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

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D3.5 Evaluation of Developed Models

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Description of Deliverable

This deliverable contains two parts. The first part contains the details of the behavioural models estimated to test the results of the field trials in Dublin and Vienna. The second part of the trial contains a validation of the emissions models used for the field trials.

Abstract

1.1 Part 1

One of the primary objectives of the PEACOX project was to examine the impact of the provision of emissions information upon the mode choice of application users. PEACOX users are assumed to assess the information that the application provides and make their transport decisions accordingly. The work presented in this part of the deliverable sets out to examine whether there was a detectable impact of emissions information upon user behaviour, using several discrete choice modelling techniques. This analysis included the formulation of a base model, the addition of socioeconomic and travel variables, the segmentation of models, and the use of more advanced modelling techniques. The remedial data collection processes implemented following the first field trial allowed for the successful collection of appropriate data for the formulation and convergence of the required models, however, based upon the user inputs the subsequent models demonstrated poor goodness of fit and cannot be considered to truly reflect the impact of emissions information on user mode choices. Based upon these model results, plus the descriptive statistics and users' comments, it is not possible to state that the provision of carbon dioxide emissions information has the ability alter users' transport choices.

1.2 Part 2

Part 2 of the deliverable documents the validation of the PEACOX door-to-door emission model from the second field trial followed by a first validation in D3.4. A simplified version of the model was introduced for the second field trial in order to present instant results to the users. Thus, the report a presents unit CO_2 emission factors for all modes for this simplified model, their justification for selection, and validation of emission prediction trips by statistical analysis, and model comparisons.

The validation was performed by a three-step procedure. In the first step, assessment of the emissions rate calculated from the field trial were conducted and visually presented. In the second part of the validation, the predictions of the new simplified and original emissions models (D 3.4) were compared, analysis of the different factors for the original model were analysed by statistical comparison. In addition, a few samples of emissions figures that were

calculated by the models for different trips were compared against trip segment predictions calculated by the Comprehensive Modal Emission Model (CMEM) model. The conclusion of the samples was found to be consistent with the previous results found using a VISSIM analysis (D 3.4).

The findings of this investigation again demonstrated that the model was acceptable for routing comparisons.

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2. Part 1 Introduction-Behaviour Model

This part of the deliverable concerns the 2014 PEACOX application field trials, and specifically how the data collected from these trials was used to construct the appropriate discrete choice models. It outlines the data collection and formatting methods and appropriateness of the selected modelling approaches, and describes the construction and calibration of the choice models, as well as the application of more advanced modelling techniques to the data set. It also provides a critical assessment of the data collection and modelling process, while providing a number of recommendations for potential improvements to similar studies.

2.1 Scope of the Deliverable

The purpose of this part of the deliverable was to apply the modeling techniques outlined in D 3.4 to the data collected as part of the first Dublin and Second Vienna trial of the PEACOX application. This deliverable aims to create a better understanding of how emissions information impacts upon user mode choice, and test the hypothesis that the provision of emissions information has the ability to alter individuals transport choices. For a background to the modeling techniques being utilized in this deliverable, please see D 3.4.

3. Data Collection and Formatting

3.1 Choice Modelling

Before examining the specific techniques applied and results gathered for the PEACOX trial, it is important to consider the appropriateness of the choice modelling paradigm with regard to the provision of emissions information. Using this approach we consider that each time the users access the PEACOX application for desirable travel information, such as trip time information (Brazil and Caulfield, 2013), they are also provided with carbon dioxide emissions information in the process. It is assumed that users then assess the information displayed by the application and base their decisions upon this information (Louviere, 2005). In the specific case of the PEACOX trial it is assumed that the users assessed the emissions information that they were provided with by the application, and used this to choose between the modes/routes available to them.

3.2 Trial Data

The validation of the behaviour model was dependent upon the collection of a large number of observations in an appropriate data format. This section will outline how these observations were collected and processed, and what changes were enacted to remedy the difficulties experienced in the initial Vienna trial (For further details please see the D 3.4).

3.2.1 Logged Application Data

The primary source of data for the analysis pertaining to this deliverable was collected using the data logging feature of the PEACOX application. When the user searched for a route he/she was given a number of available options. The user then selected one of these routes to gain more information about its properties. At this point the user had the option to choose the route, and when appropriate, activate the navigation client. When the user exited this screen, he/she was asked whether or not he/she had consumed the route displayed.

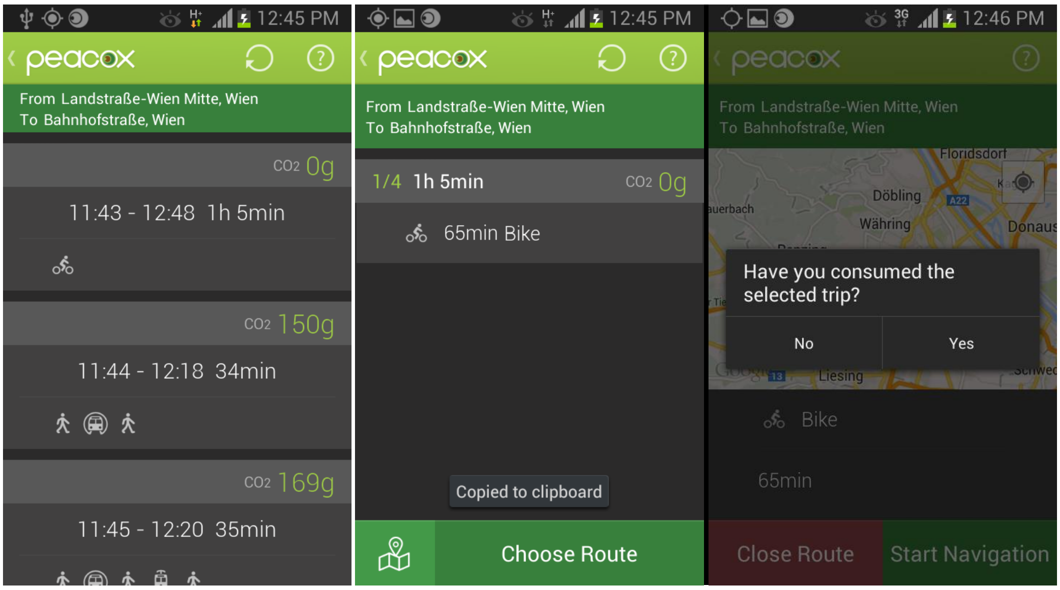


Figure 1 PEACOX Interface

While this system relies on the honesty of the user, with regard to accurately reporting the routes they have taken, it does have a number of advantages, in terms of choice modelling data collection, over the GPS traces system previously used in the first Vienna trial.

- Users' selections are mapped directly to the attribute levels (trip time and carbon emissions) presented to them by the application in the route comparison screen. This is essential for modelling the impact of variation of attribute levels.
- Issues of mode detection, and related accuracy problems, are not encountered when using this approach rather in contrast to employing GPS data collection.

However, there are also a number of potential drawbacks that must also be considered with the adoption of this method:

- The route/mode recorded reflects the users' stated choices rather than an actually observation of their behaviour in the real world. It is possible that the user may deviate from this route or choose not to travel at all.
- It is likely that users may undertake a number of trips where they access the application for travel information, but not select a given option.

However, based upon the data needs of the prescribed models as well as the lessons learned from the first Vienna trial, it was considered that this approach would yield the best results for analysis, while retaining the smooth functionality of the application.

3.2.2 Participant Survey Data

As part of the evaluation process, CURE/AIT ran a number of surveys to establish, amongst other things, the socioeconomic characteristic of participants, their environmental and transport attitudes, and how often they used and followed the PEACOX application. This socioeconomic information can also be incorporated into the model to provide further explanatory power and is further explained in the next section.

3.3 Pre-trial Data Collection

It was essential for purposes of model estimation that enough valid observations were collected. The more observations that were collected, the better the data set, as not only does model estimation improve, but also more potential segmentation opportunities emerge. To address this concern, users were asked to utilise the PEACOX application for a number of hypothetical trips. As these trips have varying characteristics, such as trip purpose, available modes, and familiarity with origin and destination points, this both helped to ensure that there are enough observations to allow model convergence, while also providing a potentially richer data set than may have been generated in a trial of medium term length. This data collection process also enabled users to become comfortable with using the PEACOX application, while allowing the consortium to ensure that users are correctly logging their trips. Table 1 outlines the hypothetical trips that users were asked to assess.

Table 1: Pre-trial Scenarios

Scenario	Description	Restrictions
1	Home to Work	No Restrictions
2	Work to Home	No Restrictions
3	Home to Work	No Car Available
4	Work to Home	No Car Available
5	Home to Work	Bad Weather
6	Work to Home	Bad Weather
7	Home to Shopping	No Restrictions
8	Home to Friend's House	No Restrictions
9	Home to Friend's House	No Car Available
10	Home to Sports Arena (Aviva)	No Restrictions
11	Home to Social Event (Restaurant/City Centre)	No Restrictions
12	Unknown to Unknown* (<2km)	No Restrictions
13	Unknown to Unknown (<2km)	No Car
14	Unknown to Unknown (<2km)	Bad Weather
15	Unknown to Unknown (<5km)	No Restrictions
16	Unknown to Unknown (<5km)	No Car
17	Unknown to Unknown (<5km)	Bad Weather
18	Unknown to Unknown (<10km)	No Restrictions
19	Unknown to Unknown (<10km)	No Car
20	Unknown to Unknown (<10km)	Bad Weather

It must be noted that the observations arising from this pre-trial experiment cannot be considered to be revealed preference observations. Rather, this experiment should be considered to be a stated preference test with the primary purpose of ensuring adequate observations. However, due to the nature of the data logging process used to record user trips as part of the PEACOX field trials, the in-trial observations also cannot be considered to be completely true revealed preference observations as they rely on the users to correctly input their trips, rather than automatic detection. While this logging situation cannot be considered to be ideal, as there is room for erroneous trips, in an effort to avoid the problems regarding data collection that arose with the first trial in Vienna, this was considered to be the most appropriate approach.

3.4 Trial Data Modelling

Figure 2 outlines the steps taken to produce the discrete choice models relevant to the PEACOX field trials.

Once data was received from ICCS regarding the recommendations that users had received and the modes/routes that they stated they had chosen, a number of sequential and parallel steps were required to arrive at the desired model formats. These principally concerned the reformatting of the data to ensure its suitability for modelling, as well as the incorporation of additional variables arising from the participant surveys.

