The Unconventional Hydrocarbons Traffic Impact Model (UHTIM Version 2) User Manual

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Disclaimer:

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Contents

1. Introduction:

The Unconventional Hydrocarbons: Traffic Impacts Model Version 2 (TIMv2), has been developed by Newcastle University as part of the European Union Horizon2020 funded M4ShaleGas project. The model allows the calculation of a variety of environmental parameters (e.g. Greenhouse Gas Emissions, Local Air Quality Pollutants, Noise and axle loadings on roads, that arise from the traffic associated with 'unconventional' extraction of fossil-fuels (e.g. hydraulic fracturing for gas).

The first version of the model was implemented as part of the ReFINE (Researching Fracking in Europe) programme, and was described in a peer-reviewed in the journal *Environment International* (Goodman *et al.*, 2016). Post M4ShaleGas, subsequent additions to the model, including the ability to transfer information to third-party air-quality modelling tools, have also been conducted under the auspices of ReFINE.

The URL for the model and accompanying website, hosted at Newcastle University is: http://research.ncl.ac.uk/uhtim (Goodman and Thorpe, 2017).

1.1 Background:

The M4ShaleGas report '*Review of Impact of Well Site Infrastructure*' (Worrall *et al.*, 2017) states that the exploitation of unconventional hydrocarbon resources will generate a variety of surface transport activities. These will occur at every stage of development: from initial exploration and test drilling, through production well development, through to final well-plugging and decommissioning. The primary, traffic-related, concern regarding hydraulic fracturing (colloquially 'fracking') activities is the possible use of large numbers of tankers and heavy trucks to transport the required volumes of water, sand and proppant materials. Likewise the removal of contaminated flow back liquids or produced water, may be problematic in the absence of adequate pipeline or recycling facilities, as these must then be removed by tanker to water treatment facilities.

Surface transport activities have been identified as having an impact on the environment through:

- Greenhouse Gas (GHG) emissions (primarily CO_2);
- Emissions of gases that cause Local Air Quality (LAQ) issues (primarily NO_x/NO_2 and particulate matter);
- Creation of noise, and associated annoyance and disturbance;
- Damage to both road surfaces and road sub-structures, leading to cracking and 'pot-holing';
- Congestion, disruption to other traffic, and community severance;
- Occurrence of incidents, accidents and spills;
- Light pollution.

Whilst ultimately adherence to regulations, best practice, sound prior planning, development of supporting infrastructure and improvements in technology may drastically reduce the need for, and impacts of, traffic activities, there remains the requirement to be able to assess the impact of operations in a holistic fashion – hence the development of the Traffic Impacts Model.

1.2 UHTIMv2 Basic Concepts:

The UHTIM model has, at its core, a number of basic, fundamental concepts. The key concept is that the user wishes to model an industrial process (e.g. 'Fracking') that will impose some kind of loading of vehicles during its development and operation, onto an existing (road) network. The overall spatio-temporal domain of the model is termed the *Region*.

The industrial process(es) to be modelled may be concentrated at a single *Site*, or be located at multiple *Sites* across the *Region*. Each site is modelled as a sequence of *Processes*, each of which may have a number of *Phases*. Each *Phase*, in-turn, may be associated with one or more *Traffic Demands* for a particular *User Class* made up of individual vehicle types (e.g. Type N-III Petrol Vans meeting Euro 4 emissions standards) or composite fleet of vehicles (e.g. Heavy Goods Vehicles). The model requires definitions for both individual *Vehicle Types* and *Fleet* (User Class) compositions to calculate environmental parameters. All Sites, Processes, Phases and Traffic demands have attached temporal data, to define their start and end times. These defined periods should 'nest' within each other – e.g. a Process can only have either the same, or shorter, period as its parent site. It cannot start earlier, nor extend beyond the site's period.

A *Traffic Demand* is further associated with a particular *Site Access Policy* in a typical week (e.g. "Weekdays outside of the AM and PM peak periods" – this access policy may be mandated by legal considerations during the planning process). Typically one access policy per a user class is associated with vehicle flows *inbound* to the site, whilst another, separate policy is used for the same vehicles *outbound* from the site. This separation of round trips into individual *Vehicle Movements* allows the modelling of loading factors to be taken into account (i.e. HGVs arriving loaded and departing empty being associated with differing emissions factors), as well as layovers on site.

