Peacox – Persuasive Advisor for CO2-reducing cross-modal trip planning

Project Reference: 288466

FP7-ICT 2011: 6.6 Low carbon multi-modal mobility and freight transport)

Project Duration: 1 Oct 2011 – 30 Sept 2014

D.3.1

Door to Door Emissions Models

Trinity College Dublin

Author(s)

Md. Saniul Alam

Dr. Aonghus McNabola

Date: 31/07/2012

Dissemination level: (PU, PP, RE, CO): PU

Project Co-Funded by the European Commission within the 7th Framework Program

Abstract

Information on CO_2 emissions should be easily understandable and instantly accessible to an individual while making or planning a trip in order to facilitate environmentally friendly driving behaviour and reduce the associated environmental impacts. In order to facilitate this task as a part of the Peacox project, the Trinity College Dublin (TCD) team carried out research on a door to door emission modelling and developed two emission models which can i) estimate real time emission and ii) predict emission for any multimodal trip by trip cases.

The models are designed in a straightforward way as though emission can be calculated for a trip by trip case on the mobile devices. The models account for vehicle information (e.g. Euro emission standard category[1], vehicle weight and engine size, fuel technology and catalyst converter), weather data, congestion, and occupancy etc, as inputs. The emissions factors used for private cars have been taken from the ARTEMIS [39, 40] project, whereas emission factors for public transport have been taken from a study of Dublin public transport modes. The models can act automatically for peak and off-peak cases based on empirical evidence inputted into the model.

TCD team reviewed extensive literature on Eco-Driving and similar driver behaviour modelling, and solved the limitations of existing models such as accounting for cold starts emission or the absence of both real-time estimation and prediction emission models in a system for door to door emission modelling.

----

1 European emission standards define the acceptable limits for exhaust emissions of the vehicles sold in the EU member states.

Glossary of Terms

ARTEMIS: Assessment and Reliability of Transport Emission Models and Inventory Systems, or the ARTEMIS project developed a harmonised emission model all means of transport to provide consistent emission estimates at the national, international and regional level.

Catalytic converter: A catalytic converter is a vehicle emissions control device, which converts toxic by-products of combustion in the exhaust of an internal-combustion engine to fewer toxic substances by way of catalysed chemical reactions.

Cold start emission: It occurs because of higher emission rates than the average emission factor for a few minutes while starting a vehicle engine after a long time. This happens during the time difference between cooling state and lighting up the catalyst convertor (until the temperature reaches 300-350^{o}C).

Eco-Driving: A smart and safe way of driving, in terms of avoidance of sudden acceleration and breaking, and choosing of an eco-friendly route that offers low emission compared to other best possible routes (e.g. time priority route, shortest distance route) for that origin-destination pair.

Eco-routing: Choosing a route that offers low emission compared to other best possible options like time priority route, shortest distance route.

DART: An electric commuter system/train operating in the greater Dublin area.

Door-to-Door Model: A model that consider all modes from origin to destination.

Euro emission standard category: European emission standards define the acceptable limits for exhaust emissions of the vehicles sold in the EU member states.

GPS device: The Global Positioning System (GPS) Device is a space-based satellite navigation system that provides location and time information.

g/kwh: Gram per kilowatt, emission factor for electricity generation.

Intelligent Transport System Infrastructure: Here, it refers to traffic signalling systems like SCOOT, SCATES or UTOPIA.

LUAS: Light electric tram system operating in Dublin city.

Multimodal Trip: A trip comprised of several modes, e.g. car-bus-walk, walk-Luas-DART.

Occupancy: Number of occupants using a vehicle/transport.

Parking time: The idle time of a vehicle which represents the degree of a catalytic convertor's coolness/temperature. The Model accounts for this by calculating the difference between two subsequent model applications by the user.

Peak and off peak hour: Usually in peak hours the transport demand is high and streets become congested whereas the opposite happens during an off-peak hour.

PEMS: Portable emission monitoring system device (PEMS)

Road grades: The grade of a road refers to the amount of inclination of that road to the horizontal.

Real-Time Traffic: Real-time traffic means the actual condition of the traffic in a particular network in the real time sense. This traffic information can be obtained from GPS device, mobile devices, satellite images or analysing data from ITS infrastructure.

Table of Contents

List of Figures

List of Tables

1. Introduction

Vehicle emissions are the subject of wide concern among government agencies worldwide, for its known negative environmental impacts, including human health [1] and climate change [2, 3]. It was noted [4] that transport emissions comprise 26% of the overall CO_2 emissions in the EU. This is a cause for concern due to the high traffic demand growth rate, estimated to increase by 50% for freight and 35% for passengers between 2000 and 2020 [5]. In response to this and the emission of green house gases in other sectors, many countries have committed to reducing their total emissions by set percentages over the coming years to combat climate change and improve environmental health [6]. As a result, governments are intensifying efforts to reduce CO_2 emissions across all sectors, including transport through various initiatives.

In the transport sector, these initiatives include improvements in vehicle technology and the implementation of various policy tools to combat climate change. These tools cover a wide range of areas such as direct interventions on vehicle movement, e.g. fuel tax, congestion pricing, parking pricing policies, overall system management, etc. Others include improvements in public and sustainable transport, carbon tax systems [7, 8], subsidy provision for Eco-Driving [9] and raising public awareness of carbon footprints. Increasing the awareness of individuals about the impact of their activities on the global environment has the potential to reduce CO_2 emissions. It was argued [10] that achieving policy targets for individual carbon emissions reduction will require measures to improve the individual's decision-making and practices resulting in behaviour change. Thus, people need information about carbon emission while/before they make any trip. By providing individuals with emissions information they can make environmentally informed decisions about their travel options.

1.1 Background of the Deliverable in the given context

The Peacox project has set grounds for handling eco friendly driving issues more efficiently along with their other set targets. The aim of the third work package of the Peacox project is to build a model which will estimate emission for the door to door application. In other words, the model will be capable of estimating emission from a trip for an individual that may comprise different modes (e.g. bike, car and public transport) . A trip with an origin and a destination may have many possible routes. Thus, the user will be able to choose an option from a given set of options to peruse his/her journey for his/her destination in more environmentally friendly ways.

This deliverable presents a review of the available literature on trip-by-trip emission modelling, identifying the opportunities and challenges facing this emissions reduction tool. The reported benefits and possible disadvantages of the existing models are outlined, and models on emissions estimation and prediction are developed that are capable of providing carbon footprint information to road users. The possible limitations and recommendations for improving the models are also outlined.

1.2 Scope of Work Package:

The Peacox project's Description of Works (DOW) outlined: *The requirements of this emissions model are that it is able to estimate emissions in real-time and predict emissions on a particular trip before the individual makes that trip*. This signifies that the emission model will be based on real time traffic information and predict emission before the individual makes a trip. However, taking account of the limitations (section 2.2), the model will also be capable of calculating emissions while the trip is underway (see also section 2.3). Trajectories data from real-time traffic information do not represent the aggressiveness or gentle travel behaviour of the driver well. Thus, we feel it is important to include additional capabilities of real time emission modelling to achieve the overall goals of the Peacox project. Considering the primary aim of work package 3, the objectives of the work pack include:

Objective 1: Ascertain efficient, accurate and effective methods of estimating CO_2 emissions.

Objective 2: Create an emissions model that will predict CO_2 emissions from transport before a trip is undertaken.

Objective 3: Create an emissions model that will estimate CO_2 emissions from transport in real time or after a trip is complete.

The models have been designed in such a way that they are later capable of taking account of the other emissions such as nitrogen oxide (NO_X), sulphur dioxide (SO_2) and Particulate Matter (PM_{10}) if deemed necessary.

2. Literature Review and Identification of Critical Issues

The purpose of the Peacox project is similar to the concept of facilitating Eco-driving, more specifically eco-routing. A critical review on the literature (briefly summarised below) provides a good understanding of the subject matter and highlights important issues to consider for carrying out the modelling tasks.

2.1 Methods and Practices

Several different strategies have been developed to facilitate Eco-Driving, including training courses, driving contests, driving assistance tools (e.g. displays communicating suggestions on vehicle speed or route choice) and tools for acceleration control (e.g. an active acceleration pedal). Among these, driver learning has been shown to have a lower impact in the long term. Driver training and the addition of vehicle control devices for Eco-Driving have received significant attention amongst Eco-Driving investigations. However, Eco-Route choice has received little attention in contrast.

It has been estimated that the choice of route, using a fuel consumption and emission model, can result in energy savings of up to 23% if motorists choose lower emissions routes (Eco-Routing) [13]. An investigation was conducted in Sweden to analyze fuel consumption and CO_2 emission using a navigation system where optimization of route choice was based on the lowest total fuel consumption. It was found that 46% of trips, which were the result of a drivers' spontaneous choice of route, were not the most fuel-efficient. These trips could save, on average, 8.2% of fuel by using a fuel-optimized navigation system. This corresponded to a 4% fuel reduction for all journeys [14]. The available evidence therefore suggests that significant fuel and CO_2 emissions savings could be achieved through the adoption of Eco-Routing behaviours and technologies in single trips. However, it could be also argued that if Eco-Routing information was disseminated widely to road users this may make a suggested route no longer the eco-friendly choice if all drivers choose that route. Such criticism could be eliminated if the selection of Eco-Route is based on real-time data rather than the current practice of static or average value models. It must also be recognised that the widespread adoption of Eco-Routing would ideally result in an equilibrium state in terms of CO_2 emissions between available route choices. Therefore, the fuel and emissions savings found in previous investigations based on controlled experiments may overestimate the ultimate savings achievable using this technique.

Apart from Eco-routing, the information on Eco-Driving policy provides contradictory information in the literature. An investigation was [15] conducted at a signalized road where vehicles were equipped with dynamic Eco-Driving technology and found that there were indirect network-wide energy and emissions benefits to overall traffic, even at low penetration rates (5% to 20%) of those vehicles. This was due to the influence of Eco-Driving vehicles on the behaviour of the following vehicle in a line of traffic, i.e. the following vehicle(s) are also forced to reduce hard acceleration and braking. However, investigations [16] have also shown that an Eco-Driving car only impacts the following cars driving behaviour and has a little impact on other cars behind in the same lane. It was also reported that Eco-Driving may also increase the number of the overtaking cars, i.e. drivers overtaking an Eco-Driver resulting in increased emissions and road safety risks. In addition, as the evidence suggests, controls on driving may cause a reduced individual impact on the environment when considered in isolation but at the level of an entire traffic network this may interfere with traffic performance [17]. It can also be argued that the introduction of speed based Eco-Driving behaviour, may reduce the signalized intersection capacity by allowing fewer numbers of vehicles to pass at an intersection for a given period of time.

Thus, speed control based Eco-Driving is a debatable topic and requires further investigation. Still, widespread Eco-Driving could result in an increase in traffic congestion time and as a result CO_2 emissions. However, this point is unclear and requires further research as signal timings may be adopted to accommodate such changes in driver behaviour. Furthermore Eco-Driving on longer distance journeys in the absence of congested city centre type traffic would clearly not suffer from this complication. Thus, this could be useful in uncongested traffic situation.

2.2 Limitations of the Current Practices

Static emissions modelling for Eco-Driving is widely available; however, existing models have limitations in terms of predicting the trip by trip emissions precisely. Predicting emission is clearly associated with Eco-Routing strategy. It has been noted that most of the available tools are capable of predicting emissions for a given route/trip, based on average vehicle trajectory data or the average emission rate, but none of them account for real time traffic information.

Emissions can also be estimated in real time, capturing instantaneous engine data by using additional data capturing devices for facilitating speed/acceleration control based Eco-Driving. Sometimes specific navigation or display devices are necessary to get real-time or predictive emission information which adds additional monetary cost.