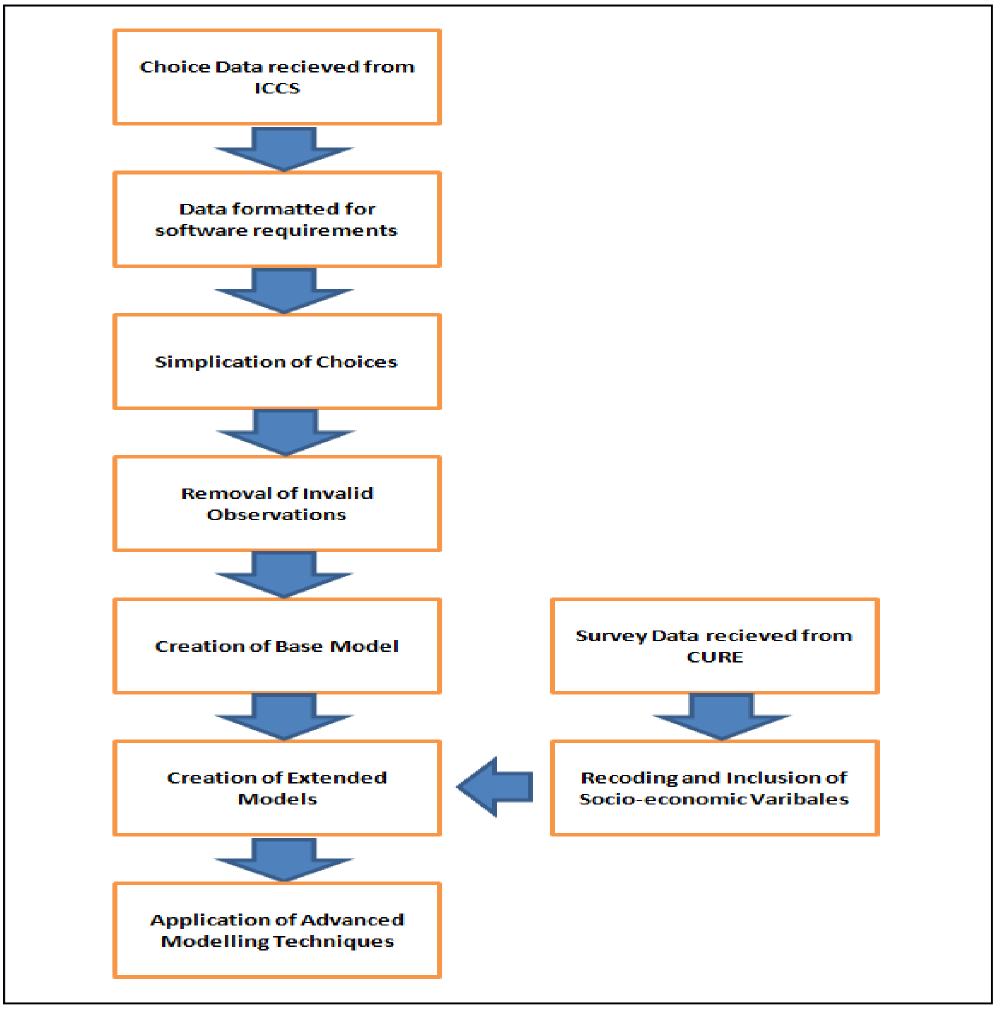


Figure 2: Modelling Methodology

3.4.1 Data Simplification

For the purposes of creating a generalized model, it was decided to create a simplified choice paradigm by considering the four following categories of modes as being available to users:

- Walk
- Cycle
- Public Transport
- Car

As there were a wide range of public transport options available to PEACOX users in the two respective cities, it was decided to create groups of options which shared common characteristics, such as emissions and service levels. This was done primarily to ensure that there were enough valid observations for each alternative, given the relatively small set of observations arising from the trials. This becomes especially true once the multi-modal nature of public transport trips is considered. For example is a "Walk-Bus-Bus-Walk" trip closer to a "Walk-Bus-Walk" trip or a "Walk-Tram-Bus-Walk" trip? This approach also avoided the subjective issue of attempting to map modes from one city onto those from the other i.e. does the Luas tram service in Dublin match Vienna's trams or U-Bahn. The reasoning behind the approach concerning two distinct issues is outlined below.

3.4.2 Issue 1: [Multiple and Highly Similar PT Options]

Consider a situation where two users make searches using the PEACOX application and are returned the information in Table 2. While it is clear that direct comparisons can be made between the Walk, Cycle, and Drive options, it can be argued that the six public transport options (in bold) are all distinct multimodal options. To allow for the application of discrete choice methods in a meaningful way, it was therefore necessary to group these options to together. Where trips were multimodal in nature (as all public transport trips tend to be), if the dominate mode was a public transport mode, the trip was considered to be a public transport trip for the purposes of this analysis.

Table 2: Multimodal Issue

User 1			User 2		
Mode	Trip Time	Emissions	Mode	Trip Time	Emissions
Walk	XX	XX	Walk	XX	XX
Cycle	XX	XX	Cycle	XX	XX
Walk-Bus	**XX**	**XX**	**Walk-U Bahn-Walk**	**XX**	**XX**
Walk-Bus-Bus-Walk	**XX**	**XX**	**Walk-Tram-Walk**	**XX**	**XX**
Walk-Rail-Bus-Walk	**XX**	**XX**	**Walk-Tram-Bus-Walk**	**XX**	**XX**
Drive	XX	XX	Drive	XX	XX

Where the users had been presented with multiple public transport modes by the recommendation engine, the following rule was implemented to determine which option to include in the choice set:

- If the option is public transport and selected by the user, it is included in the choice set
- If no public transport option is chosen, the option with the lowest associated time value is included.
- The decision to only include one public transport option in the choice set, although the application may have provided more than one option, arose from the following issue

3.4.3 Issue 2: [Public Transport Mode Matching]

For the sake of meaningful comparison and model convergence, the public transport options are grouped together and the analyst now is presented with a configuration similar to the first example. However the alternatives outlined in the previous table “Public Transport 1”, “Public Transport 2”, and “Public Transport 3” are merely labels. There is no guarantee that the underlying option for Public Transport 1 for one choice situation is the same as the underlying option for Public Transport 1 in another situation. Using the example above Public Transport 1 for the first user is a Bus trip, whereas for second user it is a U-Bahn trip. For further illustrate this point it can be seen that while there are six public transport options provided to the users in Table 2, none of them can be considered to be equivalent in an objective manner.

Table 3: Public Transport Issue

User 1			User 2		
Mode	Trip Time	Emissions	Mode	Trip Time	Emissions
Walk	XX	XX	Walk	XX	XX
Cycle	XX	XX	Cycle	XX	XX
Public Transport 1	**XX**	**XX**	**Public Transport 1**	**XX**	**XX**
Public Transport 2	**XX**	**XX**	**Public Transport 2**	**XX**	**XX**
Public Transport 3	**XX**	**XX**	**Public Transport 3**	**XX**	**XX**
Drive	XX	XX	Drive	XX	XX

Feedback from users at the post-trial interviews indicated that they appeared to follow this grouping pattern, as they referred to desire to either use public transport or a non-motorized mode, but did not appear to differentiate between the public transport modes. For the purposes of this approach the Park and Ride option was considered to be a car option.

4. Initial Models

4.1 Base Model

The initial model was constructed using a standard MNL approach based upon the observations recorded by the PEACOX application during the Dublin and Vienna field trials. Based upon the filtering process outlined in the previous section, 461 of the 763 initial observations from both cities were considered for analysis using this method. The decision to first analysis the data with an MNL model was based upon approaches highlighted in the relevant choice modelling literature (Yanez et al, 2011; Hensher et al, 2005). According to Hensher et al (2005), *"Regardless of what is said about advanced discrete choice models, the MNL model should always be the starting point for empirical investigation. It remains a major input into the modelling process, helping to ensure that the data are clean and that sensible results (eg parameter signs and significance) can be obtained from models that are not 'cluttered' with complex relationships)."* This model can be considered to be the "base model" for the behaviour analysis in a discrete choice setting. Further modelling approaches are discussed in the next section. The utility produced by each of alternatives modes available to the users was described in terms of the emissions and trip time presented to the user by the PEACOX application. This model was defined by the following utility equations:

*U(walk)=const+walk_time*time+walk_emissions*emissions*

*U(bike)=const+bike_time*time+bike_emissions*emissions*

*U(Pub Trans)=consts+pub_trans_time*time+pub_trans_emissions*emissions*

*U(Car)=car_time*time+car_emissions*emissions*

Where: walk_time,walk_emissions, bike_time, bike_emissions, pub_trans_time, pub_trans_emissions, car_time, and car_emissions are the model variables and time and emissions are respective trip time and associated emissions for each of the modes under consideration. This model did not include any information regarding either the current travel habits of the users or their socioeconomic characteristics; rather it was designed to explicitly examine the impact of the information provided by the application upon travel behaviour.

Table 4 presents the results of the base model.

Table 4: Base Model

Model 1 (Base Model)		
Observations N=461		
Variable	Coefficient	T Stat
Walk Time	-.01***	2.6
Bike Time	.018*	1.6
Pub Trans Time	.025***	3.1
Pub Trans Emissions	.00087	1.0
Car Time	-.076***	-4.3
Car Emissions	.00125***	3.9
Log Likelihood	-611.3307	
Rho Squared Constants only	0.0292	
Rho Squared No Coefficients	0.0434	

*Significant at 90% confidence **Significant at 95% confidence ***Significant at 99% confidence

Before discussing the sign and significance of the variables presented in the table, it is important to consider the Rho-Squared values associated with the model. These values are analogous with the R^2 value that is used in determining the goodness-of-fit for standard regression models. Rho Squared No Coefficients indicates the predictive improvement that the model provides over a simple division based on the number of alternatives, while Rho Squared Constants Only indicates the predictive improvement that the model provides over the market share observed in the data set. Rho Squared values ranging between 0.2 and 0.4 are accepted to be indicative of a good model fit (Hensher et al, 2005). Using this criterion to evaluate the base model it is clear that this model has a poor goodness-of-fit. This essentially means that, based on the data collected from the PEACOX users, an examination of the information provided by the recommender does a poor job in explaining the observed choices.

With regard to the sign and the significance of the parameter coefficients produced which can be considered to be somewhat counter intuitive. Coefficient signs for both walk time and car time are significant and negative suggesting that as time decreases for these modes, their utility increases. However, the signs for both public transport time and bike time suggest that as time increases, the utility of these modes also increases. While this could conceivably be true for both modes, as users may consider these modes only when taking longer journeys, this does appear to be somewhat counterintuitive. With regard to the parameter coefficients associated with emissions levels, no values are produced for walking and cycling as these can be considered to be constants, whereas the values associated with car and public transport appears to be significant but suggest that an *increase* in emissions also produces an increase in those modes utilities.

5. Inclusion of Other Variables

Taking the model outlined in Table 4 as the base model, a number of additional variables were incorporated into the model with the purpose of attempting to improve the predictive power of the model. These variables included the socioeconomic characteristics of the users, as well as information regarding their transport attitudes. These variables were taken from the in-trial surveys conducted by CURE/AIT. As not all users completed the surveys in full, where data is missing, their observation are excluded from the modelling process by the software. Therefore, these models tend to be based upon fewer observations than the base model.

Table 5 outlines the variables that were tested in the various models.

Table 5: Additional Variables

Variable	Range	Coding
Age	19-69	As per Age
Gender	Male, Female	Male=1, Female=-1
City	Vienna, Dublin	Vienna=1, Dublin=-1
Car Owner	Yes, No	Yes=1, No=-1
Public Transport Ticket Owner	Yes, No	Yes=1, No=-1
Bicycle Owner	Yes, No	Yes=1, No=-1
Level of Environmental Concern	Strongly Disagree-Strongly Agree	1-5
Attitudes to Cycling/Walking/Driving/Public Transport	Strongly Disagree-Strongly Agree	1-5

5.1 Socio-economic Models

This following provides the results of the inclusion the following socioeconomic variables to the base model:

- User Age
- User Gender
- User City

5.1.1 Age Model

Table 6 presents the inclusion of the Age variable into the model. As the model set up requires socioeconomic variables to be excluded from utility equation of one alternative, no age variable is produced for the "Walk" option.

Table 6: Age Model

Model 2 (Age Model)		
Observations N=347		
Variable	Coefficient	T Stat
Walk Time	.01**	2.0
Bike Time	.013	0.9
Pub Trans Time	.046***	3.9
Pub Trans Emissions	.00031	-0.4
Car Time	-.098***	-3.7
Car Emissions	.0012***	3.3
Bike Age	.0029	0.4
Pub Age	-.01	0.4
Car Age	.006	0.5
Log Likelihood	-451.5953	
Rho Squared Constants only	0.0291	
Rho Squared No Coefficients	0.0612	

*Significant at 90% confidence **Significant at 95% confidence ***Significant at 99% confidence

An examination of the age variables for the modes under consideration reveals that none of these variables appear to be statistically significant. This would appear to suggest that the age of the users did not have an impact upon their mode choices.

5.1.2 Gender Model

Table 7 presents the results of the incorporation of the Gender variable into the base model. As with the age model, the walk option is held constant to allow for comparison.

Table 7: Gender Model

Model 3 (Gender Model)		
Observations N=349		
Variable	Coefficient	T Stat
Walk Time	.01**	2.2
Bike Time	.014	1.1
Pub Trans Time	.046***	3.1
Pub Trans Emissions	.00007	0.1
Car Time	-.078***	-3.8
Car Emissions	.0012***	3.3
Bike Gender	-.1280	-0.8
Pub Gender	-.2686*	1.9
Car Gender	1546	0.8
Log Likelihood	-453.4647	
Rho Squared Constants only	0.0315	
Rho Squared No Coefficients	0.0627	

*Significant at 90% confidence **Significant at 95% confidence ***Significant at 99% confidence

An analysis of the results of this model reveal that only the public transport gender variable is statistically significant at 95% confidence. The sign of this variable is negative which would suggest that female users are more likely to use public transport.