The road network is assumed carry a certain volume of traffic upon it, even in the absence of site activities – this forms the *Baseline* traffic conditions (also called 'Business as Usual', 'Do Nothing' or 'Do Minimum' conditions in transport modelling parlance). When the model is run to encompass the various processes at Sites, the combined baseline, plus site traffic demands assigned on the network form the *Site Active* (or 'Do-Something', or 'Do-Scheme') traffic conditions. A complete model run for both 'Baseline' and 'Site Active' conditions constitutes a '*Scenario*' The user class for the baseline conditions is assumed to be a generic fleet encompassing all vehicles, appropriate to the region, or more than one user class may be assigned, appropriate to specific types of road within the region. Both the Baseline and Site Active traffic conditions can be scaled to simulate variations at the weekly, monthly or annual levels (e.g. to simulate Summer Holiday periods, or per-annum traffic growth).

Physically the road network consists of *Nodes* and *Links*. A node represents a physical point in space that can be an actual object (e.g. a road junction), an arbitrary connecting point between two links travelling in the same direction needed to adequately represent the road in the model (e.g. a point where road gradient changes substantially), or an abstract *Centroid* location, used as a point for adding demand loads onto the network (e.g. a site entrance).

Nodes are connected by links. Each link represents a unidirectional section of road with some generic properties (e.g. same carriageway width or gradient). Travel times (and hence speeds, and ultimately emissions) are calculated based on the physical length of the link and its associated *Speed-Cost* (or Cost-Flow) curve which defines how vehicles on the road behave at different loading levels (i.e. an abstract definition of the 'type' of road, and how its available capacity affects journey times or 'cost' to travel on the road).

Figure 1 illustrates an example of the concept of all of these objects being contained within a defined region, as applied to a Fracking operation. The defined sites represent individual well pads, whilst processes and process phases are associated both with the well-pad itself, and the individual wells situated on the pad.

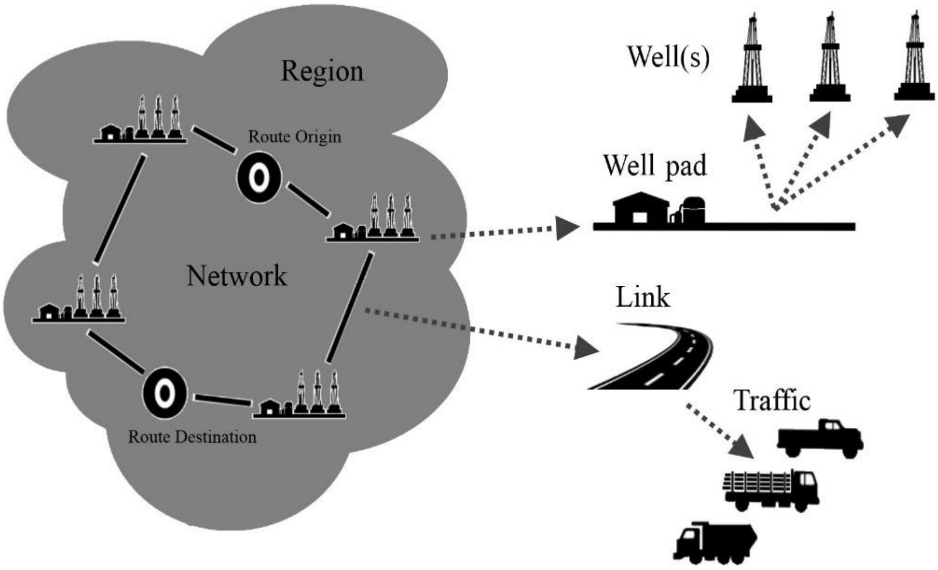


Figure 1: Illustration of the UHTIMv2 region concept applied to a fracking operation (Goodman et al., 2016)

Figure 2 illustrates how defined Process Phases in a fracking operation may be linked to traffic demand, traffic demand periods and vehicle routes.