Of the generally used models capable of estimating individual carbon footprints, models can be classified into aggregated data, personal diaries, and trip-by-trip cases [26]. The latter case is suitable for the promotion of Eco-Driving and can be further classified by mobile phone application based or online based models. There are also some other models whose usability is limited to within the research arena. Limitations of all of these models will be discussed in the following categories:

A. Additional device use

B. Methodological accuracy of the application/suitability for Eco-Driving

C. Timing of application: Prediction, Real Time, Post Trip.

A. A study [18] reported on the development of a system whereby some devices were added to vehicles to assist drivers in Eco-Driving/safe driving in Japan. Assisting devices displayed instantaneous fuel rate and CO_2 emissions information, also advising on acceleration/braking rates. An application of a similar study [19] used the same approach, which also required a device to be installed in a vehicle to obtain data from the engine in real time. Similar to this approach, another study [20] evaluated the long-term impact of an Eco-Driving training course where GPS measurements were used to monitor the position and speed of vehicles and another device was used to obtain electronic engine data. A group of researchers [21] developed a navigation tool to assist drivers in choosing a route based on energy and emissions. The inherit challenges of these approaches for mass acceptability is the use of additional devices whether as a display device or as a data capturing device for each vehicle/user. Such additional cost to users would be an unattractive feature.

B. Real time emission calculation in existing practice is not often critical on modelling issues. These limitations include missing vehicle trajectory data, online vs. offline mode and classical methodological concerns.

A project [22] used accelerometer data and the advanced physics engine from the gMeter application, (gMeter computes power, fuel usage/cost, crude oil consumption, and carbon emission), however it does not use GPS data. Investigations [23] used an accelerometer for mode detection and used a GPS device to compute the travelled distance, a mandatory input for computing the CO_2 emissions. A company [24] reported that the CarbonDiem smartphone application detects transportation mode, in real-time, by studying the speed, position and pattern of the movement using GPS data, GSM Cell Tower location and the phones sensors. However, the identified limitation here is the vehicle trajectory in this case, calculated by accounting for travelled distance and an average emissions factor.

Offline real time models developed with strong theoretical backup also may not be suitable for real-time trip-by-trip cases due to either simplification of analysis whether based on the link based approach or due to driving cycles. Link based approaches often take account of average values whereas driving cycle based modes have the criticism of using either smooth acceleration profile (e.g. European Driving Cycle) or not representing actual driving conditions and thus underestimate the emission [25]. In the context of trip by trip emissions modelling, the following methodologies may not be suitable for real time applications.

Researchers [26] outlined the development of an Eco-Driving model that accounted for engine stress and vehicle specific power (derived from speed and acceleration) to characterize six primary driving patterns for links with some additional data. The link-based driving pattern classifier was subsequently applied to estimate the fuel consumption and emissions characteristics for each link in the study. An application by [27] that dealt with a Vehicle Transient Emissions simulation Software (developed within the EU 5th framework project DECADE) calculating emissions per second (instantaneous (one Hz) speed data from the GPS receiver) and fuel consumption made by a vehicle during a defined 'drive-cycle'. A study [28] developed an eco-friendly route model using Eco-Driving cycles through the use of the dynamic programming optimization method for a vehicle in off-line simulation. However, due to the high computational cost of this methodology it is unlikely to be suitable for real-time dissemination of CO_2 information.

Other important methodological limitations for real time applications are: ignoring road grade, the detailed trajectory of a vehicle and not accounting for hot and cold emission factors. A number of studies reported that CO emission rate increases as road grade increases for light-duty gasoline vehicles [29], [30], and [31]. Investigations [29] indicated that during periods of high engine load more CO and consequently less CO_2 is discharged as fuel to air ratio is not sufficient. Therefore, emission factors vary for CO and CO_2 significantly in these cases.

C. Post trip evaluated information [32] seems to have less impact on Eco-Driving compared to on-route information. Thus, it can be argued that both the prediction and estimation of emissions are necessary for on route or pre-trip decision making if the aim is to reduce the carbon foot prints of individuals. The discussed Eco-Driving tools clearly have a limitation as none of the tools can provide real-time calculations and prediction simultaneously. It is obvious that predicting emission/fuel for a future trip should be based on route segments rather than vehicle trajectories as the latter is impossible to predict. Thus, the previous investigations have predicted emissions/fuel for routes ignoring real-time traffic information. Rather those models are based on very basic distance based analysis (e.g. [33, 34]). In many cases, emphasis has been given on sharing past travel data/historic data for

Eco-Route choice [35]. So, trip-by-trip emission prediction modelling based on real time traffic is not yet well established.

2.3 Required features for Emission modelling in the context of the project

A. Project requirement

The project requires that the emissions models will be capable of predicting emissions based on real time traffic information for a route, which may be comprised of one or several different modes. One possible way of conducting the task is building a model capable of taking input from link-based speed or a driving cycle based approach, however, these will never represent an individual's driving behaviour. An individual may act differently with aggressive driving in the roadways where a predicted speed (from link-based speed or driving cycle based approach) as an input for the prediction model may show lower emission. Thus the aim of the project may be compromised to some extent. To avoid such an occurrence, a new model which will be capable of estimating emission in real time is proposed in addition to the prediction model. This model will help the user to understand his emissions contribution from his vehicle's trajectories and driving behaviour. Thus, a system is necessary to develop for assisting Eco-Driving behaviour which includes both real time estimation and prediction emission models.

B. Input requirement

There is an inconsistency between the required input and existing emission factors (e.g. input data can be spatially referenced, thus road grade can be obtained but, emission factor does not count the effect of the road grade.) will affect the precision of the emission estimation. Apart from this, it is expected that there will be large variation in results for a single trip between the emission estimation model and prediction model if the input speed for the prediction model significantly differs from the real time driving condition. Thus, to get the best result it is necessary to connect the input source with real time speed information systems like the Intelligent Transport System Infrastructure. Otherwise, a recommended route may not be an optimal one if every driver chooses the optimal one and the speed data for the links may provide invalid input for estimating emissions factors for the links.

3. Modelling Methodologies

3.1 Introduction

To calculate and predict emission as accurately as possible (Objective 1) in the given mobile device context with existing knowledge on emission factors, the following general methodology (Figure 3.1) has been developed, which is applicable for both, the real time and the predication model (Objective 2 and 3). To ensure accuracy, the model will account for all possible factors mentioned in the Peacox Description of Work (DoW). For instance, the model will take account of the effect of the cold start emissions which is dependent upon the weather data, particularly temperature. Wind flow and wind direction effects are difficult to incorporate for individual vehicles due to lack of data and are thus omitted. Real time speed (from prediction based on real-time traffic or instantaneous speed from GPS) of the vehicles will be a surrogate for congestion, to some extent using the same logic argued by [36] for modal models (i.e. considering instantaneous second by second vehicle trajectories speed and acceleration) which are capable of taking congestion into account.

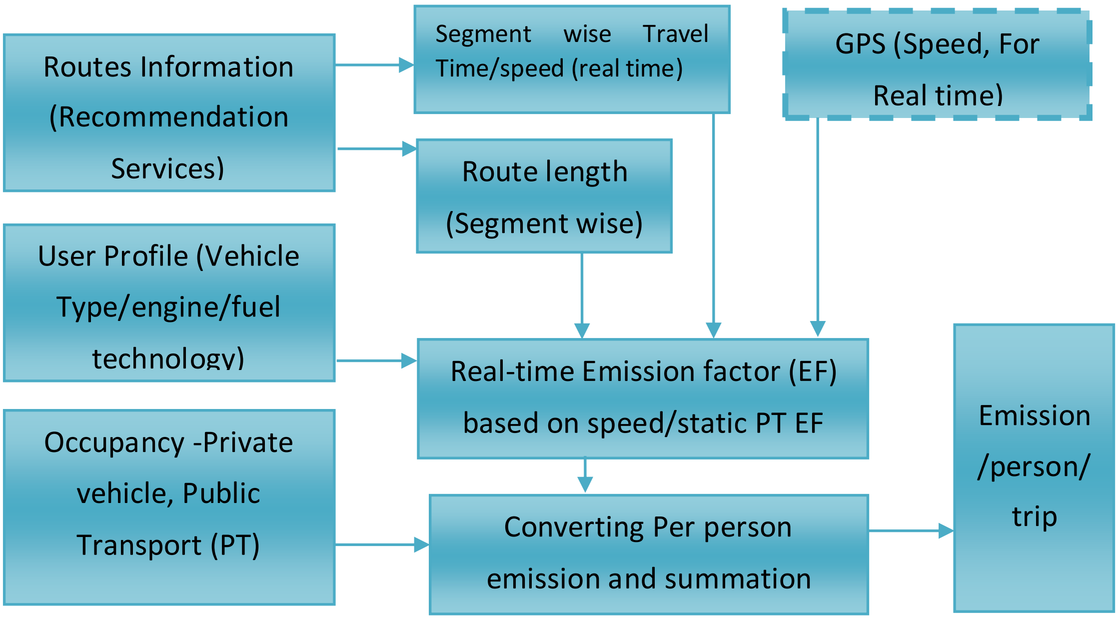

Figure 3.1 Basic Emission Modelling Methodology

The model accounts for a general classification of modes for public transport, but more precise classification of private vehicles based on fuel type, emission standard, and catalytic converter is included. However, it was not possible to include the effect of vehicle age or state of repair on emission for the individual trip level. To provide individual carbon footprint data, it is necessary to convert all emissions output for a person trip. Thus, occupancy for all the vehicles has been taken into account.

The following user scenario demonstrates the relationship between the two models. A set of options will be displayed on the graphical user interface where the emission prediction model will give possible emissions for different routes to an individual. One of the routes may be preferable to that individual, and they might choose such a route. Thus, the route, mode and corresponding information will be sent to the real-time model to start its calculation. At that time, the model will capture information from different sources along with the GPS component and estimate emissions for given inputs until the user presses the stop button.

3.2 Assumptions of the models

A few assumptions have been developed below for the models taking Dublin city as a case study and considering the limitations of the available emission data. These assumptions will also be used in the model created for Vienna. The assumptions associated with the emission factors are still valid for these models (see below).

Model Assumptions:

- Weekends will be considered off peak throughout the day.
- Morning Peak Period: 7-9 am and Evening Peak Period: 4-7 pm for the week days.
- Peak and off peak hour emission factor or occupancy are assumed to be constant for the peak and off-peak period respectively.
- Peak and off-peak road situations are assumed to be constant throughout the day and will be applicable for overall transportation network regardless of modes.

- ARTEMIS Cold Start Euro 4 emission equations for petrol have been taken for Euro 5 and 6. Similarly, Euro 3 cold start emission equation has been taken for Euro 4, 5 and 6 vehicles.
- Cold Start emission equations are not subject to engine capacity. Where such equations are not available, equations for vehicles with similar characteristics have been taken into account.
- For Real time emission estimation, hot excess emission has been calculated at the earlier stage of the model estimation and then a fraction of the emission will be added according to the distances travelled.

3.3 Logic behind building the assumptions (Case study: Dublin City)

To convert emission factor from a vehicle trip (e.g. g CO_2/km/trip) to a person trip (e.g. g CO_2/km/trip/person), it is necessary to account for the temporal occupancy factor in each trip. Existing knowledge [11, also in Figure 1, appendix] on an emission-occupancy relationship across different modes is useful here. However, access to occupancy data for each mode is not convenient in real time applications and thus the models consider low resolution occupancy factors according to weekdays and weekends in the form of peak and off-peak periods (Figure 3.2).