5.1.3 City Model

Table 8 presents the results of the incorporation of the City variable into the base model. For this model the walk option was again held as constant. This option was chosen as it was felt that walking would be the mode least likely to be impacted upon by the respective cities existing transport infrastructure.

Table 8: City Model

Model 4 (City Model)		
Observations N=351		
Variable	Coefficient	T Stat
Walk Time	.038	.8
Bike Time	-.0089.046	-.1
Pub Trans Time	.034***	2.8
Pub Trans Emissions	-.00216**	-2.0
Car Time	-.1189***	-3.8
Car Emissions	-.1280***	2.8
Bike City	-.08	-.5
Pub City	-.7***	-4.3
Car City	.158	.6
Log Likelihood	-447.3786	
Rho Squared Constants only	0.0499	
Rho Squared No Coefficients	0.0806	

*Significant at 90% confidence **Significant at 95% confidence ***Significant at 99% confidence

An analysis of the inclusion of the city variable appears to suggest that users based in Dublin would be more likely to take public transport than those based in Vienna. While this may appear to be a counter-intuitive finding, as Vienna can be considered to have a superior public transport system, this may be a result either of the differences in the sample characteristics, or of the trips that the respective users chose to log.

5.2 Attitudinal and Environmental Concern Models

This section provides the results of the inclusion the following attitudinal variables to the base model:

- Attitude towards walking
- Attitude towards cycling
- Attitude towards public transport
- Attitude towards driving
- Stated environmental concern

5.2.1 Attitudes Model

Table 9 presents the results of the incorporation of the attitudinal variables into the base model. For this modelling approach it was decided to assess the impact of the user's attitude to his/her probability of selecting a given mode. Therefore the utility equations were of the form:

U(Walk)…..+walk_attitude*attitude to walking

U(Bike)…..+bike_attitude*attitude to cycling

U(Pub)…..+pub_attitude*attitude to public transport

U(Car)…..+car_attitude*attitude to driving

While it is possible to also examine the impact of users' attitudes towards one mode with respect their likelihood of taking another, e.g. if a user is positively disposed to cycling are they less likely to drive, this had the possibility of creating a large number of ancillary models. As the impact of attitude on mode choice was not the primary concern of the PEACOX project, this avenue of exploration was not pursued further.

Table 9: Attitudes Model

Model 5 (Attitudes Model)		
Observations N=361		
Variable	Coefficient	T Stat
Walk Time	.011***	2.0
Bike Time	.012	.8
Pub Trans Time	.043***	3.4
Pub Trans Emissions	.00005	-.1
Car Time	-.072***	-3.1
Car Emissions	.0014***	3.7
Walk_Walk Attitude	.0885	.6
Bike_Bike Attitude	.1280	1.0
Pub_Pub Attitude	.016	.1
Car_Car Attitude	-0.242	-.2
Log Likelihood	-455.8703	
Rho Squared Constants only	0.0263	
Rho Squared No Coefficients	0.0578	

*Significant at 90% confidence **Significant at 95% confidence ***Significant at 99% confidence

An examination of the parameters relating to the impact of the users' attitudes towards a given modes upon their likelihood to take said mode, suggest that there is no strong relationship within this dataset.

5.2.2 Environmental Concern Model

Table 10 outlines the results of the inclusion of the stated environmental concern of users upon their mode choices. Coefficients for the impact of environmental concern suggest that higher levels of environmental concern lead to a higher likelihood of the user either cycling or driving. In the case of the Car option this would appear to be counter intuitive, as increased expressed environmental concern would be assumed decrease the likelihood of the individual driving. The cycling output parameter is more intuitive, as it suggests that increased stated environmental concern leads to a higher likelihood of the individual cycling.

Table 10: Environmental Concern Model

Model 6 (Environmental Concern Model)		
Observations N=347		
Variable	Coefficient	T Stat
Walk Time	.0.2***	3.6
Bike Time	.015	0.9
Pub Trans Time	.054***	4.4
Pub Trans Emissions	-.00001	0.0
Car Time	-.1231***	-5.1
Car Emissions	.004	0.9
Bike_EnvCon	.1867***	2.7
Pub_EnvCon	.033	0.5
Car_EnvCon	.848***	6.8
Log Likelihood	-424.3454	
Rho Squared Constants only	0.0877	
Rho Squared No Coefficients	0.1197	

*Significant at 90% confidence **Significant at 95% confidence ***Significant at 99% confidence

5.3 Section Conclusion

While the inclusion of additional variables into the base model may be considered to have yielded some interesting results, none of the models presented in this section can claim to provide an adequate goodness-of-fit, and therefore do a good job of explaining the behaviors recorded by the users. Following these findings it was decided to apply more advanced modeling techniques to the data in the hope of producing more meaningful results. However, the poor performance of the initial MNL model would appear to suggest that there are underlying issues with the dataset.

6. Further Modelling Approaches

6.1 Panel Data and Mixed Logit

While the MNL model can be considered to be the starting point for any discrete choice modeling process (Hensher et al, 2005), there are a number of issues that arise when it is applied to panel data. The term panel data refers to where data is collected multiple times from a number of respondents rather than a single observation from a large sample. One of the issues that arises from this is that observations are likely to be related, and therefore, for example, there is likely to be less information in 10 repeated responses from 10 individuals than 1 response each from 100 respondents, even though both situations produce 100 observations. According to Yanez et al (Yanez et al, 2011) while having more responses per individual increases the likelihood of capturing more effects, having repeated and identical observations within the data set can reduce the model's ability to reflect true phenomenon.

A number of approaches have been suggested to help overcome these problems including corrective methods such as bootstrapping and jackknifing; however one approach that is becoming increasingly popular is the use of Mixed Logit models. Whereas the standard logit models assume that there are fixed taste parameters for all the respondents, the mixed logit approach considers that there are different parameter taste coefficients for each of the respondents. Therefore there is a probability density function that can be specified to allow for the distribution of the coefficients across the relevant population (Train, 2003). This approach may be considered to be an improvement upon the MNL model for the purposes of modeling panel data such as PEACOX data set.

Due to the software available to the modelers, and based upon the recommendations of the PEACOX reviewers, it was decided that the best course of action was to examine the PEACOX data set using a Mixed Logit (MXL) approach.

6.2 Mixed Logit Models

6.2.1 Normal Distribution Model

The first of the Mixed Logit models created used the same equations as the base model, however rather than considering the output parameters to be fixed estimates, it is assumed that they are distributed across a normal distribution. The results presented in Table 11 represent the best model produced during the analysis of the data collected as part of the trial.

Table 11: Mixed Logit Model 1

Model 7 (Normal Distribution Mixed Logit Model)			
Observations N=461			
Variable	Coefficient	T Stat	95% Interval
Walk Time	.928***	9.14	.728 to 1.12
Bike Time	-1.44**	-2.05	-2.82 to -.06
Pub Trans Time	2.13***	10.64	1.74 to 2.52
Pub Trans Emissions	-.037	-1.03	-.107 to .033
Car Time	-6.48***	-5.92	-8.33 to -4.33
Car Emissions	.098***	10.03	.078 to .118
Log Likelihood	-475.9		
Rho Squared Constants only	0.0687		
Rho Squared No Coefficients	0.101		

*Significant at 90% confidence **Significant at 95% confidence ***Significant at 99% confidence

6.2.2 LogNormal Model

Table 12 presents the results of the LogNormal model. In this case the parameters under investigation are assumed to be distributed across a log normal distribution. An examination of the results of this model indicates that its performance is below that of the model based upon a normal distribution.

Table 12: Mixed Logit Model 2

Model 8 (LogNormal Distribution Mixed Logit Model)			
Observations N=461			
Variable	Coefficient	T Stat	95% Interval
Walk Time	-3.11***	-8.77	-3.8 to -2.41
Bike Time	-3.59***	-3.67	-5.5 to -1.67
Pub Trans Time	-2.33***	-6.89	-2.99 to -1.66
Pub Trans Emissions	-6.49***	-6.24	-8.53 to -4.45
Car Time	-9.69	-.02	-936 to 917
Car Emissions	-5.71***	-19.58	-6.28 to -5.14
Log Likelihood	-494.45		
Rho Squared Constants only	0.0324		
Rho Squared No Coefficients	0.0663		

*Significant at 90% confidence **Significant at 95% confidence ***Significant at 99% confidence

6.2.3 Uniform Distribution Model

Table 13 presents the results of the uniform distribution model. While this model distribution is less commonly used than others, it was investigated in the hope that it might provide some improvement on the base model. However, as is evident from the associated Rho-squared values, this model also produces a poor goodness-of-fit

Table 13: Mixed Logit Model 3

Model 9 (Uniform Distribution Mixed Logit Model)			
Observations N=461			
Variable	Coefficient	T Stat	95% Interval
Walk Time	-.643***	5.36	0.4 to 0.88
Bike Time	-1.75	-1.31	-4.37 to 0.87
Pub Trans Time	1.76***	5.97	1.18 to 2.34
Pub Trans Emissions	-.084	-1.49	-0.19 to .002
Car Time	-5.23***	-2.33	-9.63 to -0.83
Car Emissions	.062***	5.7	-0.04 to 0.08
Log Likelihood	-479.47		
Rho Squared Constants only	0.0297		
Rho Squared No Coefficients	0.0617		

*Significant at 90% confidence **Significant at 95% confidence ***Significant at 99% confidence

Table 14 presents a comparison between the mixed logit models examined and initial MNL base model. It is clear from the table that there is not a large level of consistency in the parameter estimates produced by the respective models. While the variable signs associated with the LogNormal model can be considered to generally be the most intuitive, the insignificance of the car time variable is inconsistent with the estimates produced by all the other models. With respect to emissions estimates, the public transport emissions coefficient is only significant in the base model (where it is positive), whereas the car emissions coefficient is positive and significant in three of the models, suggesting that an increase in emissions also leads to an increase in that mode’s utility.

Table 14: Model Comparisons

Variable	Base Model	Normal Distribution	Lognormal Distribution	Uniform Distribution
Walk Time	-.01***	.928***	-3.11***	-.643***
Bike Time	.018*	-1.44**	-3.59***	-1.75
Pub Trans Time	.025***	2.13***	-2.33***	1.76***
Pub Trans Emissions	.00087*	-.037	-6.49***	-.084
Car Time	-.076***	-6.48***	-9.69	-5.23***
Car Emissions	.00125***	.098***	-5.71***	.062***
Log Likelihood	-611.3307	-475.9	-494.45	-479.47
Rho Squared Constants only	0.0292	0.068	0.0324	0.0297
Rho Squared No Coefficients	0.0434	0.101	0.0663	0.0617

6.3 Mixed Logit: Additional Variables

As with MNL models, it was decided to attempt to incorporate additional variables, other than time and carbon dioxide emissions, into the respective models. However, when these variables were added model convergence was not achieved. Given the relatively poor performance of the initial models, and that the many of the additional variables are repeated (due to the panel nature of the data, it is unlikely that such variables would have produced a marked improvement.

7. Interpretation of Results

7.1 Results

The purpose of this deliverable was to examine the impact of emissions information upon the mode choices of the PEACOX application users during the Dublin and Vienna field trials. For the purposes of providing such analysis, Model 7 (The Normal Distribution Mixed Logit Model) has been selected for further analysis as it provided the best fit for the data collected. Based upon the outputs of this model, a number of interpretations can be made. These relate to the two attributes under consideration: trip time and emissions. While emissions information may be the principal concern of the project, it is important to consider the coefficients associated with travel time as they enable the modeler to gain an understanding of whether the general model outputs are making intuitive sense.

7.1.1 Trip Time Parameter Coefficients

The modeling process examined the impact of trip time information upon the users' mode choices. This attribute was included as research has shown that it is one of the most important attributes in mode choice decisions (Commins and Nolan, 2011), and that it is one of the most desirable functions of a journey planning smartphone application (Brazil and Caulfield, 2012). This was also one of the trip attributes highlighted by the PEACOX application. Information on trip time was provided for all the modes that users were presented with.