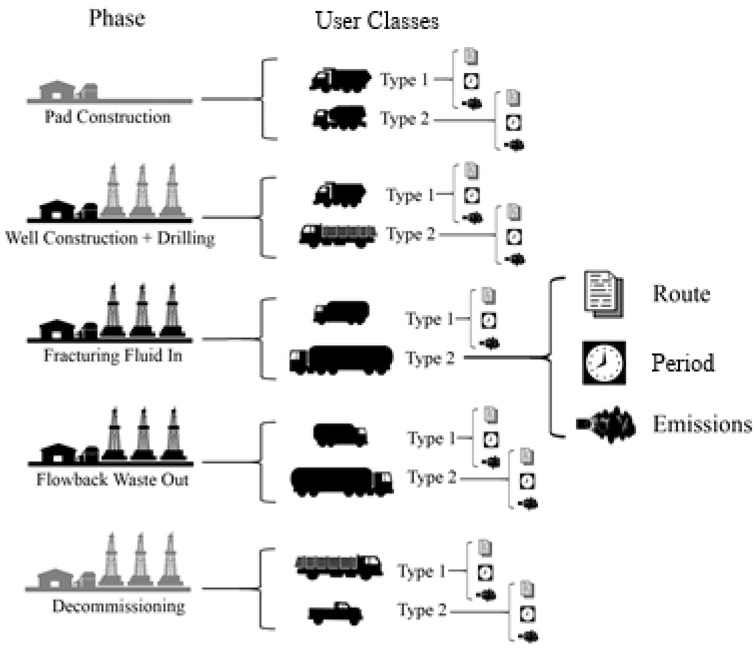


Figure 2: Operational Phases linked to Traffic Demands. Note 'Vehicle' in Figure 2 may represent anything from a specific, individual vehicle to a user class made of many different proportions of vehicles (modified from Goodman et al., 2016)

Vehicles associated with traffic demands are loaded onto the network at the appropriate times using one of a variety of *Assignment Functions*. Currently, as no modelling of queuing at junctions is explicitly taken into consideration (though elements of this can be 'baked in' to carefully selected speed-cost curves), nor are blocking back effects of excessive congestion considered, and outputs are at the bulk 'flow-speed-density' level on links, the approach may be deemed one of simple *Macroscopic Assignment* modelling. Vehicles may travel by defined *Routes* formed of 'chains' of links, or given a route during the assignment process from an *Origin* (O) node to a *Destination* (D) node. Either way a particular link, or O-D pair may be identified using the IDs of its parent starting (A) and ending (B) nodes. Links are therefore identified by their *A_B IDs* in the model – all A_B pairs must be unique. Currently the model doesn't handle separate, segregated lanes, nor banned turns for certain user classes, though it is hoped these could be added in the future.

Environmental effects are calculated using the assigned traffic flow volumes, the average speed of flows on links and the user classes under consideration. Four broad types of effect are considered:

1. Greenhouse Gas Emissions (i.e. CO_2) are calculated from the overall Vehicle Kilometres Travelled ('VKM' or sometimes 'VKT') on each link to give total mass of emissions;
2. Air pollutant emissions (e.g. Particulate Matter (PM) or Oxides of Nitrogen (NO_x)) are mass-based emissions calculated in the same way as Greenhouse Gasses;
3. Noise levels at the roadside, calculated as a single value for each link;
4. Axle loadings on road surfaces and sub-structure, calculated in terms of Equivalent Standard Axle Loadings (or ESALs).

2. Getting Started:

2.1 System Requirements:

The UHTIM applications require a PC running Microsoft Windows (Vista/Win7/Win8/Win10, 32bit or 64bit), with 32 MB available memory and 1GB available disk space.

2.2 Windows Installation:

The files provided for installation (either .zip archive or .exe self-extracting archive) contain an archive of the seven UHTIM applications, along with three directories containing:

1. default emissions rate data ('BaseData');
2. a sample set of input file templates ('BaseInputs');
3. a complete set of input directories and files for the tutorial scenario (see 'Tutorial') section.

Several Windows batch '.bat' files that may be used to run the tutorial scenario are also included in the main directory.

All UHTIM applications have been written for the Windows (Win-32, x86) operating environment in C++ and compiled using Visual Studio 2017. Hence the Visual Studio 2017 C++ x86 runtime libraries must be installed on the user's machine. These are included in the self-extracting archive, and should be checked and installed automatically when using the self-extracting archive installer. Alternately, when using the zipped files, the runtime libraries may be found and downloaded here: https://visualstudio.microsoft.com/downloads/ under 'Other Tools and Frameworks' – see Figure 3. Simply download then run the 'VC_redist_x86.exe' file.