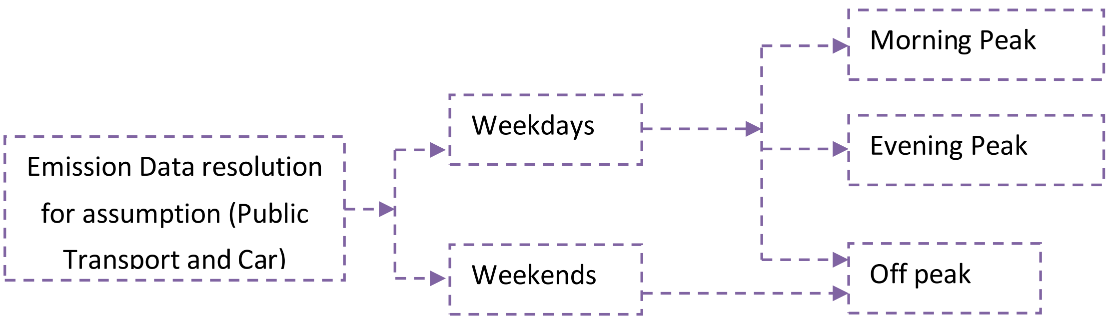

Figure 3.2 Occupancy factor for peak and off peak periods.

Taking Dublin as a case study, it has been found from Road User Report 2004, 2009,Dublin that peak period in weekdays remains stable more or less at 7am-9am for morning peak and 4pm-6pm for evening peak (as evidence found from the year 2003 and 2008, Figures 2 and 3 in appendix). As, there is no distinct peak in weekends (Figure 4 in appendix), the whole day has been considered off-peak periods. It has been assumed in the models that maximum occupancy occurs for peak periods and normal occupancy in an off-peak period (Table 3.1) and this will be stable throughout the day. Based on this, emissions factors for public transport has been taken from a study [11] and has been included in the Table 3.2.

Mode	Average Speed(km/hr)	Max Occupancy Peak Period	Normal Occupancy at Off-peak
DART*	30	945	428
Dublin bus	13.5	90	45
LUAS**	24	235	117.5
Private car	66	1*** (instead of 4)	1.4

Table 3.1 Occupancy per vehicle/Mode, Source [11]

* An electric commuter system/train operating in the greater Dublin area.
**A light electric tram system operating in Dublin city.
***Exception as 95% car has single occupant/driver during peak hour, Source [37].

3.4 Emission Factors

Emissions factor from public transport have been calculated based on the following methodology discussed in study [11].

- Bus: Emission factors for bus transport were generated using journey length and fuel consumption estimates provided by the company running Dublin buses.

- LUAS and Dart: As both are electric powered transport, the average speed, distances travelled were estimated first to calculate the electric power consumption. Then CO_2 emission factor for the Irish electricity generation fuel mix was used along with occupancy data to estimate CO_2.

To calculate emission factor from an electric powered public transport (EV) for other cities the following modified equation [from 38] can be used.

- **CO_2 factor for EV user (g/ km/person) =** [{(emission factor for electricity generation - g/kwh × annual kWh consumed by EV)/annual EV passenger kilometres)} × journey length by EV]/average distance in km travelled by an EV user.

Table 3.2 Emission factor for public transport, Source [11]

Mode	At Max Occupancy		At Normal Occupancy	
	g CO_2 per Passenger km	g CO_2 per passenger per second*	g CO_2 per Passenger km	g CO_2 per passenger per second*
DART	11	0.092	29	0.242
Dublin bus	17	0.064	34	0.128
LUAS	64	0.427	128*	0.853

*Derived value considering average speed from table 3.1, ** assumed double of maximum occupancy

Although, the DoW states that the emission model will be based on existing/established methods for estimating traffic emissions such as COPERT 4, MOBILE5 or EMFAC, the developed models here will actually take account the ARTEMIS equations (valid for 5-140km/h) which are the latest addition to the knowledge for emission factors for the EU area.

A study [39] under TRL was carried out reviewing emission factors for hot exhaust emission from the vehicles where ARTEMIS project was also reviewed. This emission factors estimation methodology has been adapted in this project for cars from that study. The emission factors were estimated in the following form:

$$\boldsymbol{Y = (a + bx + cx^2 + dx^3 + ex^4 + fx^5 + gx^6)/x}$$

Where, y= Emission factor in g/km; x= Speed in km/h; Coefficients= a, b, c, d, e, f and g

To account for the "Excess cold start emission per start" equations developed by the ARTEMIS Project has been included in the model [40]. The general cold start equation is:

$$\mathrm{EE}(\boldsymbol{T},\boldsymbol{V},\boldsymbol{\delta},\boldsymbol{t}) = \boldsymbol{\omega}\mathbf{20}^{\circ}\mathrm{C},\mathbf{20}\boldsymbol{km}/\boldsymbol{hr}.\int(\boldsymbol{T},\boldsymbol{V}).\frac{\mathbf{1}-\boldsymbol{e}^{\boldsymbol{a}\boldsymbol{\delta}}}{\mathbf{1}-\boldsymbol{e}^{\boldsymbol{a}}}.\boldsymbol{g}(\boldsymbol{t})$$

Where, EE= excess emission for a trip in g; V= Mean Speed in km/h during cold period; T=ambient temperature in 0^{o}c; t=Parking time in hours; δ= d/d_c (T, V), dimensionless travelled distance=travelled distance, $\omega 20^{o}$C, 20km/h= reference excess emission at 20^{o}C and 20km/h.

To calculate the vehicle emission according to the given input for each model, vehicle characteristics have been coded in the Tables 1-4 in the appendix. Cold start emission equations and associated values, as well as hot emission co-efficients were also included in the Tables 5-8 in the appendix. These factors and equations have been used to build the models for the Peacox project. No evaporative emission has been considered in the model for two reasons: a lack of available data and negligible amounts of emission are expected for a single trip from this mechanism.

3.5 Modelling Platform

The program for the model has been written and delivered on the MATLAB® platform. MATLAB Builder™ JA will be required for the system developer to create Java™ classes from MATLAB® programs to integrate into Java programs, developed by other partners.

4. Real Time Emissions Estimation Model

The aim of the project component under TCD is to build an emission model. Two distinct pieces of models are required to meet the tasks for emission modelling in the project.

4.1 Introduction

The first model will give real time emission taking account of vehicle trajectories from the Global Positioning System data.

4.2 Input Requirement

The aim was to build these models in terms of adaptability the partners' data, simplicity of analysis and suitability of the model in this context. Here, context refers to the mobile application as well as the trip-by-trip scenario. It has been taken into account that a trip can be a multi-modal trip, modes that can be used for a trip are Car(C), Dart (D),Bus (B), Tram (T) and Walk (W) successively. The real-time emission models are dependent upon different sources of data, both external sources (like temporal data from an inbuilt clock etc.) and inter-partner data (e.g. instantaneous trajectories and corresponding modes from GPS component, user profile and recommended services/routing engine, etc.). The required inputs for the model are below:

- GPS data: travel time and length according to mode.
- Total car travel length.
- User Profile information (Private vehicle type-Euro category, vehicle weight and engine size, fuel technology and catalyst converter, Real time Temperature etc).
- Available Travel Modes in the city.
- Private vehicle and Public transport occupancy.
- Database of Emission Equations for private car.
- Database of Emission rates for public transport.
- Time and Date.
- Traffic information: Peak and off-peak periods.

4.3 Model Architecture

Arrows in the Figure 3.3 show the access for input values in the real time model for each time application. The numbers in the bold downward arrow show the access sources for such inputs from the corresponding partner components.

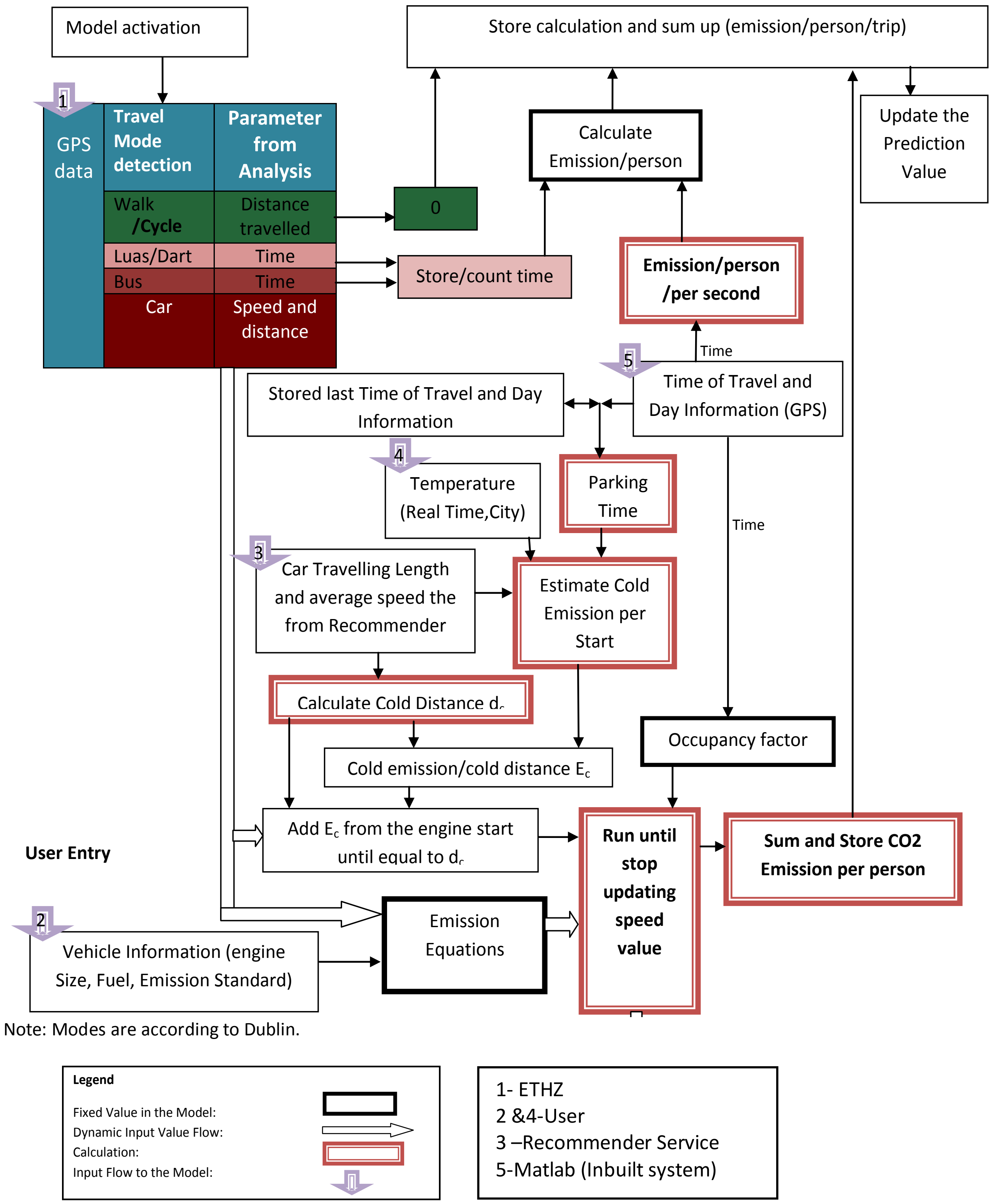

Figure 3.3 Real Time Emission Model Architecture

4.4 Dependency to the other components

The real time emissions model will be dependent on:

- The route recommender for total length of the recommended car route (this information will be delivered from the prediction model to the real time emission model when a user will select a route from a number of options).
- Travel mode detection component and GPS Data for travel time and length according to mode. Please see model adaptable coded value in the Table 2, appendix for detected modes by GPS component.
- Users Profiles (First User Setting: Private vehicle type-Euro category, vehicle weight and engine size, fuel technology and catalytic converter etc. and for each time model application temperature data is needed). Please see the model adaptable coded value for vehicle category in the Table 1, appendix which is expected to access from user profile. It should be also noted that a signal like '99x99' digit is needed in the GPS input file to follow the command to stop calculation. The input format from the other components has been mentioned in the Figure 5, appendix.