Walk Trip Time: The walk trip time coefficient from Model 7 is significant and positive at 99% confidence, suggesting that an increase in trip time makes the walking mode more desirable. However, this is a counter intuitive finding and is the opposite to the results of the other base models.

Bike Trip Time: The bike trip time coefficient from Model 7 is significant and positive at 95% confidence, suggesting that a decrease in the trip time would increase the likelihood of the user choosing to cycle. This result makes sense as it would be expected that decreased travel increases a mode's attractiveness.

Public Transport Trip Time: The public transport trip time coefficient from Model 7 is significant and positive at 99% confidence, suggesting that an increase in trip time makes this mode more desirable. Again can be considered to be a counter intuitive finding; however this is also reflected in both the MNL and Uniform distribution models.

Car Trip Time: The car trip time coefficient from Model 7 is significant and negative at 99% confidence. This suggests that a decrease in the trip time associated with the car mode would increase the utility of this mode and make it more likely that it would be selected. This reflected in two of the other models.

7.1.2 Emissions Parameter Coefficients

The primary purpose of this deliverable was to investigate the impact of emissions information upon the mode choice of PEACOX application users. For the purposes of this model only two modes (or more precisely groupings of modes) were considered: Public Transport and Car. Emissions values for walking and cycling were always set to zero for trips recommended by the PEACOX application. Therefore, as these values can be considered constants, they are omitted from the models.

Public Transport Emissions: In all models, with the expectation of the base MNL model, the coefficient for public transport emissions was found to be negative but not statistically significant at 90%, 95% or 99% confidence. This would appear to suggest that this information did not play a role in the users mode choices. This would be in contrast to the findings of the stated preference study run in Dublin earlier in the project.

Car Emissions: The car emissions coefficient was found to be significant and *positive* in all the base models with the exception of the lognormal model. This would appear to suggest that as emissions arising from the car options increased so too did the attractiveness of this mode. This is both counter intuitive, and also contradicts the feedback received from users at the final workshops.

7.2 Input Variables Correlation

One issue that arises with regard to the data produced by the PEACOX application is the potential correlation between the trip time and the emissions information. This issue was not initially considered as the more complex emissions model had a number of input factors such as cold start emissions and the impact of weather variations that made the link between trip time and emissions weaker than in the simplified model. However, with the simplification of the model, the likelihood of these variables being correlated increased. This was an unforeseen consequence of the attempts to improve the applications performance, and was only detected after the trials had been completed. Table 15 present an analysis of the correlation between emissions and trip time for the two motorized modes under consideration. The non-motorized modes had fixed emissions levels (always set to zero) and therefore were not considered for analysis.

Table 15: Model Comparisons

Comparison	Person R Squared
Car Time/ Car Emissions	0.402**
Pub Trans Time/ Pub Trans Emissions	0.220

* Statistically significant at 0.01 level (2 tailed)

8. Critical Review

8.1 Potential Explanation for Poor Model Performance

The modelling that arose based on the PEACOX trials can be considered not to have produced well-fitting models. There are a number of potential explanations for this problem. These can be divided into a number of broad areas:

8.1.1 Input Data Issues

There are two primary sources of data that impact upon the models presented in this document. The first source was the choices recorded by the application when users indicted that they had chosen to travel via one of the modes/routes presented to them. This provided the choice variable as well as the travel time and emissions inputs. The other primary source of information was the surveys that were conducted throughout out the trials. These surveys provided information regarding the socioeconomic, attitudinal, and travel habit input variables for the models. There are a number of potential issues that may have impacted upon the quality of the data.

8.1.2 Choice Paradigm Assumptions

This modelling approach is based upon a Discrete Choice Modelling approach. This approach considers that an individual is presented with a number of alternatives and associated attributes and based upon these attributes the user chooses between the alternatives. Therefore a number of assumptions are made:

1. The user takes time to assess the information about the options provided by the application
2. The user makes a choice rather than engaging in habitual behaviour

It is possible that rather than using the PEACOX application as journey planner, the users were using the application to search travel and arrival times for pre-chosen modes, or to confirm pre-existing ideas regarding services levels.

8.1.3 After Trip Logging

One other concern that arose related to the problem of users logging trips after they had taken them. The PEACOX logging system was in some sense a trust based system. Users would search for routes between an origin and destination and then indicate which option they intended to choose based on the information provided. However, if users were using the application as a trip logger, the information that they were presented with would have no ability to influence the user's choice as the trip had already been made.

It is important to remember that the users were asked to use the PEACOX application in a manner that may not reflect how they would interact with such an application in a real world setting. While this was necessary to allow for the collection of the necessary data over a defined period, it may result in unrepresentative observations being captured.

8.1.4 Selective Logging

Another issue that arises from the logging procedure is the possibility that users were only logging a certain trip(s) repetitively. This may occur because the user has formed a habit wherein they accessed the PEACOX trip for the same trip each time to complete the purpose of the trial, and may forgotten to access the application when making new or less familiar journeys.

8.1.5 Potential Survey Data Issues

The second potential source of error, with regard to input data, arises from the survey data that is used to supply the variables regarding the users' socioeconomic characteristics, their attitudes towards the environment, and their existing travel attitudes. One issue that arose concerned the lack of information from users, who failed to either complete the surveys or who did not answer specific questions. Where a user did not supply information and the related variable was examined in the model, the observations provided by that user could not be included in the model.

As with a self-reporting survey it is possible that issues such as social desirability bias may have arisen. This may be especially true with regard to metrics regarding issues such as environmental concern where there may be a perception that it is socially desirable to state that your level of concern are greater than they actually are.

8.1.6 Attribute Consideration

The discrete choice modelling approach is built upon the assumption that individuals assess the available options, in this case routes and modes of transport, based upon a number of attributes. For the purposes of the PEACOX trials these attributes were considered principally to be the trip time and emissions associated with the route recommendations provided by the application. However, if an individual does not pay any attention to a given attribute, it is not possible for this attribute affect his/her choice. To examine where or not users were actually taking in the emissions information presented to by the application, an experiment was conducted as part of the pre-trial workshops. This experiment involved the hypothetical trips outlined in Table 1 that were used to collect additional observations. When users were completing these scenarios, they were also asked to state for each scenario whether they had:

- Only looked at the travel time information
- Only looked at the emissions information
- First looked at the travel time information and then the emissions information
- First looked at the emissions information and then the travel time information

Table 16 presents the results for average user assessment for each of the hypothetical trips considered.

Table 16: Attribute Assessment

Only Time	46.8%
Only Emissions	6%
First Time, then Emissions	46%
First Emissions, then Time	1.2%

These results indicate that in 46.8% of cases emissions information is not even considered by the application user. In total only in only 7.2% of cases was the emissions attribute given primary importance. If this information is not assessed it is impossible for it have an impact upon the users' behaviours.

8.1.7 Lack of Working Data

It was initial envisaged that the data collected from first field trials in Vienna could be analysed to assess the appropriateness of the discrete choice modelling to this project. However, the data collection issues outlined in D 3.3 rendered it impossible to test this approach. Therefore unfortunately issues that may have been detected in the first trial did not appear and therefore remedial steps such as the implementation of either a control group or control period.

9. Descriptive Statistics and Post Trial Survey

9.1 Descriptive Statistics

While the choice modeling approach may have not produced what can be considered as highly meaningful results in terms of explaining the users' choices, an analysis of the underlying trends of the users may help to provide some insight to the impact of the PEACOX application upon their behaviors.

9.1.1 Emissions per Week

Table 17 and Figure 3 present an analysis of the per week average per trip emissions for PEACOX users in the two test cities. For the purposes of this analysis, none of the stated preference trips from the pre-trial workshops are included. For the purpose of this comparison the weeks refer to the trial weeks rather than calendar weeks e.g. Week 1 of the Dublin trial and Week 1 of the Vienna trial are compared, not the specific dates. These emissions values were calculated from the emissions associated with the modes/routes that the application users stated that they had taken.

Table 17: Emissions per Week

	Dublin	Vienna
Week 1	663 g/CO_2	769 g/CO_2
Week 2	726 g/CO_2	648 g/CO_2
Week 3	645 g/CO_2	901 g/CO_2
Week 4	889 g/CO_2	724 g/CO_2
Week 5	744 g/CO_2	726 g/CO_2
Week 6	735 g/CO_2	636 g/CO_2
Week 7	616 g/CO_2	583 g/CO_2

The results displayed in Figure 3 indicate a spike in per trip emissions in the middle weeks of the trial in both Dublin and Vienna. The cause of this spike is unclear. Variations in weather patterns were examined as possible cause, but were ruled out due to no apparent explanatory pattern being found.

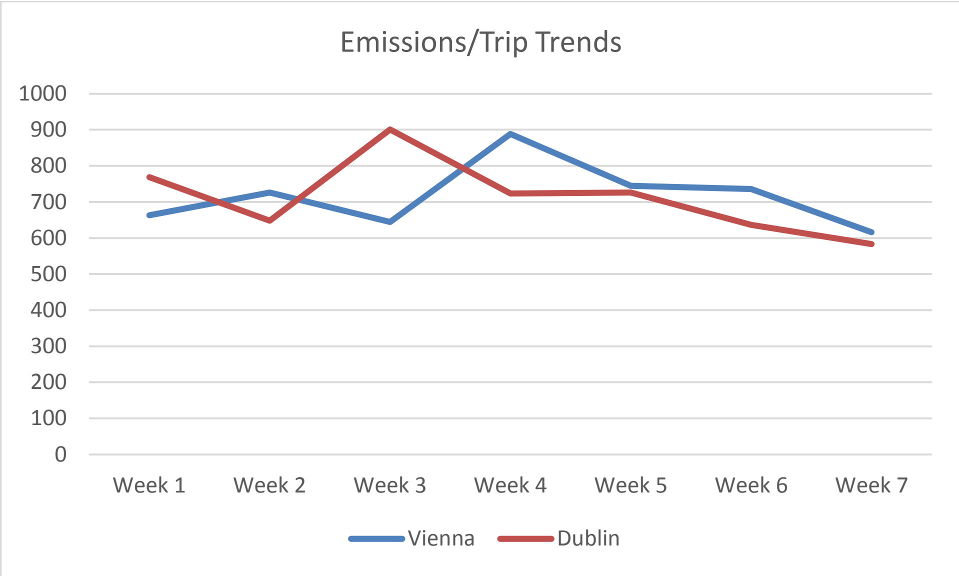


Figure 3: Emissions Trends

9.2 Post-Trial Survey

In the event that issues such as those described in previous sections arose with the modelling process, Trinity College Dublin decided to run a post-trial survey as part of the final workshops. This short survey was designed to provide some qualitative feedback from the users regarding the perceived impact of the PEACOX application upon their behaviour. This survey was only conducted with the Dublin users. Table 18 presents user comments regarding the perceived impact of emissions information on their choices, while Table 19 presents the impact of emissions information upon their awareness. It should be noted that these comments refer to the users' overall behaviour during the field trials, not just the trips logged using the application. It can be seen that while users appear to value the application in terms of its ability to raise their awareness of the issue of transport emissions and provide them with a better understanding of the emissions associated with specific modes, the ability of the information supplied by the application produce long term behaviour change is limited.

Table 18: User Comments (Behaviour)

“At the start of using the app it did but it couldn't keep me motivated”
“Has encouraged me to cycle more”
“I already use public transport. Walking/cycling is not an option due to distance from town”
“Encouraged me to walk more”
“Encouraged me to cycle more”
“I've stopped taking the car to the train station entirely and prefer using the bike, both financially and physiologically”
“I did walk a lot already (more cost effective and proximity to town) but the app encouraged me to walk”
“Other factors were more important to me”
“It influenced my decision when other options were somewhat similar in terms of cost/time however in general I usually choose routes I always took”
“Made me feel guilty for driving etc so walking only option”
“Didn't realise how much CO_2 driving actually produced”
“Not a lot but for a few trips I decided to take a more sustainable mode because of the app”
“At the start of using the app I tried very hard but the app couldn't keep me motivated”

Table 19: User Comments (Attitudes)

"Quantified CO2 (damage)" "Made me aware of how much CO_2 the car etc. produced" "Gave me a rough idea of typical CO_2 values for various transport modes" "CO_2 data very informative and influential" "Made me more aware of CO_2" "Increased my awareness but did not change my habits very much" "Increased awareness of problem" "Wasn't aware before of the magnitude of my impact on overall CO_2 emissions "Didn't realise how much public transport contributes to my carbon footprint. I try to walk as much as" "Made me think about it more" "I don't think it made me care more (poor thing to say) but I used it more as a route planner as I would not"

10. Discussion and Recommendations

Unlike the first Vienna trial, it was possible to create functioning discrete choice models based upon the observations collected during the PEACOX field trials. This was due in large part to two sets of remedial action which had been taken in the intervening time:

1. The shift towards using the application as the principal collection point for observations regarding the users travel behavior.
2. The implementation of pre-trial hypothetical trip data collection to ensure an adequate number of observations was collected to allow for successful model convergence.

