because measuring heavy-duty engines or vehicles is expensive. A method has been developed in PHEM to normalise the engine maps into a standard format, which enables the development of average engine maps independent of the engine size (rated engine power). This method can effectively overcome the sample size limitation and secure much more reliable emission factors for heavy-duty vehicles.

Ideally, an optimal emission model for New Zealand can appropriately account for both actual driving dynamics in NZ and the emission characteristics of the NZ vehicle fleet in terms of its diverse origins. Given the dominance of Japanese vehicles in the fleet, it seems to be more logical to develop the model based on Japanese emission data. The MOT is now collecting the data from JCAP II and the Tokyo Metropolitan Government’s emission testing programs. In addition, it appears that the ARTEMIS emission factor database should be investigated for the New Zealand-new vehicles in our fleet certified to European standards. Emission data from Australia may also need to be studied, as they have conducted several large studies of in-service vehicles which have included models common to those in New Zealand.

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