5. Emissions Prediction Model

The prediction model will give a prediction about the emission for the routes recommended by the Peacox app.

5.1 Introduction

Emissions can be predicted for different routes, and an optimal route can be selected based on the least emissions route. A simplistic model should be used to calculate emission where improved speed or travel time link data will be the modelling input.

5.2 Input Requirement

The prediction model will take input for modes (e.g. car, walk, bus, and tram) and corresponding route IDs, length from the recommended routes and use those data against emission factors/equations and other variables in the model for predicting emission.

The emissions prediction models will require the following data input:

- Modes and segment length according to Route segment IDs for an entire trip.
- Real time speed (based on real time traffic) according to route segment IDs.
- User Profile information (Private vehicle type-Euro category, vehicle weight and engine size, fuel technology and catalyst converter, Real time Temperature etc).
- Available Travel Modes in the city.
- Private vehicle and Public transport occupancy.
- Database of Emission Equations for private car.
- Database of Emission rates for public transport.
- Time and Date.
- Traffic information: Peak and off-peak periods.

5.3 Model Architecture

The architecture for emission model has been included in the Figure 3.4.

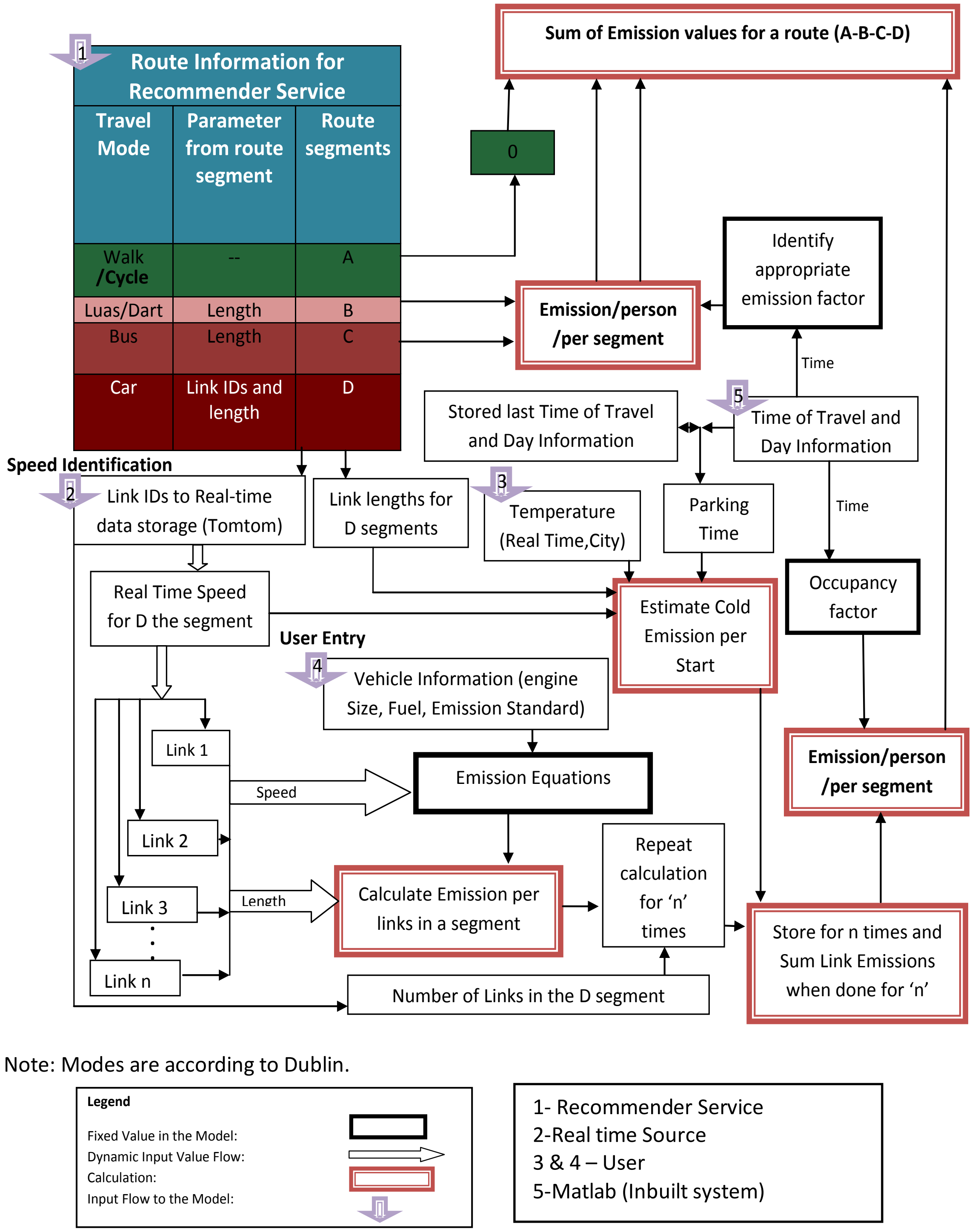

Figure 3.4 Emission Prediction Model Architecture

The emission prediction models have been designed in a way that it will take account of mode and travelled distance for public transport and will take speed information from the real-time source according to the link IDs for a recommended route and will generate emission factors for those link IDs (Figure 3.5).

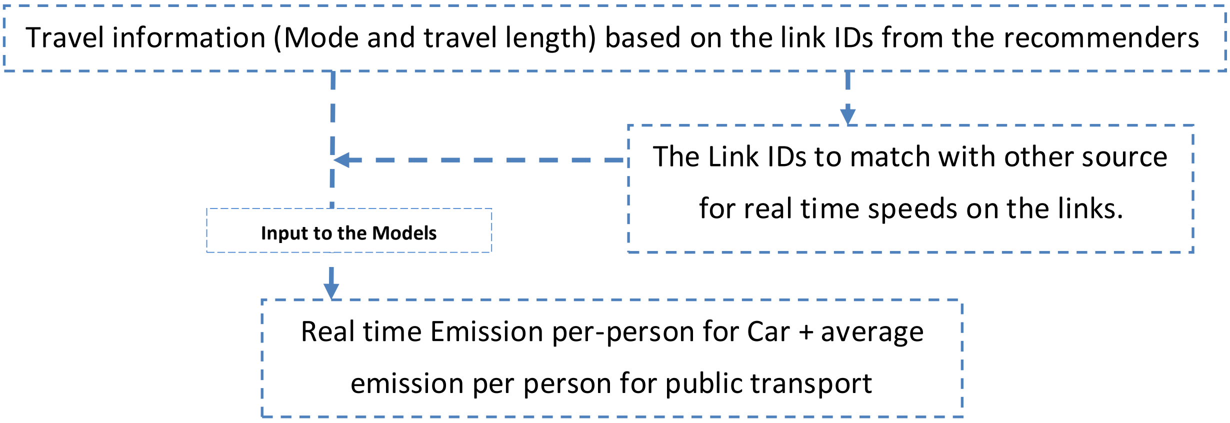

Figure 3.5 Inputs for Prediction Emission Model

5.4 Dependency to the other components

The emissions model will be dependent on:

- Modes and segment length according to Route segment IDs for an entire trip.
- Real time traffic data (speed and travel time per segment according to the above Route segment IDs from TomTom or, Floating car data or Intelligent Transport Infrastructure).
- Users Profiles (First User Setting: Private vehicle type-Euro category, vehicle weight and engine size, fuel technology and catalyst converter etc. and for each time model application: Temperature). Please see the model adaptable coded value for vehicle category in the Table 1 (appendix), which is expected to be accessed from user profile. Also, the input format from the other components has been mentioned in Figure 5 (appendix).

6. Model Validation and Limitations

6.1 Validations

According to DoW, the validation of the models will be done through a traffic micro-simulation software package VISSIM using traffic data from the cities (Dublin and Vienna) and simulate the travel time and congestion levels on several routes. As emission factors were taken from established sources, the validation will be expected to be accurate as the factors used in the VISSIM will have same characteristics of emission data in terms of limitations (section 6.2).

For field testing and validation, a portable emission monitoring system device (PEMS) and mobile GPS device are required. A PEMS device will be required for measuring emission in field tests for validation. Whereas, the GPS device will provide speed and acceleration input for cross checking the data by real time emission model.

6.2 Limitations

A number of factors can affect the validation approach, because many real world conditions were not included while emission factors were generated. Those may cause a significant difference between calculated/predicted emissions and output from PEMS data. For instance, usage of air conditioning (AC) systems may cause excess fuel consumption (thus, increase in emission) which would not be possible to accumulate with emission factors due to lack of the technological representative parameters [41]. In addition, as emission factors often filter out the effects of road grades or other factors while establishing the basic emission factor/equations, it is expected to have an impact upon calculated emissions by the models in the non-flat terrain in Dublin. A number of studies reported that the CO emission rate increases as road grade increases for light-duty gasoline vehicles [30, 31]. Therefore, emission factors vary for CO_2 with the increase of CO in the hilly roads. Thus, may reduce the accuracy of emission estimation. The effect of road grades, auxiliaries (e.g. lights) on emission can be used [44], but addition of new variables may cause unnecessary complexities for the mobile application.

7. Sample Test

A route length of 38.30km in the Greater Dublin Area was chosen as a means of illustrating the operation of the CO_2 emissions modules and obtaining sample results. This route comprised a number of possible modes in the Dublin area, e.g. Car, Dart, Walk, Bus and Luas. Model input data for this route was generated using the information obtained from the below route description and data from the literature review [12].

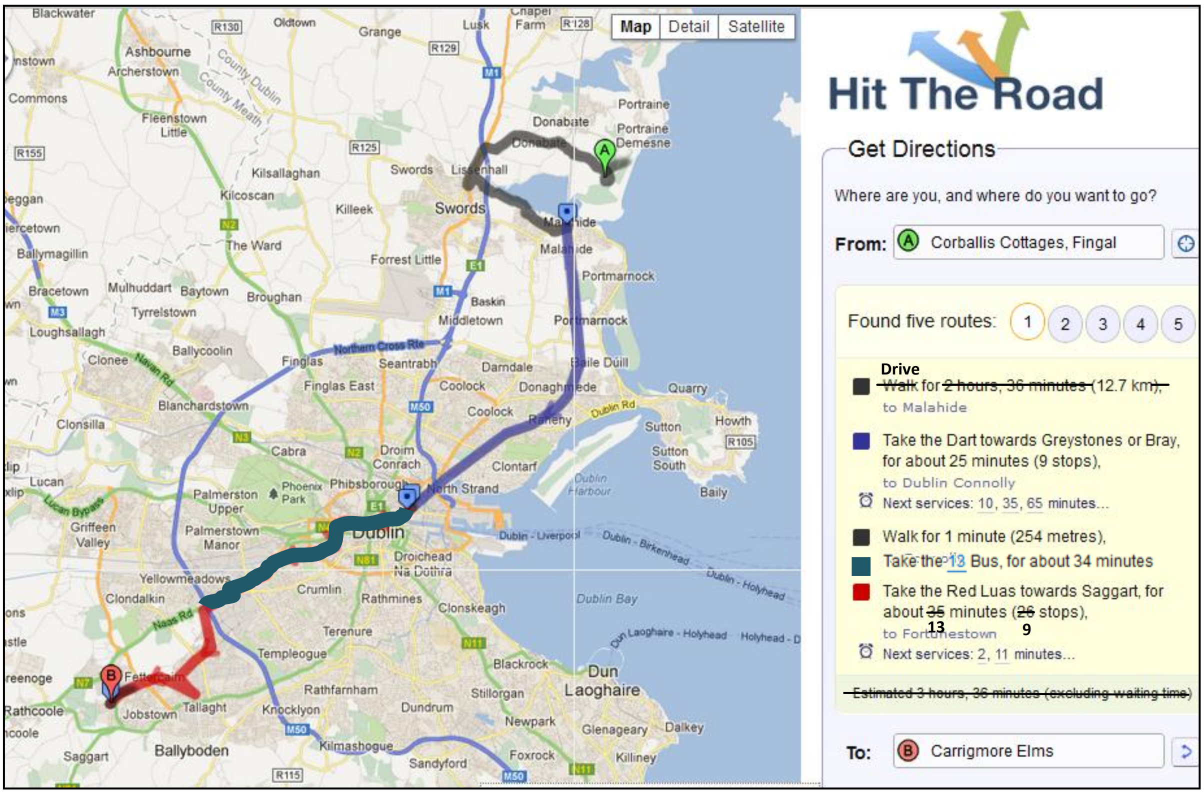

Figure 3.6 O-D of the route for the test run.