These steps allowed for the creation of the models as per the description of the deliverable in the description of work. This enabled both MNL and Mixed Logit models to be created based upon the data logged by the application. However, even with these advances, the models produced cannot be considered to do a good job at explaining the behavior of the users. With this in mind, the next section provides a number of recommendations with regard to future studies of this nature.

10.1.1 Recommendations

Based upon the experiences gained from working with discrete choice modeling as part of the PEACOX trials, a number of recommendations can be made for the design of future similar studies. These include:

The need for control group or period: The ability of the discrete choice models to detect the impact of emissions information appears to be below what was expected and needed. For future studies of this nature the use of either control groups or a control period is recommended at it would allow for the comparison of mode choice trends with the introduction of an intervention such as the PEACOX application. Such an approach would require fewer resources in terms of modeling effort but may ultimately yield more insightful results. Such an example can be seen with the ecoPlus experiment that formed part of this project.

Extended Timeframe: Due to the relatively short timeframe of PEACOX trials it is questionable as to whether the users in fact encountered enough situation where they did not have pre-existing knowledge of the options available, and therefore had a genuine need to access the application. If the users were mainly using the application to record trips they normally take, it is likely that they had pre-formed habits and were not engaging in choice behavior. If were possible to significantly extend the trial period so that more natural application usage was observed, results may be different.

Target Non-habitual Travelers: A final recommendation is the targeting of non-habitual travelers who have little previous knowledge of the alternatives available to them, and therefore will genuinely engage in choice behavior. An example of which may be distributing an application to tourists or conference delegates and assessing its impact on their mode choices.

11. Conclusions

This part of the deliverable set out to evaluate whether the provision of emissions and exposure information could have a measureable impact upon the transport choices of PEACOX application users. The impact of exposure information was not considered as this information was not delivered to users as part of the version of the application used for the second field trial. Therefore, the modeling process was primarily concerned with the impact of carbon dioxide emissions information. Based upon the findings of the models arising from the logged data, both multinomial logit and mixed logit, it is not possible to state with any degree of confidence that the provision of transport emissions information via a smartphone application has the ability to change the transport choices of users. The emissions information relating to the non-motorized modes (walking and cycling) did not change and therefore was not considered for the modeling process. The emissions information for public transport was not significant in the models, whereas the results regarding the car emissions suggested that this information *encouraged* driving. An analysis of the descriptive statistics also fails to provide any insight into how the emissions information could have impacted user choices; however this is hampered by the lack of a control data set for comparison. In the case of such results occurring, secondary data collection techniques were employed to ensure the trials could still provide valuable insight into the role of an application such as PEACOX. The post survey comments taken from Dublin users suggest that while users appear to have been interested in application and the CO_2 information it provided, using the application did not greatly impact upon their travel habits. Perhaps the least encouraging result, with regard to the potential role of emissions information in informing mode choice, arises from the attribute assessment research carried out as part of the field trial workshops in both Dublin and Vienna. These findings appear to suggest that, for roughly half of the trips considered by users, individuals simply did not consider the emissions information they were presented with when making their selections. If individuals are not even assessing the emissions information they are presented with it is impossible for such information to play a role in mode comparisons, and therefore mode choice. Considering that the users in question were being actively encouraged to think about their transport emissions by the trial organizers, and were in an experimental setting where social desirability biases may play a role, it is likely that this may over represent individuals' likely interaction with such information. This would suggest that while the PEACOX application may have a role to play in raising awareness of the environmental impact of emissions information; it cannot be considered, in isolation at least, to be an effective method of instigating behavior change. These findings would appear to be in line with other literature, as individuals simply do not yet prioritize environmental impacts and encounter too many barriers to transitioning to more sustainable modes.

2. Part 2 Introduction – Emissions model

The PEACOX project has set grounds for encouraging eco-friendly trips. One of the aims of the third work package of the PEACOX project is to build a validated model which will estimate emission for door-to-door applications. In other words, the model will be capable of estimating realistic emission from trips that may be comprised of a single mode, or a combination of different modes (e.g. bike, car and public transport).

This section of the deliverable documents the validation of the PEACOX door-to-door emission model from the second field trial followed by a first validation in D3.4. A simplified version of the model was introduced for the second field trial in order to present instant results to the users. The report includes:

-Simplified model structure

-Unit CO_2 emissions for simplified model

-Result analysis for both of the models

- Comparison of the models and evaluation.

The validation was performed by a three-step procedure. In the first step, assessment of the emissions rate calculated from the field trial were conducted and visually presented. In the second part of the validation, the predictions of the new simplified and original emissions models (D 3.4) were compared, analysis of the different factors for the original model were analysed by statistical comparison. In addition, a few samples of emissions figures that were calculated by the models for different trips were compared against trip segment predictions calculated by the Comprehensive Modal Emission Model (CMEM) model. The conclusion of the samples was found to be consistent with the previous results found using a VISSIM analysis (D 3.4).

The findings of this investigation again demonstrated that the model was acceptable for routing comparisons.

12. Modelling scheme of the simplified door-to-door emission model

The primary objective of the PEACOX journey planner is to encourage travellers to use environmentally friendly modes of transport for their desired trips, limiting their travel-related carbon footprint. Thus, the model is required to present a realistic comparison of CO_2 emission across alternative routes involving a range of suitable modes.

The PEACOX app was field tested in Vienna and Dublin. Thus, all road-based and rail travel modes in the two cities have been considered for the PEACOX journey planner. The model has been designed for real-time application, according to the Description of Work (Figure 4). However, this model was too complex for the real-time journey planner, and consumed a large amount of computation time than what was expected (Report by Fluidtime on 18/10/2013). Thus, a simplified version of the model (see Figure 5) was subsequently developed after recommendation from the projects reviewers.

In previous modelling practice, simplifications reduce the complexity of model integration. For instance, simplicity was conducted for VERSIT+micro software. The model was too complex to be integrated with micro-simulation software, thus a reduction of vehicle categories in Versit + made it more simple, and easy to handle. Both of the original and simplified emission models were working behind the PEACOX app during second field trial, while only data from the simplified model was presented to the users.

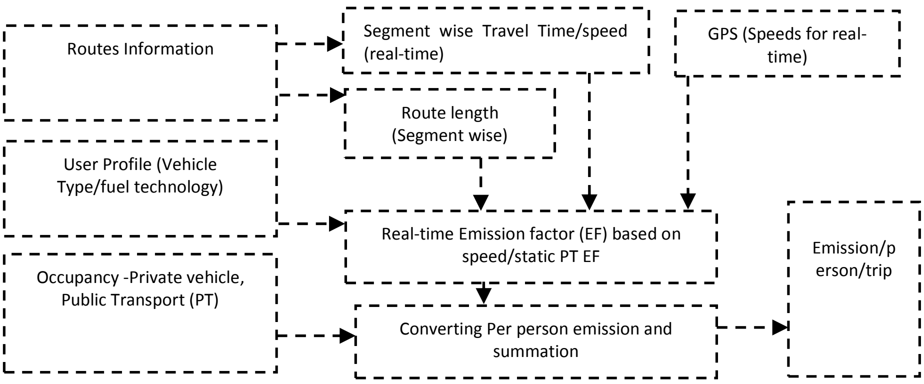


Figure 4: Basic structure of emission modelling methodology: Initial model

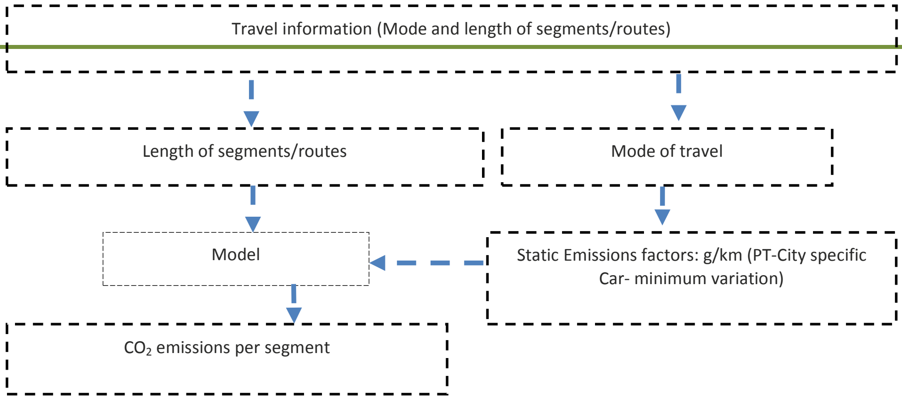


Figure 5: Basic emission modelling methodology: simplified model

The changes at a glance in simplified model are:

- No temporal variation in congestion (Peak/off-peak).
- Number of car categories reduced: 8 (instead of 96).
- No cold start emissions included.
- Car emissions are no longer sensitive to speed changes.

The Emissions factors (EF) were varied according to peak and off-peak times as well as according to the two cities. However, only one factor (e.g. off-peak) for each category of public transport in each city was chosen in simplified model (see Table 20).

Table 20: Public Transport EF factors

Location	g/km	Engine type/Fuel	Mode-Local Name
Vienna	14	Electrified Metro	S-Bahn, U-Bahn
	21	Electrified tram	Local Railways (Lokalbahn Wien-Baden), Tram under Wiener Linien
	60	Liquid gas	Night Bus, Wienerlinien
	34	Diesel	Regional Bus, ÖBB-Postbus GmbH
Dublin	29	Electrified Metro	DART
	34	Diesel	Dublin bus
	128	Electrified tram	LUAS
	66.45	Diesel Train	Train
	198	Euro 4 standard	Black Taxi

In the original model there were almost 100 equations that generated emissions factors for petrol and diesel vehicles according to their engine size, euro emission standard, etc. In order to reduce the number of computational steps involved and thus reducing the number of equations, a reduction in the number of vehicle classes was enacted. Thus, only the latest technology (i.e. Euro-6 for four engine sizes) for petrol and diesel vehicles has been included in the simplified version of the model. In addition, only emissions factors generated for a speed of 60km/hr were applied instead of applying equations to account for variations in speed (see Table 21). Using difference in engine sizes and fuel technology would maintain the variation of the car size that might have an affect the CO_2 tree of the PEACOX app. Cold-emissions factors were not included as a part in the simplified model because generation of these included many complex equations, and required additional inputs (e.g. real time city temperature, catalyst converter information, gross vehicle weight and last trip information). Omitting this information would result in a simplification in the estimation process.

Table 21: Car EF factors

Vehicle weight and Engine Size	g/km	Fuel Technology, Emission Standard at 60km/hr
<2.5 tonnes (1400cc)	98	Petrol, Euro VI
<2.5 tonnes (1400-2000cc)	109	
<2.5 tonnes (>2000cc)	154	
2.5 - 3.5 tonnes (any)	241	
<2.5 tonnes (1400cc)	72	Diesel, Euro VI
<2.5 tonnes (1400-2000cc)	89	
<2.5 tonnes (>2000cc)	134	
2.5 - 3.5 tonnes (any)	253	

13. Methodology for evaluation

To validate the model as accurately as possible the following general methodology has been developed that fulfils the requirement of the description of work. The methodology covers:

- Time performance analysis in MATLAB
- Overview of the data and comparison of average emissions of initial and simplified models
- Checking the impacts of different factors that were modelled for PEACOX
- Evaluation

The time performance analysis sets a basis for developing the simplified version of the model. This model was also developed with original model for the second field trial. The data from both of the models were analysed in relation to the criteria set out in D 3.1. Finally, the evaluation was conducted in relation to the project's overall aim.