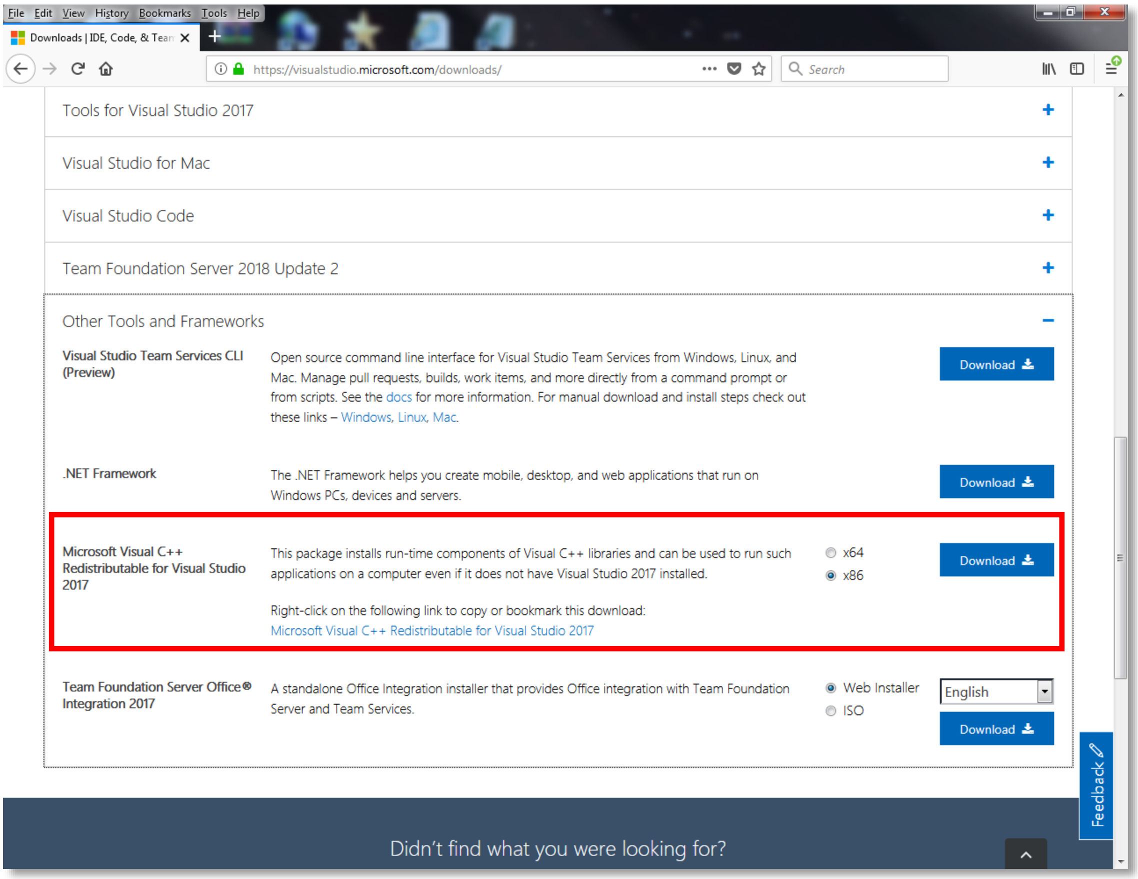


Figure 3: Microsoft Visual Studio 2017 C++ Redistributable Runtime Libraries Download Location

2.3 Running the example project:

Assuming you have installed using the UHTIMv2.zip archive to a directory, and all required files are present:

Open the windows command prompt (e.g. select the windows '***Start***' menu, select '***Run***', Type '***cmd***' and press '***OK***');

From the command prompt change to the UHTIMv2 installation directory (e.g. if the installation is to the E: drive, in a directory called UHTIMv2, type '***E:***' (enter) then '***cd uhtimv2***' (enter).

Once in the UHTIMv2 directory, type '***test_complete_run <"Project_Directory"> <"Project_Name"> <"Base_Directory">*** (enter), where ***<"Project_Directory">*** is the path to where you wish project outputs to be saved, ***<"Project Name">*** is the sub-directory that will be created in the project directory to contain all outputs, and ***<"Base_Directory">*** is the path from which the base pollutant tables and project input data will be copied from (i.e. the *BaseData* and *BaseInputs* directories). For example, to run the test project from the 'E:\UHTIMv2' installation directory, and return outputs to a 'NewProject' sub-directory in the installation directory type: '***test_complete_run "E:\UHTIMv2" "NewProject" "E:\UHTIMv2"***' (enter) at the command prompt. NB: When entering parameters, note the use of double quotes around each parameter, and do not include a separating character at the end of the path names;

After each application in the suite completes, you will need to hit a key to start the next application in the chain;

At the end of the test run, a summary of results may be found in '***<"Project_Directory">\<"Project_Name">\Summary***' (e.g. 'E:\TIMv2\NewProject\Summary' based on the example in step 3. above).