The route in the Figure 3.6 shows the origin (O)- Corballis Cottages, Fingal (A) to destination(D) - Carrigmore Elms (B) in Greater Dublin Area, Ireland. The basic route and mode information were obtained from http://hittheroad.ie. The basic data is shown below (Table 3.3):

Table 3.3: Basic data for the test route

	Route segment Information			Derived basic data for test run			
Mode	Information	Unit	Mode	Average	Distance	Travel Time	Travel Time

				Speed (km/hr)*	(km)	(hr)	(Minutes)
Car	12.7	km	Car	66.00	12.70	0.192	11.55
Dart	25	minutes	Dart	30.00	12.50	0.417	25.00
Walk	254	Meter	Walk	5.00	0.25	0.051	3.05
Bus	34	minutes	Bus	13.50	7.65	0.567	34.00
Luas	13	minutes	Luas	24.00	5.20	0.217	13.00

*[12]

A number of data sets have been generated in the Excel software to represent the partner components' datasets (see Appendix Table 9 representing data from recommender service, Table 10 representing data from real time speed provider component, and Table 11 representing the GPS data). The mean values for the speed and total distance travelled have been kept same in the generated data as the original data. However, speed standard deviations (SD) for modes were varied for GPS data (Table 3.4). Similar to the GPS component, the mean of the real time speed data for the links were kept same as given the mean, i.e. 66km/hr for car with a SD of 31.48.

Table 3.4 Confirmed Consistency between generated Inputs for both Models

Mode	Calculated Map Data		Generated GPS Data		
	Speed-km/min	Distance-km	Speed-km/min (Average)	Distance-km (total)	Speed SD
Car	1.1	12.7	1.1	12.7	0.63
Dart	0.5	12.5	0.5	12.5	0.15
Walk	0.0833	0.25	0.08	0.25	0
Bus	0.225	7.65	0.23	7.65	0.12
Luas	0.4	5.2	0.4	5.2	0.25

The vehicle for this test run was assumed to be of a Euro III emission standard having weight of less than 2.5 tonnes, engine size 1400cc with a catalytic convertor and petrol as a fuel source.

The emission estimation processes for the cars in the models are particularly sensitive to temperature, parking time[2], etc. whereas peak and off-peak factors are applicable to all the modes. The models were run in the evening off peak period twice consecutively with ten minutes interval, considering the ambient temperatures as 12 ^{o}C and 18 ^{o}C respectively. The results obtained from two models in various combinations for the route were found consistent and realistic for both the public transports (Table 3.5) and cars (Table 3.6).

Table 3.5 Public Transport CO_2 Emission for the test route

	Public Transport Emission kg/trip/person -Off-peak		
	Bus	Dart	Luas
Real-time Model	0.22	0.43	0.67
Prediction Model	0.2219	0.425	0.6656

Table 3.6 Car CO_2 Emission for the test route

	Car Emission kg/trip/person -Off-peak			
	80 min Parking Time[2]		10 min Parking Time[2]	
	12^0c	18^0c	12^0c	18^0c
Real-time Model	2.08	1.51	1.5	1.48
Prediction Model	1.4837	1.4586	1.4552	1.4366

8. Conclusion

The methodologies have been developed and trip-by-trip emission models for the door to door scenario have been developed for the given task of Peacox project. The Real time model will facilitate eco-friendly driving capturing important features which are missing in similar existing applications, e.g. the temperature variations (which affect cold start), resulting in more precise emission estimation for a single trip. Whereas for prediction, improved speed data (based on real-time traffic) will provide an accurate estimation of emission in the roads. Integrating the tasks with other components, establishing the input access and estimation processes are heavily dependent upon the partners and thus the further modification may be carried out.

----

2. Parking time is the idle time of a vehicle which represents the degree of a catalyst convertor's coolness/temperature. Model accounts for this by calculating the difference between two subsequent model applications by the users.

References

[1] S. Ye, W. Zhou, J. Song B. Peng , D. Yuan,Y. Lu Y, and P. Qi. Toxicity and health effects of vehicle emissions in Shanghai. Atmospheric Environment Vol. 34, pp 419-429, 1999.

[2]E. Uherek, T. Halenka ,J. Borken-Kleefeld, Y. Balkanski, T. Berntsen,C. Borrego,M. Gauss, P.Hoor, K. Juda-Rezler, J. Lelieveld, D. Melas, K. Rypdal, and S. Schmid. Transport impacts on atmosphere and climate: Land transport, Atmospheric Environment. Volume 44, Issue 37, pp 4772–4816, 2010.

[3]A. W. Strawa, T. W. Kirchstetter, A. G. Hallar, G. A. Ban-Weiss, J. P. McLaughlin, R.A. Harley and M. M. Lunden. Optical and physical properties of primary on-road vehicle particle emissions and their implications for climate change, Journal of Aerosol Science. Volume 41, Issue 1, pp 36–50, 2010.

[4]S. Nocera and F. Cavallaro. Policy Effectiveness for containing CO2 Emissions in Transportation, Procedia Social and Behavioral Sciences 20 703–713, 2011.

[5]DGET, Directorate-General for Energy and Transport. Mid-term review of the European Commission's 2001 White Paper on Transport, 2006. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2006:0314:FIN:EN:HTML , accessed on 20th February 2012.

[6]Kyoto protocol, 1997 United Nations Framework convention on Climate change, available at http://unfccc.int/kyoto_protocol/items/2830.php, accessed on 20th February 2012.

[7]S. Giblin and A. McNabola. Modelling the impacts of a carbon emission differentiated vehicle tax system on CO2 emissions intensity from new vehicle purchases in Ireland. Energy Policy 37 (4), 1404–141, 2009.

[8]H. Hennessy H. and S.J. R. Tol. The impact of tax reform on new car purchases in Ireland, Energy Policy (39), 7059–7067, 2011.

[9]IEA (International Energy Agency), 200?, Policies and Measures Database, available at http://www.iea.org/textbase/pm/?mode=pm&id=355&action=detail, (Updated on 2012) Accessed on 10, February 2012.

[10]L. Whitmarsh, G. Seyfang and S. O'Neill. Public engagement with carbon and climate change: To what extent is the public 'carbon capable'?, Global Environmental Change 21, 56–6,2011.

[11] C. Walsh, P. Jakeman, R. Moles, B. O'Regan. A comparison of carbon dioxide emissions associated with motorised transport modes and cycling in Ireland, Transportation Research Part D, 3 392–399, 2008.

[12] B. E. Ainsworth, W. L. Haskell, M.C.Whitt, M.L. Irwin, A. M. Swartz, S. J. Strath, W. L. O'Brien, D. R. Bassett Jr., K. H. Schmitz, P. O. Emplaincourt, D. R. Jacobs, A. S. Leon, . Compendium of physical activities: an update of activity codes and MET intensities. Medicine and Science in Sports and Exercise 32, 498–516, 2000.

[13]K. Ahnand and H. Rakha. The effects of route choice decisions on vehicle energy consumption and emissions. Transportation Research Part D 13, pp151–167,2008.

[14]E. Ericsson, H. Larsson and K. Brundell-Freij. Optimizing route choice for lowest fuel consumption – Potential effects of a new driver support tool. Transportation Research Part C (14) , 369–383, 2006.

[15]H. Xia, K. Boriboonsomsin and M. Barth. Indirect network-wide energy/emissions benefits from dynamic eco-driving on signalized corridors, Proc. In the 14th International IEEE Conference, ISSN: 2153-0009, 2011.

[16]R. Ando and Y. Nishihori. How does driving behavior change when following an eco-driving car?. Procedia Social and Behavioral Sciences 20 , 577–587,2011.

[17]G. Qian and E. Chung. Evaluating effects of eco-driving at traffic intersections based on traffic micro-simulation. In Australasian Transport Research Forum 2011 Proceedings 28 - 30 September 2011, Adelaide.

[18]R. Ando, Y. Nishihori and D. Ochi. Development of a System to Promote Eco-Driving ad Safe-Driving .In Proceedings of the Third conference on Smart Spaces and next generation wired, and 10th international conference on Wireless networking, ISBN3-642-14890-5 978-3-642-14890-3, Springer-Verlag Berlin, Heidelberg,2010 .

[19]Earthrise Technology 2010. Eco-Way for Eco-driving; Available at http://173.228.122.78:8080/earthrise/html/eco-way.html (Accessed on 15-03-2012)

[20]B. Beusen , S. Broekx, T. Denys, C. Beckx, B. Degraeuwe, M. Gijsbers, K. Scheepers, L. Govaerts , R. Torfs and L.I. Panis. Using on-board logging devices to study the longer-term impact of an eco-driving course, Transportation Research Part D (14) 514–520,2009.

[21]M.J. Barth, E. Johnston, and R. R. Tadi . Using GPS Technology to Relate Macroscopic and Microscopic Traffic Parameters. Transportation Research Record: Journal of the

Transportation Research Board, Volume 1520 / 1996 (Energy and Environment), Transportation Research Board of the National Academies, 2007.

[22]Hunter research & technology, 2008. greenMeter. Available at: http://hunter.pairsite.com/greenmeter/,Accessed on 17-05-2012.

[23]V. Manzoni, D. Manilo, K. Kloeckl and C. Ratti. Transportation mode identification and real-time CO2 emission estimation using smartphones: How CO2GO works (Technical Report), SENSEable City Lab, MIT and Dipartimento di Elettronica e Informazione, Politecnico di Milano, Milan, Italy, 2011.

[24]CarbonDiem, 2012. What is CarbonDiem? Available at: http://www.carbondiem.com/carbondiem.xhtml;jsessionid=958E56D6A72606F1FEE3A2D28A6BB39B, Accessed on 17-05-2012.

[25]L. Pelkmans and P. Debal. Comparison of on-road emissions with emissions measured on chassis dynamometer test cycles. Transportation Research Part D (11) ,233–241,2006.

[26] J. Kang , T. Ma, F. Ma and J. Huang . Link-based Emission Model for Eco Routing, Proc. In the 11th International Conference on ITS Telecommunications, 2011.

[27]C. Beckx, L. I. Panis, D. Janssens and G. Wets. Applying activity-travel data for the assessment of vehicle exhaust emissions: Application of a GPS-enhanced data collection tool., Transportation Research Part D 15, 117–122,2010.

[28]F. Mensing, R. Trigui and E. Bideaux. Vehicle Trajectory Optimization for Application in Eco-Driving, IEEE,2011.