14. Time performance check

The time performance check showed that the MATLAB model is capable of yielding results within seven seconds if there are 140 links (see Figure 6). The minimum required time for running this model is 2 seconds. However, the report from Fluidtime shows a different scenario (see Figure 7), and in the first trial, the result appeared overly time consuming at around 5-40 seconds depending on the request. The differences in these comparisons arise due to differences in the MATLAB and Java versions involving different structures and codes. Besides, JAVA worked online with complexity of calling servers, getting data and storing values while other MATLAB worked with given data in a single system. However, in short the simplified model overcomes this situation, and the remainder of this report confirms the simplified models acceptability for cross-multimodal Eco-routing.

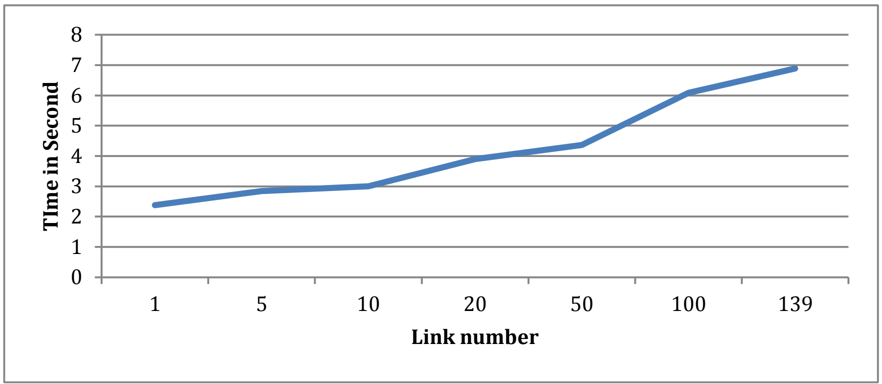


Figure 6: Time performance analysis of emissions model in MATLAB

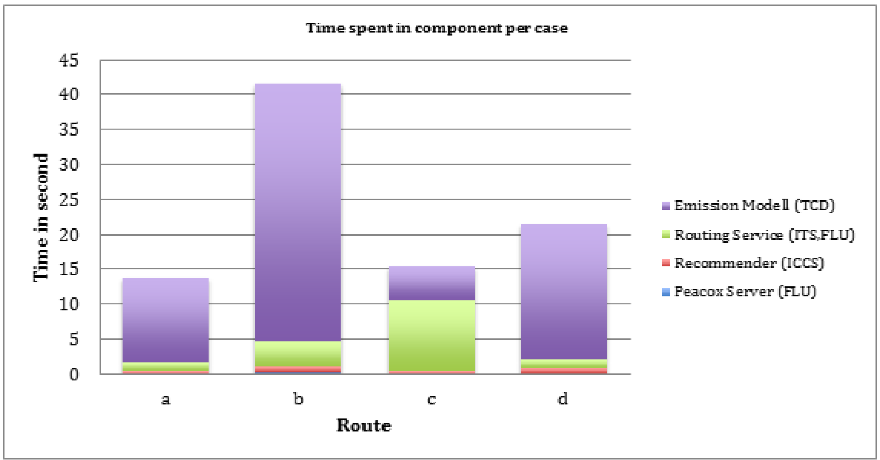


Figure 7: Time performance analysis of four routes for difference Peacox app components by Fluidtime (Emissions model in Java version)

15. Overview of the field trial data

The results that were presented in the PEACOX application in the field trial were stored in the server according to the segments/links. Figures 8-13 show the estimation of CO_2 figures for different modes using both versions of the emissions model.

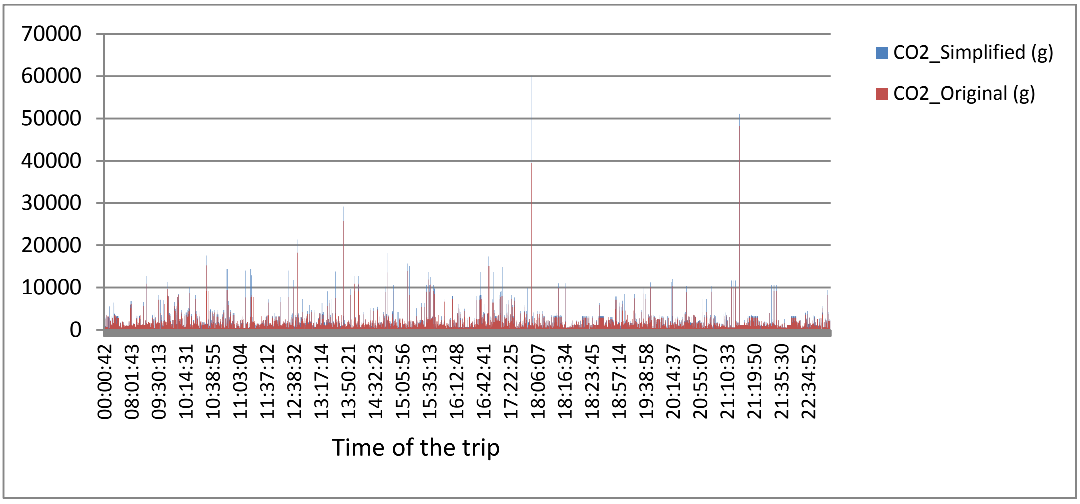


Figure 8: Car emissions estimations generated by both models

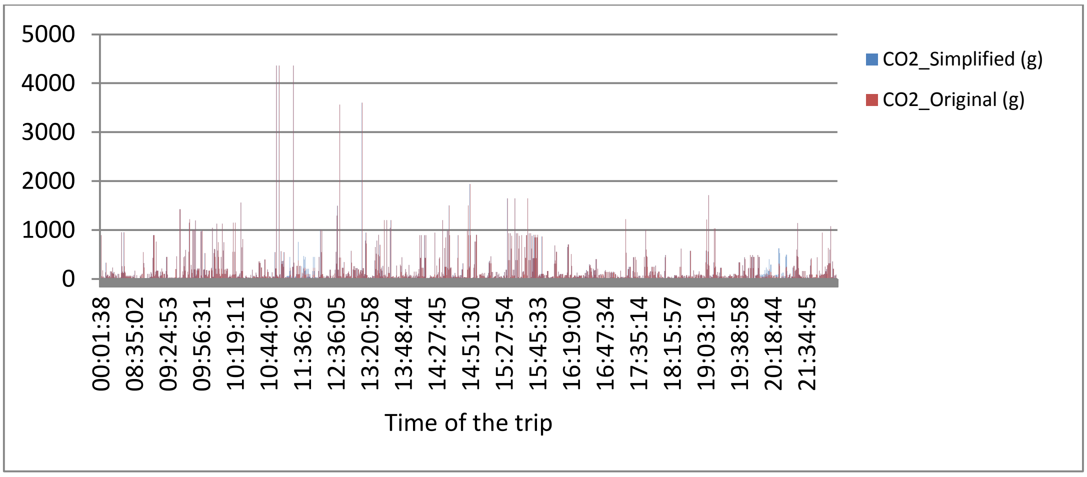


Figure 9: City/Regional Bus emissions estimations generated by both models

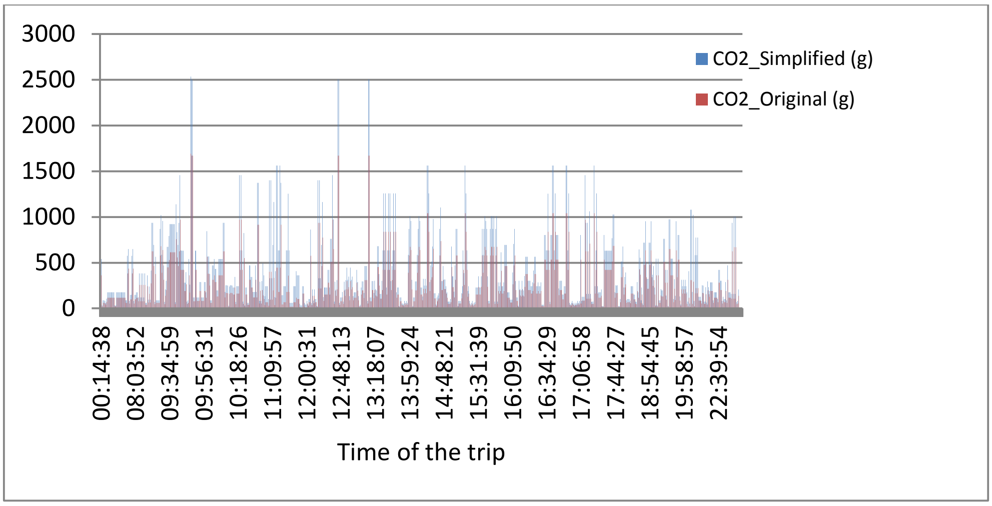


Figure 10: Train emissions estimations generated by both models

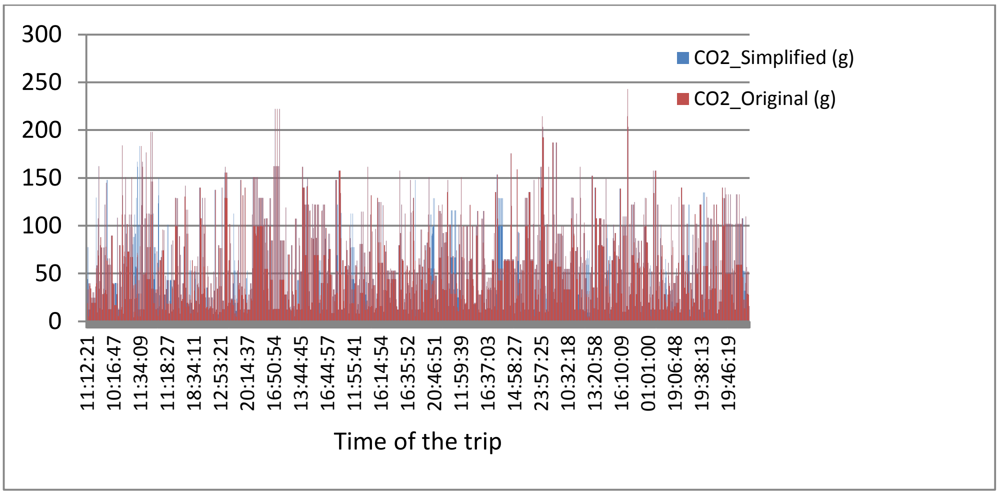


Figure 11: Metro emissions estimations generated by both models

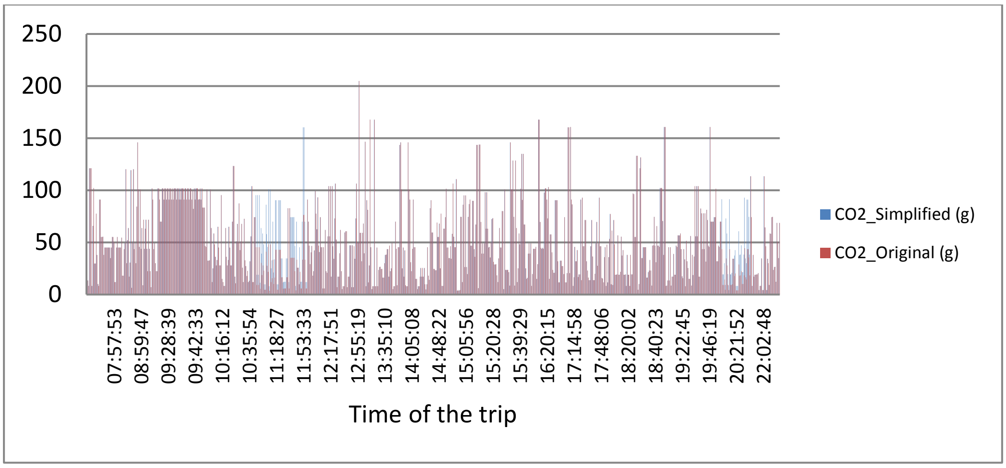


Figure 12: Tram emissions estimations generated by both models

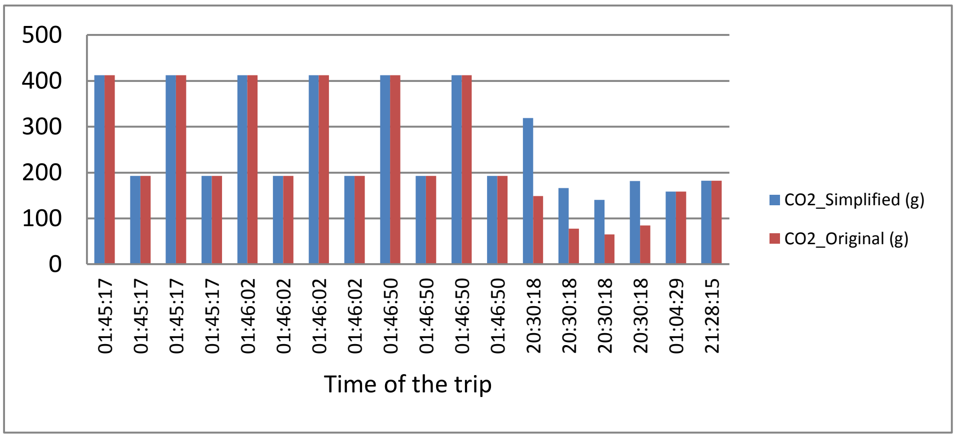


Figure 13: Night Bus emissions estimations generated by both models

It can be noted in the Figures 8-13 that the estimations are similar between the original and simplified models. The models CO_2 estimations (g) were converted into the average emissions (g/trip) and results were presented in the Table 22.