3. UHTIMv2 Component Applications:

The complete UHTIMv2 model consists of a suite of seven applications. These are run sequentially on a set of input data, to produce the environmental impacts for a given scenario. Alternately, applications may be run individually, to produce a single element of the scenario analysis. In order to do this however, inputs must be provided, either from a previous run of the UHTIMv2 model, or from third-party software which produces compatible data for input to the model element.

Briefly, the applications, and their functionalities, are as follows:

3.1 M4InitialiseProject.exe:

This application sets up the directory structures required for a scenario run. The user provides ‘M4InitialiseProject’ with a root directory path (i.e. the working path) and the desired project name. These elements form a composite ‘<project>’ directory structure (i.e. ‘c:\<working path>\<project name>’). Into this ‘<project>’ directory a variety of sub-directories, as used by the other M4 applications, are created. Once the directory structure is set ‘M4InitialiseProject’ makes a copy of the default fleet and pollution data tables (provided with the installation in the ‘BaseData’ directory) for use by the project. If ‘M4InitialiseProject’ is provided the name of an already existing project, depending on the command line settings, it will attempt to delete all existing project files, then re-create subdirectories anew, or just overwrite existing files.

3.2 M4FleetPollProc.exe:

‘M4FleetPollProc’ (M4 Fleet Pollution Processor) calculates block average pollution data for later use by ‘M4RegPollProc’. The application takes the individual vehicle definitions, fleet and pollution information from the ‘<project>\BaseData’ directory along with vehicle and fleet composition information provided by the user in the ‘<project>\BaseInputs’ directory, to create bespoke lookup tables for every ‘user class’ of vehicles (e.g. baseline fleet, 40t articulated lorry, buses etc.) needed in the scenario. Resulting outputs are placed in the ‘<project>\FleetPolTables’ directory.

3.3 M4RegTimeGen.exe:

‘M4RegTimeGen’ (M4 Region Timetable Generator) takes the description of the region, and the site processes within it, along with any weekly, seasonal or annual changes to traffic patterns in the region, and creates an increasing-date ordered timetable of ‘events’ (e.g. a site coming on-line, or the point at which at traffic growth is applied at the beginning of a month or year). This timetable is then used by the ‘M4RegTrafficGen’ and ‘M4RegPolProc’ applications to determine which activities are active at any given point in time. Outputs from ‘M4RegTimeGen’ may be found in the ‘<project>\TimeTable’ directory. Input in the form of the description of the Region and its associated sites should be placed in the ‘<project>\BaseInputs’ directory.

3.4 M4BaseTrafficGen.exe:

‘M4BaseTrafficGen’ (M4 Baseline Traffic Generator) produces initial traffic patterns within the region for a ‘baseline’ (or ‘typical’, or ‘traffic neutral’) week. Inputs to the application are read from the ‘<project>\BaseInputs’ directory, as well as from the ‘<project\TimeTable’> directory. Each hour within the week, and each user class within that hour is modelled separately (e.g. a week has 24 x 7 hours, so if a scenario requires four user classes, a total of 672 traffic patterns will be produced). Each traffic pattern is output to the ‘<project>\BaseWeek’ directory. Patterns may be generated in a number of ways, including: shortest-path assignment, incremental loading assignment, Frank-Wolfe iterative assignment, null or zero assignment, scaling from an existing assignment for another hour, or directly specifying a traffic pattern (e.g. 'preload' traffic) for the network. The algorithmic assignment options rely on generalised link costs calculated from user provided 'speed-cost' curves (e.g. UK 'COBA' (COst-Benefit Analysis) type curves, or the US 'BPR' (Bureau of Public Roads) type functions). Inputs to the application, such as the Region and Site details, the link and node files that describe the road network, or the matrix files that describe traffic patterns should be placed in the '<project>\BaseInputs' directory.