[29]G. Marsden, M. Bell and S. Reynolds. Towards a real-time microscopic emissions model. Transportation Research Part D (6), 37-60,2001.

[30]A. Kean, R. Harley and G. Kendall. Effects of Vehicle Speed and Engine Load on Motor Vehicle Emissions, Environmental Science & Technology , Vol. 37(17), 2003.

[31]N. Kelly and P.J. Groblicki. Real-World Emissions from a Modern Production Vehicle Driven in Los Angeles; Journal of Air & Waste Management Association, 43, 1351-1357,1993.

[32]K. Chibber. Car or computer? How transport is becoming more connected, BBC NEWS:BUSINESS, 26 November, 2010 , Available at: http://www.bbc.co.uk/news/business-11832473, Accessed on :17-05-2012.

[33]EMISIA 2009. Fuel & Energy Consumption Calculator, Available at: http://www.emisia.com/tools/calculator.html, Accessed on 17-05-2012.

[34]CarbonNeutral Company Limited, n'd. CarbonNeutral®driving, Available at:

http://www.carbonneutralcalculator.com/drivingcalculator.aspx, Accessed on 17-05-2012.

[35]MIT: SENSEable City Lab. N'd. CO2GO: Calculating your carbon footprint automatically and in real-time while on the move, Available at: http://senseable.mit.edu/co2go/, Accessed on: 17-05-2012

[36]R. Smit, A.L. Brown and Y.C. Chan. Do air pollution emissions and fuel consumption models for roadways include the effects of congestion in the roadway traffic flow?, Environmental Modelling & Software , Volume 23 Issue 10-11,2008.

[37]Road User Monitoring Report 2004, Dublin Transportation Office, Ireland.

[38]LUAS Website, Luas Eco Calculator - Detail Info, available at http://www.luas.ie/detailed-information.html, accessed on 22-06-2012

[39] P. G. Boulter, T. J. Barlow and I. S. McCRae 2009. Emission factors 2009: Report 3-Exhaust emission factors for road vehicles in United Kingdom. Published Project Report ,TRL Limited.

[40] P. G. Boulter and S. Lathlam 2009. Emission factors 2009: Report 4-a review of methodologies for modelling cold-start emissions. Published Project Report ,TRL Limited.

[41] S. Roujol and R. Joumard. Influence of passenger car auxiliaries on pollutant emission factors within the Artemis model. Atmospheric Environment 43 ,1008–1014, 2009.

[42]Road User Monitoring Report 2009, Dublin Transportation Office, Ireland.

[43] F. Gram. Time variations in traffic and traffic emissions. The Science of the Total Environment 189/190. pp 115-118, 1996.

[44]R. Joumard, J. André , M. Rapone, M. Zallinger , N. Kljun, M. André, Z. Samaras, S. Roujol, J. Laurikko, M. Weilenmann, K. Markewitz, S. Geivanidis, D. Ajtay and L. Paturel. Emission Factor Modelling And Database For Light Vehicles, Artemis deliverable 3, Report n°L TE 0523, June 2007.

Appendix

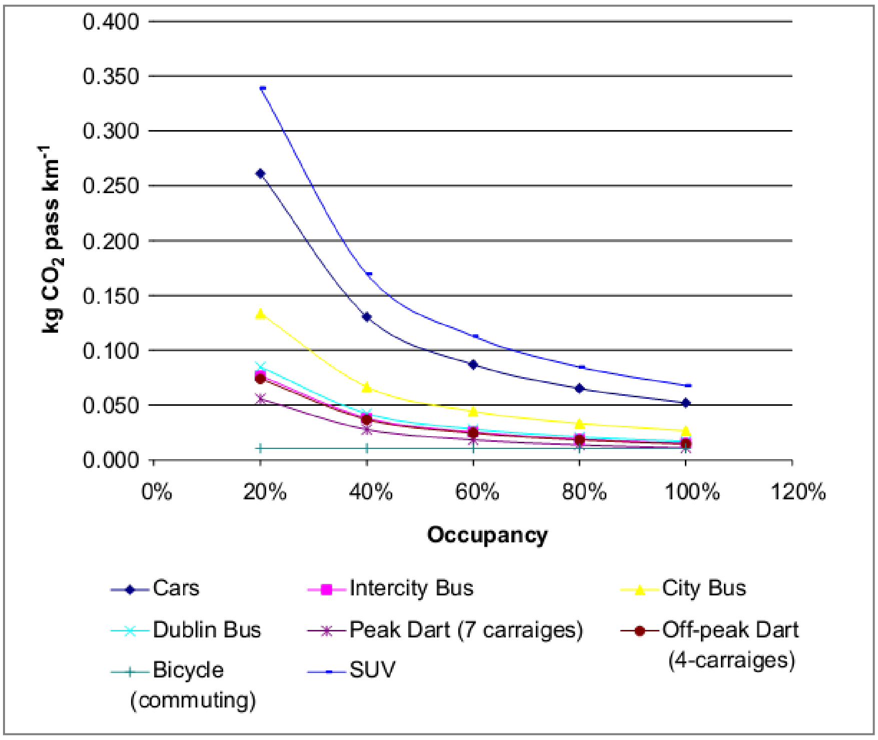

Figure 1: Effect of occupancy on overall transport emission, Source [11]

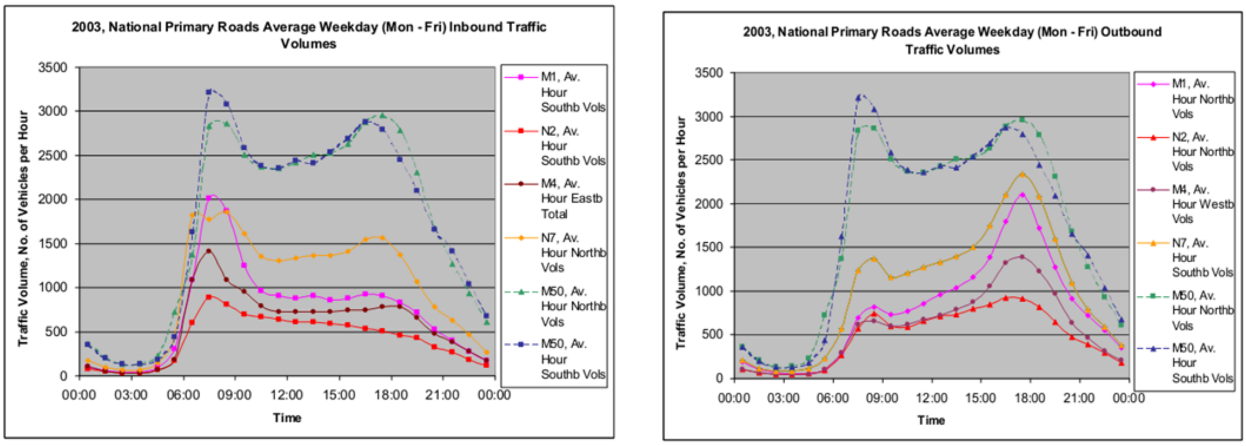

Figure 2: Dublin Traffic inbound (left) and outbound traffic flow for weekdays-2003 (Sources: 37)

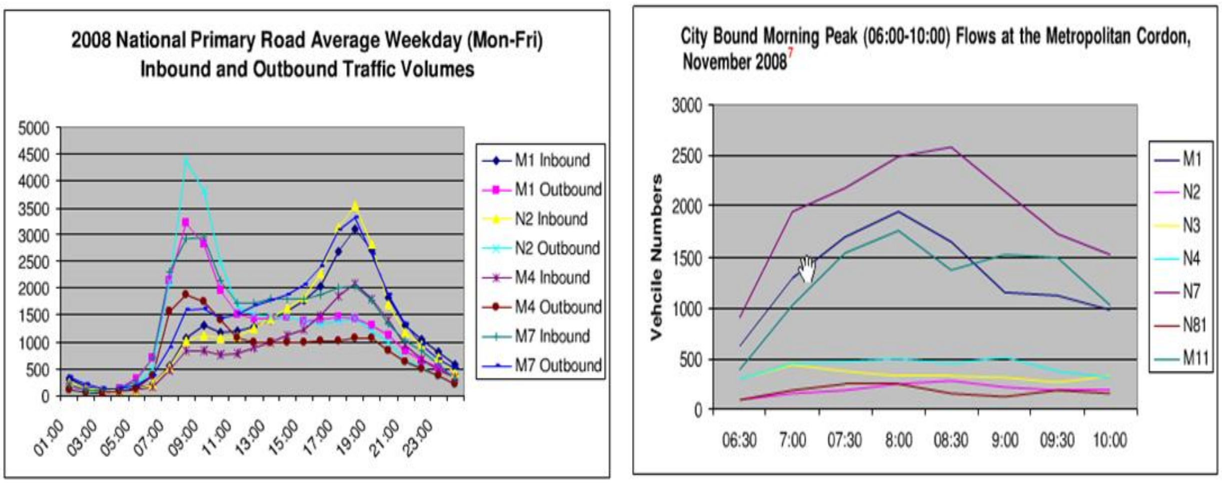

Figure 3: Dublin Traffic inbound and outbound (left), and city bound traffic flow for weekdays-2008 (Sources: 42)

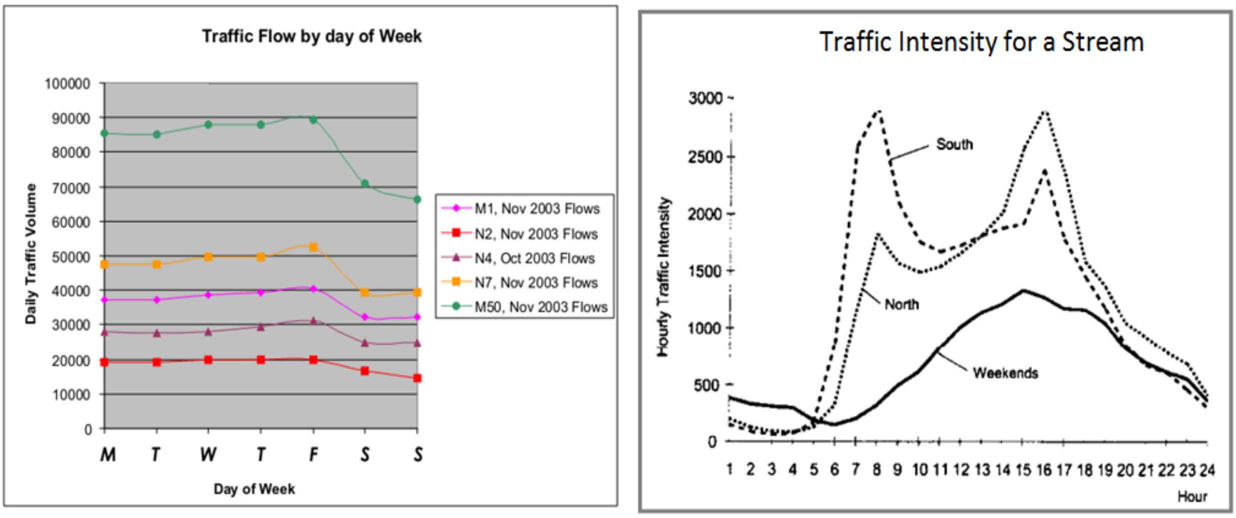

Figure 4: Traffic goes down in the weekends –left figure (Sources: 37) and there is no distinct peak usually as confirmed by the literature (right figure: source:43)

Table 1: Code for vehicle category, catalyst convertor, fuel type and emission standard