Table 22: Model generated unit CO_2 emissions

Mode	Pearson r	Average CO_2 of all the trips		Standard Deviation	
		Simplified Model	Initial Model	Simplified Model	Initial Model
Car	0.975	2204.759	2080.959	0.000	67.848
Bus City/Region	0.997	188.906	184.159	0.000	4.210
Metro	0.942	65.529	61.069	0.000	2.354
Train	0.969	416.970	263.240	0.000	2.213
Tram	0.964	51.476	48.834	0.000	3.037
Night Bus	0.928	60.000	52.000	0.000	13.689

Although, it can be noted that the Pearson r for initial and simplified model is acceptable, the average values and standard deviation shows little variation in the initial model whereas no deviations were present in the simplified model.

16. Variation in emissions estimations

The model generated emissions figures for the trips during field trial were modelled again using a regression approach. In this approach the factors that were taken into account for model development (see D 3.1 report), such as speed and peak variation were considered as predictors. The general models for each mode regardless of city were presented in Table 23. Table 23 shows the variation due to peak and off-peak factors, travel distance and duration (as a surrogate variable for speed) that were considered in the models. The results were mostly well explained by the models in Table 23, however, a few systematic deviations may be observed in the residual plots in Appendix A. Boxes 1-4 show the Analysis of Variance (ANOVA) tables and diagnosis plots for this comparison. For the car, the diagnostic plots, especially the Q-Q plot show systematic variation of the residual plot. This explains the quadratic nature of the equations applied in the PEACOX model, and inter-variability of the cars. For other models, the systematic deviation arises from the variation of the emissions factors between two cities for different modes. The ANOVA tables in the boxes in the Appendix A show the level of variation of the mean emissions figures that can be explained by each of the factors.

Table 23: Model generated unit CO_2 emissions

Car
CO_2 (g)=122.019+Peak*30.664+Duration*1295.797+Length*134.282
Max VIF 2.89; R^2=0.96
Train
CO_2 (g)=6.6512+Peak*0.4760 - Duration*57.2462+Length*13.9389
Max VIF 5.24 R^2=0.94
Tram
CO_2 (g)= -2.1188+Peak*4.7229+Duration*26.6269+Length*18.3180
Max VIF 1.02; R^2=0.93
Metro
CO_2 (g)= -2.9232+Peak*7.0092+Duration*417.7098
Max VIF 1.02; R^2= 0.86
Night Bus
CO_2 (g)= -53.79+Duration*1399.37
Max VIF: None; R^2=0.66
City/Regional Bus
CO_2 (g)=-3.9937+Peak*7.8979-Duration*40.1244+Length*34.5249
Max VIF = 5.50; R^2=0.99

17. Evaluation of the emission models

In deliverable 3.4, speed sensitivity of the passenger cars in the PEACOX emission model was assessed using VISSIM micro-simulation in Dublin. Here a similar assessment was carried out, however using GPS track data from the users. Table 24 shows a sample of user IDs which participated in the second field trial. The evaluation of the model's sensitivity in real world setting, GPS track data generated by individual vehicle was applied in CMEM.

CMEM was first developed in the late 1990's with the sponsorship from the National Cooperative Highway Research Program (NCHRP) and the U.S. Environmental Protection Agency (EPA). This model can be used at a micro-scale and macro-scale level, meaning that emissions can be modelled from a specific vehicle to aggregated vehicle fleet from various categories. The specific feature of the model is that the model does not predict emissions for specific makes and models of vehicles, but rather estimates emissions for vehicle categories. CMEM is a powerful emission modelling software and an alternative to the use of VISSIM. Thus comparison of the simplified PEACOX model predicts to another emissions model in CMEM adds further robustness to this validation exercise in that we have made comparisons with predictions from multiple standard modelling software's.

In order to carry out this analysis, the car trips that were selected by the users were separated from the large dataset. The GPS tracks from stage start and end times were identified and inputted into the CMEM with actual on-site speed and secondly, with the speed that was inputted into the model. CMEM model was developed for Light Duty Vehicles (LDV) and not specifically for any specific vehicle (unlike PEACOX), and thus, model results cannot be entirely matched.

The result shows a Pearson r of 0.822 between CO_2 estimations while comparison was made with similar input for PEACOX and CMEM (Column P and Q). However, while actual speed is used the result is not similar, as the actual speed and inputted speed has a co-relation of -0.55. This shows the importance of real-time speed requirements in the models.

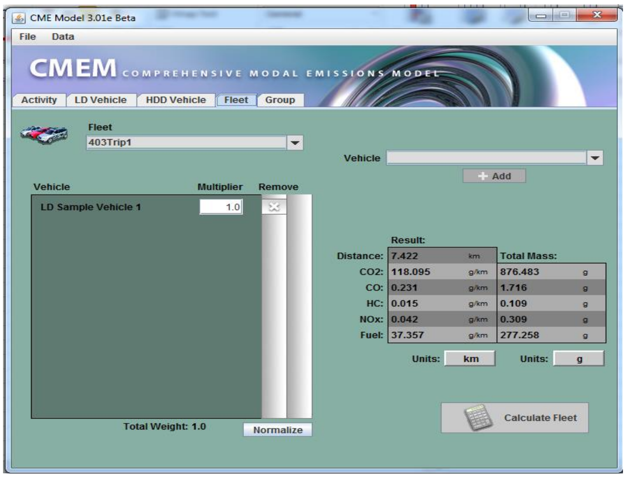


Figure 14: CMEM interface

Table 24: Model generated unit CO_2 emissions

User	Recommendation engine/ emissions models called at	Mode detection module		Original Speed (km/h)	CMEM output with original speed (CO_2 g/km)	Given speed to the model (CO_2 g/km)	CO_2 g/km		
		stage_begin	stage_end				P	Q	
							CMEM	Peacox	Simplified
403	13.08.2014 18:03:19	13/08/2014 18:12:20	13/08/2014 18:28:38	13.80	369.00	29.97	118	129	198
403	25.08.2014 12:38:25	25/08/2014 12:40:43	25/08/2014 12:51:58	35.20	225.00	11.69	259	147	198
417	23.08.2014 17:43:44	23/08/2014 18:39:48	23/08/2014 19:16:35	21.51	249.00	11.50	263	180	198
433	18.08.2014 12:40:39	18/08/2014 13:16:46	18/08/2014 13:25:10	13.99	379.00	16.14	258	170	198
437	28.08.2014 20:42:35	08/09/2014 20:42:59	08/09/2014 20:57:38	42.27	189.00	14.44	261	172	198

Validation of the model usually, implies whether the measurements are acceptable against a defined set of values or objectives. As such both of the models are working to an acceptable standard for routing analysis.

While evaluation of the models is concerned, the overall purposes of the models were necessary to be evaluated. Where the primary target of the project is encouraging people to make environmentally friendly travel decisions, improvement of precision, or accuracy of CO_2 of individual modalities was not necessary. Emission mean values of the different modes differ by a significant margin in these cities, and thus, the chances of overlap of emission factors among different modes due to increase of precision is unrealistic (Figure 10). Therefore, it is highly unlikely that the higher precision will present a private car mode of transport as more attractive than those of other modes. The initial model will be effective if the comparison was made between the different routes for passenger car driving in place of intermodal comparisons only.

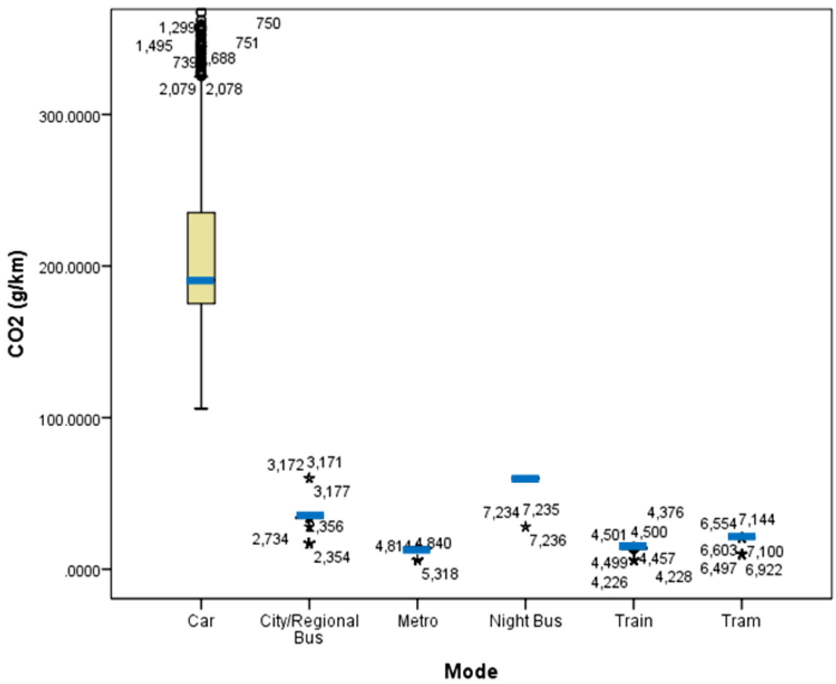


Figure 15: Box plot of the emissions factors generated by the initial model

Thus, as a part of the evaluation of the model, it could be concluded that while the focus is on the cross modal comparison, the simplified models can be confidently deployed.

18. References

Brazil, W., Caulfield., B. , Factors affecting the use of transport related smartphone applications, *9th ITS European Congress*, *Dublin*, 2013

Commins, N., Nolan, A. 2011. The determinants of mode of transport to work in the Greater Dublin Area. Transport Policy (18), 259-268

Hensher, D.A., Rose, J.M., Greene, W.H. Applied Choice Analysis: A Primer. Cambridge University Press 2005.