3.5 M4RegTrafficGen.exe:

'M4RegTrafficGen' (M4 Regional Traffic Generator) does the main work of calculating the traffic, for each user class, for every hour required by the scenario. It reads inputs from the '<project>\BaseInputs' directory, as well as from the previous application's output directories. The application produces two sets of outputs – one for 'Baseline' traffic (i.e. without the Region's Sites being active, and just accounting for any specified traffic growth – saved to the '<project>\BaselineTraffic' directory) and one for 'Sites Active' (i.e. with the timetabled traffic added to the network – saved to the '<project>\SiteActiveTraffic' directory). Within the output directories, results are further disaggregated by periods of when similar traffic patterns prevail, and then by whether results refer to network flows, or network speeds. Assignment of 'SiteActive' traffic to the road network may be done either by specifying individual routes for that traffic, or by using shortest path assignment between specified origins and destinations.

3.6 M4RegPollProc.exe:

'M4RegPollProc' (M4 Regional Pollution Processor) takes the output from 'M4RegTrafficGen' and combines it with the tabulated user class emissions rates from 'M4FleetPollProc', to give link-based total emissions. For air pollutants, values are total mass emissions per link, whilst for noise values are logarithmically added sound pressure levels at a reference distance of 10m from the roadside. As with 'M4RegTrafficGen' two sets of outputs are produced for 'Baseline' traffic – saved to '<project>\BaselinePollution' and 'SiteActive' traffic – saved to '<project\SiteActivePollution'>. Results are also disaggregated by period, pollutant and user class, to provide a rich (but complex) set of outputs.

Units for pollution outputs (e.g. conversions from 'grams' to 'kilograms' or 'tonnes'), or to affect the simple propagation model used for noise calculations, may be changed via supplying various configuration files in the '<project>\BaseInputs' directory.

Finally, 'M4RegPollProc' does a small amount of post-processing to aggregate period totals and collate both 'Baseline' and 'SiteActive' results into a single 'Summary' file. This is output to the '<project>\Summary' directory.

3.7 M4RegPostProc.exe:

The final application in the UHTIMv2 modelling chain, 'M4RegPostProc' (Region Post Processing) has a number of functions. Firstly, it converts the outputs from 'M4RegPollProc', as well as the network data provided by the user in '<project>\BaseInputs', to produce information compatible as inputs to the third-party ADMS (Air Pollution Dispersion Modelling System) suite of applications – see Section 'UHTIM Outputs: ADMS Import Files). Secondly, it produces convenient summary outputs from the mass of traffic data saved in the '<project>\BaselineTraffic' and '<project>\SiteActiveTraffic' directories. Finally 'M4RegPostProc' can output the traffic network as a set of ESRI Shape files (ESRI, 1998) for use as a display layer in GIS (Geographical Information System) software, such as ArcMap, GRASS, MapInfo etc.

3.8 Summary: User Inputs:

Very broadly, the user must accomplish the following steps, before UHTIM modelling applications can be run:

The user must:

1. Decide which pollutants are required to be modelled;
2. Decide on what user classes (fleets) are required:
    a. Decide on how the baseline, general traffic shall be handled on the road network (i.e. should it be one user class (e.g. ‘traffic’), or several, separate user classes e.g. (‘cars’, ‘vans’ etc.);
    b. Decide what additional user classes are required to model the additional traffic when sites are active (e.g. ‘HGVs’ or ‘Loaded 40t Water Tanker’ etc.);
    c. Set-up definition files for the above;
3. Decide on the spatial coverage of the road network required, then set-up a definition of the road network in terms of nodes and links, and their properties. This should result in a topologically accurate, and ideally a spatially accurate, network description;
4. Set-up how traffic for a ‘typical’ week will be modelled. This involves decisions on:
    a. What days need to be modelled separately?;
    b. Which hours in those days need to be modelled by either: applying specific flows to links, or by using a traffic assignment process, or by simply being scaled from data for another hour?;
    c. For those hours requiring assignment there need to be Origin-Destination matrices defined for traffic demands. For those hours requiring link flows, those flows need to be specified;
    d. All of the decisions and data requirements for the typical week need to be encoded in an input file;
5. Decide on how the typical week traffic should be scaled to reflect temporal changes:
    a. Day-by-Day;
    b. Month-by-Month, and;
    c. Year-by-year;
    d. Enter these scaling factors in the correct input files;
6. The region, it’s sites, processes, phases and associated traffic demands all need to be defined. Definitions need to be written to input file to cover spatial and temporal aspects (e.g. when activities start and stop, what access policies vehicles adhere to when travelling to and from site etc.), as well as referencing and linking the required vehicle fleets to activities;
7. Modelling options (e.g. for noise propagation) need to be set correctly;
8. Finally, decisions about how output data are to be scaled and presented, at the hourly and overall period levels, need to be made, and entered into the correct input files.