Vehicle Emission Standard	
Class	**Code**
Pre-Euro	100
Euro I	1
Euro II	2
Euro III	3
Euro IV	4
Euro VI	5
Euro VI	6
Fuel Technology	
Type	**Code**
Petrol	11
Diesel	12
Vehicle weight and Engine Size	
Class	**Code**
<2.5 tonnes (1400cc)	21
<2.5 tonnes (1400-2000cc)	22
<2.5 tonnes (>2000cc)	23
2.5-3.5tonnes (any)	24
Catalyst Converter	
Class	**Code**
Yes	31
No	32

Table 2: Code for modes to capture GPS mode detection

Mode	Code
Walk	1
Cycle	1
Urban Public Transport Luas	2
Urban Public Transport Dart	3
Urban Public Transport Bus	4
Car	5

Table 3: Defining vehicle category in a numeric value according to engine, fuel type and emission standard

Primary Code	Vehicle characteristics (engine size <2.5 tonnes)			Primary Code	Vehicle characteristics(engine size >2.5 tonnes)		
	Fuel Technology	Vehicle weight and Engine Size	Vehicle Emission Standard		Fuel Technology	Vehicle weight and Engine Size	Vehicle Emission Standard
1100	Petrol	<2.5 tonnes (1400cc)	Pre-Euro	1200	Diesel	<2.5 tonnes (1400cc)	Pre-Euro
11	Petrol	<2.5 tonnes (1400cc)	Euro I	12	Diesel	<2.5 tonnes (1400cc)	Euro I
22	Petrol	<2.5 tonnes (1400cc)	Euro II	24	Diesel	<2.5 tonnes (1400cc)	Euro II
33	Petrol	<2.5 tonnes (1400cc)	Euro III	36	Diesel	<2.5 tonnes (1400cc)	Euro III
44	Petrol	<2.5 tonnes (1400cc)	Euro IV	48	Diesel	<2.5 tonnes (1400cc)	Euro IV
55	Petrol	<2.5 tonnes (1400cc)	Euro VI	60	Diesel	<2.5 tonnes (1400cc)	Euro VI
66	Petrol	<2.5 tonnes (1400cc)	Euro VI	72	Diesel	<2.5 tonnes (1400cc)	Euro VI
24200	Petrol	<2.5 tonnes (1400-2000cc)	Pre-Euro	26400	Diesel	<2.5 tonnes (1400-2000cc)	Pre-Euro
242	Petrol	<2.5 tonnes (1400-2000cc)	Euro I	264	Diesel	<2.5 tonnes (1400-2000cc)	Euro I
484	Petrol	<2.5 tonnes (1400-2000cc)	Euro II	528	Diesel	<2.5 tonnes (1400-2000cc)	Euro II
726	Petrol	<2.5 tonnes (1400-2000cc)	Euro III	792	Diesel	<2.5 tonnes (1400-2000cc)	Euro III
968	Petrol	<2.5 tonnes (1400-2000cc)	Euro IV	1056	Diesel	<2.5 tonnes (1400-2000cc)	Euro IV
1210	Petrol	<2.5 tonnes (1400-2000cc)	Euro VI	1320	Diesel	<2.5 tonnes (1400-2000cc)	Euro VI
1452	Petrol	<2.5 tonnes (1400-2000cc)	Euro VI	1584	Diesel	<2.5 tonnes (1400-2000cc)	Euro VI
25300	Petrol	<2.5 tonnes (>2000cc)	Pre-Euro	27600	Diesel	<2.5 tonnes (>2000cc)	Pre-Euro
253	Petrol	<2.5 tonnes (>2000cc)	Euro I	276	Diesel	<2.5 tonnes (>2000cc)	Euro I
506	Petrol	<2.5 tonnes (>2000cc)	Euro II	552	Diesel	<2.5 tonnes (>2000cc)	Euro II
759	Petrol	<2.5 tonnes (>2000cc)	Euro III	828	Diesel	<2.5 tonnes (>2000cc)	Euro III
1012	Petrol	<2.5 tonnes (>2000cc)	Euro IV	1104	Diesel	<2.5 tonnes (>2000cc)	Euro IV
1265	Petrol	<2.5 tonnes (>2000cc)	Euro VI	1380	Diesel	<2.5 tonnes (>2000cc)	Euro VI
1518	Petrol	<2.5 tonnes (>2000cc)	Euro VI	1656	Diesel	<2.5 tonnes (>2000cc)	Euro VI

Table 4: Defining vehicle category in a numeric value according to catalyst convertor, fuel type and emission standard (engine size >2.5 tonnes)

Primary Code	Fuel Technology	Catalyst Converter	Vehicle Emission Standard
35200	Petrol	N	Pre-Euro
352	Petrol	N	Euro I
704	Petrol	N	Euro II
1056	Petrol	N	Euro III
1408	Petrol	N	Euro IV
1760	Petrol	N	Euro VI
2112	Petrol	N	Euro VI
34100	Petrol	Y	Pre-Euro
341	Petrol	Y	Euro I
682	Petrol	Y	Euro II
1023	Petrol	Y	Euro III
1364	Petrol	Y	Euro IV
1705	Petrol	Y	Euro VI
2046	Petrol	Y	Euro VI
38400	Diesel	N	Pre-Euro
384	Diesel	N	Euro I
768	Diesel	N	Euro II
1152	Diesel	N	Euro III
1536	Diesel	N	Euro IV
1920	Diesel	N	Euro VI
2304	Diesel	N	Euro VI
37200	Diesel	Y	Pre-Euro
372	Diesel	Y	Euro I
744	Diesel	Y	Euro II
1116	Diesel	Y	Euro III
1488	Diesel	Y	Euro IV
1860	Diesel	Y	Euro VI
2232	Diesel	Y	Euro VI

Table 5: Empirical Equations for cold start emission, Source [40]

New Code	Primary Code	Excess Emission	Correction CO-efficient, *f*	Cold Distance dc(T,V)	Value a
A1	38400	854.4-17.56*V	1.698-.035*V	-2.27+0.0321*V	-3.432
A2	35200,352, 704,1056, 1408,1760,2112	214.922-6.528*TT-.088*V	2.602-.079*TT-.01*V	2.807-.024*TT+.141*V	-2.33
A3	37200,34100	133.024-.306*V	1.048-.002*V	2.172+.126*V	-2.68
A4	372,384	374.171-8.405*TT-2.606*V	2.43-.055*TT-.017*V	3.474+.163*V	-4.078
A5	341	162.937-5.435*TT+.358*V	2.654-.089*TT+.006*V	3.838+.081*V	-2.714
A6	744,768	362.34-10.921*TT-.14*V	2.567-.077*TT-.001*V	4.31-.04*TT+.125*V	-3.767
A7	682	194.662-3.546*TT+.504*V	1.454-.026*TT+.004*V	4.048-.124*TT+.145*V	-2.563
A8	1116,1152,1488, 1536,1860, 192,2232,2304	171.52-..381*V	1.047-.002*V	9.093-.064*V	-3.389
A9	1023,2046,1705	186.055- 5.365*TT+2.283*V	1.496-.043*TT+.018*V	2.461-.057*TT+.173*V	-3.662
A10	1364	168.005-5.165*TT	2.597-.08*TT	5.398-.142*TT	-2.686

Table 6: Coefficient for emission equations, petrol powered vehicle and <2.5 tonnes , Source: [39]

Primary Code	a	b	c	d	e	f	g
1100	2.2606*10^3	1.0314*10^0	2.9263*10^-1	3.0199*10^-3	0	0	0
11	2.2606*10^3	8.7563*10^1	2.9263*10^-1	3.0199*10^-3	0	0	0
22	2.2606*10^3	8.0148*10^1	2.9263*10^-1	3.0199*10^-3	0	0	0
33	2.2606*10^3	7.0183*10^1	2.9263*10^-1	3.0199*10^-3	0	0	0
44	2.2606*10^3	5.9444*10^1	2.9263*10^-1	3.0199*10^-3	0	0	0
55	2.2606*10^3	4.4379*10^1	2.9263*10^-1	3.0199*10^-3	0	0	0
66	2.2606*10^3	3.1583*10^1	2.9263*10^-1	3.0199*10^-3	0	0	0
24200	2.5324*10^3	1.532*10^2	-0.43167	6.6776*10^-3	0	0	0
242	2.5324*10^3	1.3779*10^2	-0.43167	6.6776*10^-3	0	0	0
484	2.5324*10^3	1.2988*10^2	-0.43167	6.6776*10^-3	0	0	0
726	2.5324*10^3	1.1834*10^2	-0.43167	6.6776*10^-3	0	0	0
968	2.5324*10^3	1.034*10^2	-0.43167	6.6776*10^-3	0	0	0
1210	2.5324*10^3	8.4965*10^1	-0.43167	6.6776*10^-3	0	0	0
1452	2.5324*10^3	6.8842*10^1	-0.43167	6.6776*10^-3	0	0	0
25300	3.7473*10^3	2.0881*10^2	-0.8527	1.0318*10^-2	0	0	0
253	3.7473*10^3	1.9576*10^2	-0.8527	1.0318*10^-2	0	0	0
506	3.7473*10^3	1.8600*10^2	-0.8527	1.0318*10^-2	0	0	0
759	3.7473*10^3	1.6774*10^2	-0.8527	1.0318*10^-2	0	0	0
1012	3.7473*10^3	1.5599*10^2	-0.8527	1.0318*10^-2	0	0	0
1265	3.7473*10^3	1.2877*10^2	-0.8527	1.0318*10^-2	0	0	0
1518	3.7473*10^3	1.0571*10^2	-0.8527	1.0318*10^-2	0	0	0

Table 7: Coefficient for emission equations, diesel powered vehicle and <2.5 tonnes , Source: [39]

Primary Code	a	b	c	d	e	f	g
1200	1.2988*10^3	1.4063*10^2	-1.5597	1.2264*10^-2	0	0	0
12	1.2988*10^3	1.3636*10^2	-1.5597	1.2264*10^-3	0	0	0
24	1.2988*10^3	1.2848*10^2	-1.5597	1.2264*10^-4	0	0	0
36	1.2988*10^3	1.770*10^2	-1.5597	1.2264*10^-5	0	0	0
48	1.2988*10^3	1.1846*10^2	-1.5597	1.2264*10^-6	0	0	0
60	1.2988*10^3	1.0596*10^2	-1.5597	1.2264*10^-7	0	0	0
72	1.2988*10^3	9.94974*10^1	-1.5597	1.2264*10^-8	0	0	0
26400	1.2988*10^3	1.809*10^2	-1.5597	1.2264*10^-9	0	0	0
264	1.2988*10^3	1.7576*10^2	-1.5597	1.2264*10^-10	0	0	0
528	1.2988*10^3	1.6567*102	-1.5597	1.2264*10^-11	0	0	0
792	1.2988*10^3	1.5249*10^2	-1.5597	1.2264*10^-12	0	0	0
1056	1.2988*10^3	1.4665*10^2	-1.5597	1.2264*10^-13	0	0	0
1320	1.2988*10^3	1.3055*10^2	-1.5597	1.2264*10^-14	0	0	0
1584	1.2988*10^3	1.1701*10^2	-1.5597	1.2264*10^-15	0	0	0
27600	1.2988*10^3	2.5320*10^2	-1.5597	1.2264*10^-16	0	0	0
276	1.2988*10^3	2.4671*102	-1.5597	1.2264*10^-17	0	0	0
552	1.2988*10^3	2.3270*10^2	-1.5597	1.2264*10^-18	0	0	0
828	1.2988*10^3	2.1490*10^2	-1.5597	1.2264*10^-19	0	0	0
1104	1.2988*10^3	2.0203*10^2	-1.5597	1.2264*10^-20	0	0	0
1380	1.2988*10^3	1.8015*10^2	-1.5597	1.2264*10^-21	0	0	0
1656	1.2988*10^3	1.6147*10^2	-1.5597	1.2264*10^-22	0	0	0