Louviere, J.J., Hensher, D.A., and Swait, J.D. Stated Choice Methods: Analysis and Application. *Cambridge University Press*. 2005

Train, K. 2003. *Discrete choice methods with simulation*. London: Cambridge University Press

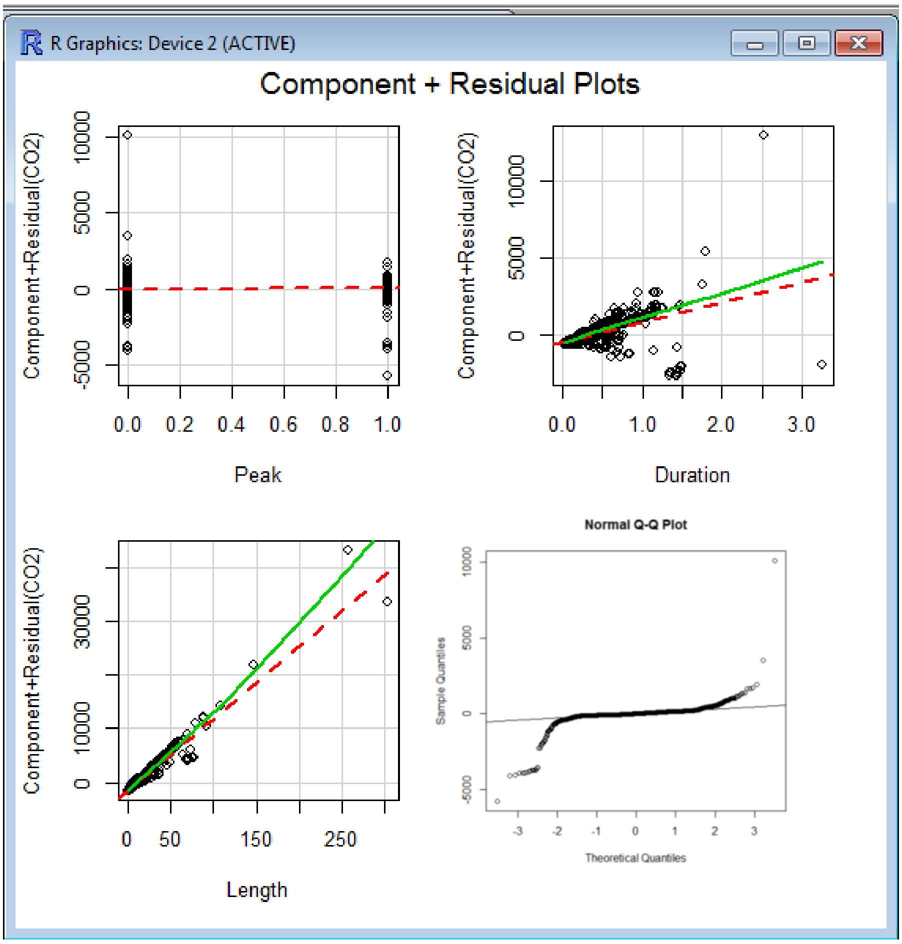
Yanez, M.F., Cherchi, E., Heydecker, B. G., and de Dios Ortuzar, J. On the Treatment of Repeated Observations in Panel Data: Efficiency of Mixed Logit Parameter Estimates. *Network and Spatial Economics* 11 (2011) 393-418

[1] Comprehensive Modal Emission Model (CMEM) user manual, available at: http://www.cert.ucr.edu/cmem/, accessed on 18.11.2014

[2] Fluidtime, Performance Analysis, Internal Project Report, Da

Appendix A

Box 1: Analysis of CO_2 estimations from car segments

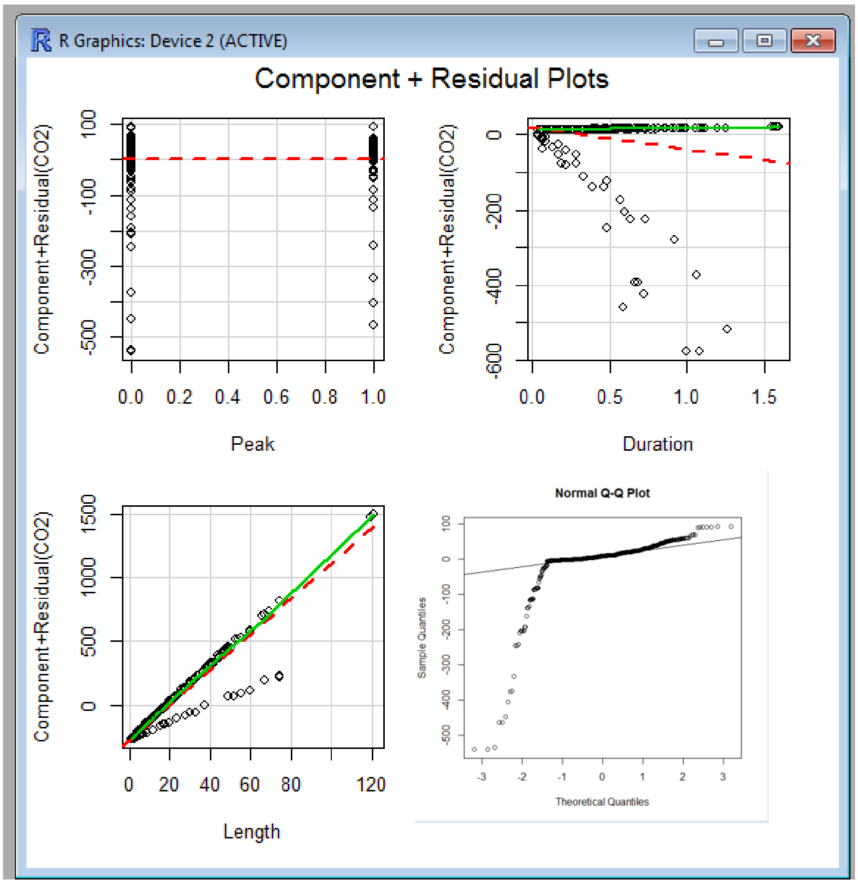


ANOVA Table

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Peak	1	2.760e+06	2.760e+06	12.36	0.000448 ***
Duration	1	8.351e+09	8.351e+09	37382.04	< 2e-16 ***
Length	1	3.070e+09	3.070e+09	13741.46	< 2e-16 ***
Residuals	2249	5.024e+08	2.234e+05		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Box 2: Analysis of CO_2 estimations from Train segments



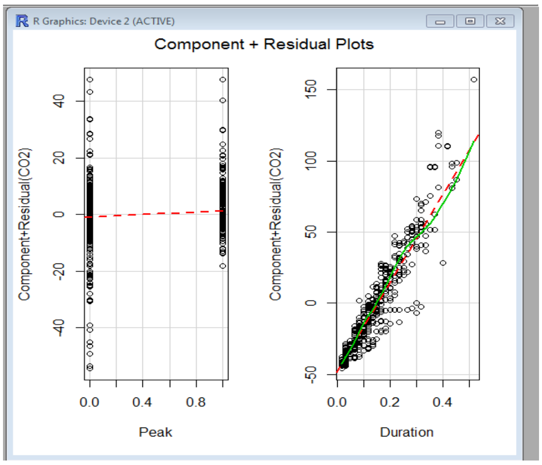
<u>ANOVA Table</u>

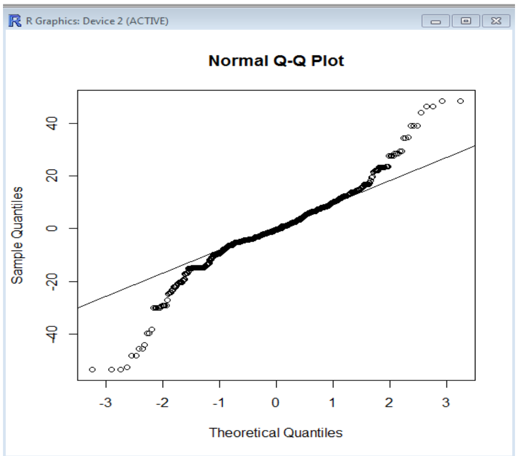
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Peak	1	20616	20616	4.658	0.0313 *
Duration	1	37723246	37723246	8522.526	<2e-16 ***
Length	1	10259567	10259567	2317.866	<2e-16 ***
Residuals	704	3116114	4426		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Box 3: Analysis of CO_2 estimations from Tram and Metro segments

Tram



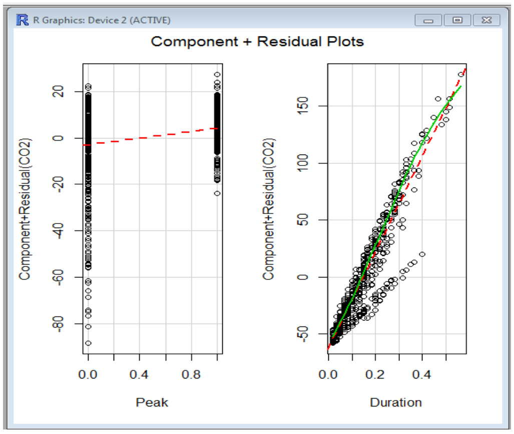


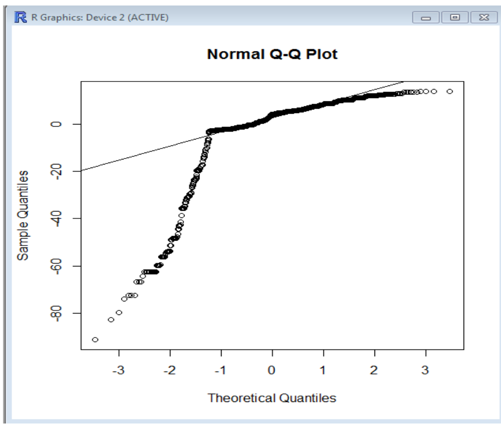
<u>Anova Table</u>

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Peak	1	36847	36847	237.7	<2e-16 ***
Duration	1	901372	901372	5814.2	<2e-16 ***
Residuals	823	127589	155		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Metro



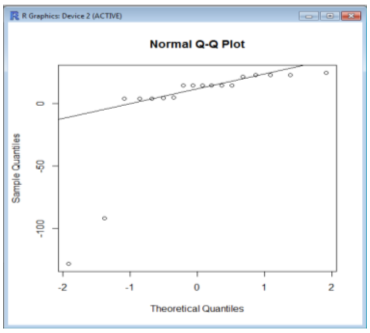


<u>ANOVA Table</u>

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Peak	1	516	516	2.717	0.0995 .
Duration	1	2907429	2907429	15321.223	<2e-16 ***
Length	1	94242	94242	496.628	<2e-16 ***
Residuals	1857	352393	190		

Box 4: Analysis of CO_2 estimations from Night bus and Regional/city Bus segments

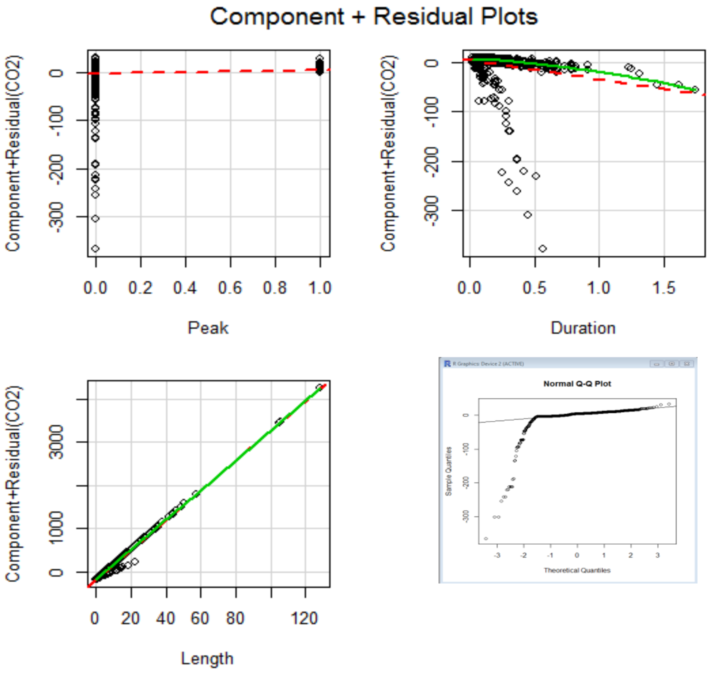
Night Bus^



ANOVA Table	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Duration	1	199088	199088	104.53	3.73e-08 ***
Length	1	62949	62949	33.05	3.85e-05 ***
Residuals	15	28570	1905		

^ No sample was obtained for peak hour travel.

Regional/City Bus



ANOVA Table	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Peak	1	1430108	1430108	1979	<2e-16 ***
Duration	1	144728369	144728369	200238	<2e-16 ***
Length	1	34167679	34167679	47273	<2e-16 ***
Residuals	1551	1121033	723		