Table 8: Coefficient for emission equations, diesel powered vehicle and >2.5 tonnes, , Source: [39]

Primary Code	a	b	c	d	e	f	g
4400	5.8599*10^3	1.3439*10^1	2.0179*10^-1	2.1654*10^-2	0	0	0
44	5.8599*10^4	2.0636*10^-1	2.0179*10^-2	2.1654*10^-3	0	0	0
88	4.8313*10^3	9.3414*10^1	9.524*10^-1	8.4173*10^-5	4.5393*10^-5	0	0
132	4.8313*10^3	9.3414*10^1	9.524*10^-1	8.4173*10^-5	4.5393*10^-5	0	0
176	4.8313*10^3	9.3414*10^1	9.524*10^-1	8.4173*10^-5	4.5393*10^-5	0	0
220	4.8313*10^3	9.3414*10^1	9.524*10^-1	8.4173*10^-5	4.5393*10^-5	0	0
264	4.8313*10^3	9.3414*10^1	9.524*10^-1	8.4173*10^-5	4.5393*10^-5	0	0
4800	4.8313*10^3	8.8452*10^1	6.3429*1^-1	1.3351*10^-2	-0.000055094	6.6419*10^-7	0
48	4.8313*10^3	8.8452*10^1	6.3429*1^-1	1.3351*10^-3	-0.000055094	6.6419*10^-7	0
96	5.4190*10^03	9.2699*10^1	6.3429*1^-1	9.7033*10^-3	-0.000030613	3.4575*10^-07	0
144	5.4190*10^03	9.2348*10^1	6.3429*1^-1	9.7033*10^-3	-0.000030613	3.4575*10^-08	0
192	5.4190*10^03	9.2208*10^1	6.3429*1^-1	9.7033*10^-3	-0.000030613	3.4575*10^-09	0
240	5.4190*10^03	9.1992*10^1	6.3429*1^-1	9.7033*10^-3	-0.000030613	3.4575*10^-10	0
288	5.4190*10^03	9.1992*10^2	6.3429*1^-1	9.7033*10^-3	-0.000030613	3.4575*10^-11	0

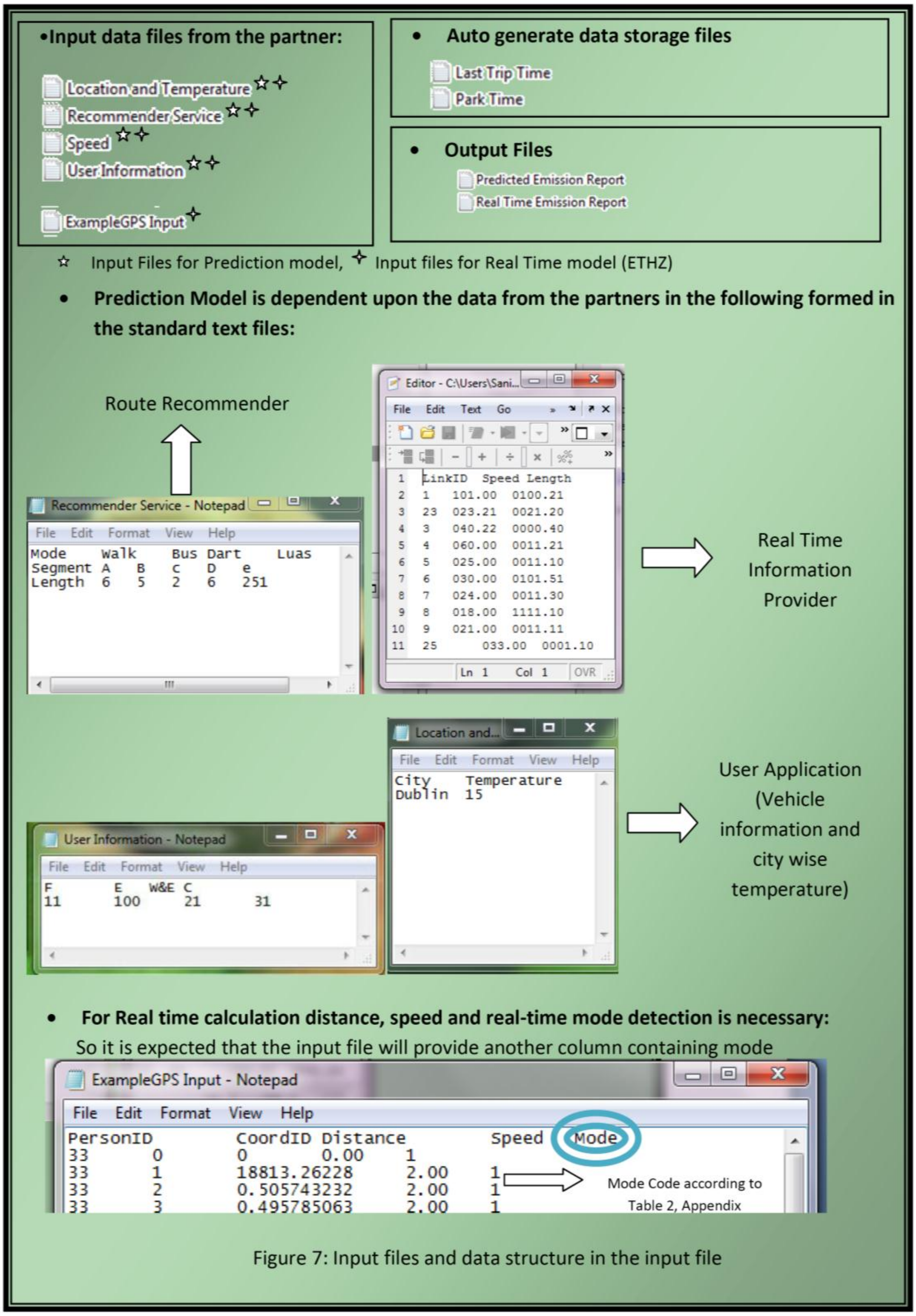

Figure 5: Input files and data structure in the input file

Table 9: Example data- Recommender's route information for the sample route

Mode	Average Speed (km/hr)*	Distance (km)
Car (A)	66	12.7
Dart	30	12.5
Walk	5	0.25
Bus	13.5	7.65
Luas	24	5.2

Table 10: Example data- links speed and information for the Car (A) segment for the sample route

Link Id	Km/hr	Distance km
12	25	2
8	40	1
3	50	1.5
41	60	0.56
56	90	1.001
21	80	0.98
45	100	1.9
445	120	1.18
87	90	1.26
78	80	0.56
22	35	0.23
24	25	0.529
12 Link Ids	66 Average	12.7 total

Table 11: Example data- GPS data for the sample route

PersonID	CoordID	Distance	Speed	Mode
33	1	0.007470588	5.4	5
33	2	0.007470588	5.4	5
33	3	0.01245098	5.4	5
33	4	0.01245098	5.4	5
33	5	0.014941176	5.4	5
33	6	0.017431373	5.4	5
33	7	0.009960784	5.4	5
33	8	0.224117647	5.4	5
33	9	0.348627451	84	5
33	10	0.256490196	61.8	5
33	11	0.298823529	72	5
33	12	0.423333333	102	5
33	13	0.398431373	96	5
33	14	0.448235294	108	5
33	15	0.398431373	96	5
33	16	0.348627451	84	5
33	17	0.398431373	96	5
33	18	0.348627451	84	5
33	19	0.398431373	96	5
33	20	0.398431373	96	5
33	21	0.373529412	90	5
33	22	0.373529412	90	5
33	23	0.435784314	105	5
33	24	0.448235294	108	5
33	25	0.373529412	90	5
33	26	0.448235294	108	5
33	27	0.348627451	84	5

33	28	0.448235294	108	5
33	29	0.398431373	96	5
33	30	0.448235294	108	5
33	31	0.348627451	84	5
33	32	0.298823529	72	5
33	33	0.348627451	84	5
33	34	0.448235294	108	5
33	35	0.348627451	84	5
33	36	0.348627451	84	5
33	37	0.254	61.2	5
33	38	0.224117647	54	5
33	39	0.199215686	48	5
33	40	0.273921569	66	5
33	41	0.281392157	67.8	5
33	42	0.224117647	54	5
33	43	0.224117647	54	5
33	44	0.007470588	5.4	5
33	45	0.004980392	5.4	5
33	46	0.002490196	5.4	5
33	47	0.288461538	18	3
33	48	0.288461538	18	3
33	49	0.480769231	30	3
33	50	0.384615385	24	3
33	51	0.576923077	36	3
33	52	0.576923077	36	3
33	53	0.673076923	42	3
33	54	0.673076923	42	3
33	55	0.480769231	30	3
33	56	0.576923077	36	3
33	57	0.480769231	30	3
33	58	0.384615385	24	3
33	59	0.769230769	48	3
33	60	0.480769231	30	3
33	61	0.480769231	30	3
33	62	0.673076923	42	3
33	63	0.673076923	42	3
33	64	0.480769231	30	3
33	65	0.384615385	24	3
33	66	0.576923077	36	3
33	67	0.384615385	24	3
33	68	0.480769231	30	3
33	69	0.384615385	24	3
33	70	0.288461538	18	3
33	71	0.288461538	18	3
33	72	0.288461538	18	3
33	73	0.083333333	4.998	1
33	74	0.083333333	4.998	1
33	75	0.083333333	4.998	1
33	76	0.018378378	1.2	4
33	77	0.091891892	6	4
33	78	0.220540541	14.4	4
33	79	0.266486486	17.4	4
33	80	0.018378378	1.2	4
33	81	0.220540541	14.4	4
33	82	0.275675676	18	4
33	83	0.206756757	13.5	4
33	84	0.266486486	17.4	4
33	85	0.367567568	24	4
33	86	0.275675676	18	4
33	87	0.202162162	13.2	4
33	88	0.266486486	17.4	4

33	89	0.220540541	14.4	4
33	90	0.091891892	6	4
33	91	0.275675676	18	4
33	92	0.220540541	14.4	4
33	93	0.367567568	24	4
33	94	0.275675676	18	4
33	95	0.202162162	13.2	4
33	96	0.275675676	18	4
33	97	0.266486486	17.4	4
33	98	0.202162162	13.2	4
33	99	0.018378378	1.2	4
33	100	0.220540541	14.4	4
33	101	0.367567568	24	4
33	102	0.202162162	13.2	4
33	103	0.091891892	6	4
33	104	0.367567568	24	4
33	105	0.275675676	18	4
33	106	0.202162162	13.2	4
33	107	0.275675676	18	4
33	108	0.275675676	18	4
33	109	0.202162162	13.2	4
33	110	0.018378378	1.2	4
33	111	0.018378378	1.2	4
33	112	0.018378378	1.2	4
33	113	0.004807692	0.6	2
33	114	0.004807692	0.6	2
33	115	0.009615385	1.2	2
33	116	0.288461538	36	2
33	117	0.043269231	5.4	2
33	118	0.048076923	6	2
33	119	0.096153846	12	2
33	120	0.144230769	18	2
33	121	0.192307692	24	2
33	122	0.240384615	30	2
33	123	0.192307692	24	2
33	124	0.336538462	42	2
33	125	0.326923077	40.8	2
33	126	0.192307692	24	2
33	127	0.288461538	36	2
33	128	0.336538462	42	2
33	129	0.144230769	18	2
33	130	0.192307692	24	2
33	131	0.384615385	48	2
33	132	0.240384615	30	2
33	133	0.144230769	18	2
33	134	0.240384615	30	2
33	135	0.432692308	54	2
33	136	0.192307692	24	2
33	137	0.240384615	30	2
33	138	0.192307692	24	2
33	139	0.048076923	6	2