It is recognised that the effort involved in specifying and obtaining data for the above steps is a non-trivial, potentially lengthy, task. Hence some suggestions, relevant to the UK, of potential sources of traffic data are given in Appendix A.

3.9 Summary: The UHTIM Modelling Chain:

With inputs defined (see previous section), the methodology encapsulated in the UHTIM applications may be summarised as:

1. Project directories are set up (M4InitialiseProject.exe);
2. Fleet-weighted emissions tables are calculated for each user class and saved for later use (M4FleetPollProc);
3. Baseline traffic for a typical week is calculated and saved for later use (M4BaseTraffGen);
4. All activities across the region are examined to create a timetable of those activities and their additional traffic demands. The timetable is saved for later use (M4RegTimeGen);
5. Using the timetable information, the typical week traffic, the scaling factors and the region activity data, 'baseline' and 'site active' traffic throughout the region are generated, day-by-day, hour-by-hour for common time periods, to allow direct comparison of both against each other. Traffic data for each hour in the period is saved for later use (M4RegTraffGen);
6. Using the hourly-traffic data and the fleet-weighted pollution emissions, calculate link-based hourly emissions and save the data for later use. Also calculate summary information based on accumulation of outputs (M4RegPollProc);
7. Use the hourly traffic and pollution data to produce further summaries, and outputs compatible with the third-party ADMS air quality management system suite of applications (M4RegPostProc).

Figure 4 summaries the UHTIMv2 modelling chain in terms of which directories are accessed for input to each application, and where outputs are written. Note that whilst 'M4InitialiseProject' must be run first, and 'M4RegTrafficGen', 'M4RegPollProc' and 'M4RegPostProc' must be run in order as each, in-turn, uses the outputs from the previous application. However 'M4BaseTraffGen', 'M4RegTImeGen' and 'M4FleetPollProc' only rely on inputs from either '<project>\BaseInputs' or '<project>\BaseData', so could be run in any order.

3.10 UHTIM: Strengths and Weaknesses:

The methodology used by UHTIM has a number of inherent strengths and weaknesses that the user may need to be aware of. These may be further classified as technical issues related to the direct running of the model on a desktop PC, and in the quality and interpretation of traffic assignment and emission results.

3.10.1 Strengths:

- The UHTIM approach is a 'cradle-to-grave' one, capable of handling both traffic analysis and emissions calculations, both spatially and temporally;
- 'Baseline' and 'Site Active' conditions are calculated in a single run, using pre-calculated time periods common to both, allowing direct comparison of the effects of each phase of an operation;
- The user has the ability to customise site activities completely – whilst the model was intended for analysis of unconventional hydrocarbon exploitation activities, almost any industrial process requiring a transport element could be modelled, down to day/hour resolution, if necessary;
- Output emissions data can be used directly in the ADMS air-quality management software;
- The applications are generally simple to use and scenarios easy to set up;
- The applications generally have a small memory footprint when running.

3.10.2 Weaknesses:

- The traffic assignment approach is a 'macroscopic' one, with traffic characteristics on a link described using bulk parameters (flow, speed, density). There is no detailed modelling of effects at junctions, nor of 'blocking back' effects of congestion – so there may well be under-prediction of emissions in such cases;
- The 'speed-emission' curves supplied with the applications as default data are out-of-date, and need substantial revision, especially considering NO_x emissions from modern light diesel vehicles;
- The use of 'speed-emission' curves has also attracted criticism in some quarters of giving a false 'sense of accuracy' relating to small speed changes in some cases (HA, 2015);
- There is (currently) no modern Graphical User Interface (GUI) for the user to be able to enter scenario data, nor review outputs. The use of manual editing of text files for input is time-consuming and error prone;
- At present, all applications are 'single-threaded' and produced a very large number (10,000s) of intermediate, human-readable files when running. Performance wold be substantially improved by multithreading elements of the processing code to make more use of modern processors, by retaining more information in memory, and use of binary file formats for intermediate file storage;
- Whilst the applications have been designed to be expandable, to date they have only been tested with limited number of sites (<10), on small networks (<100 links). Actual practical limits aren't known.

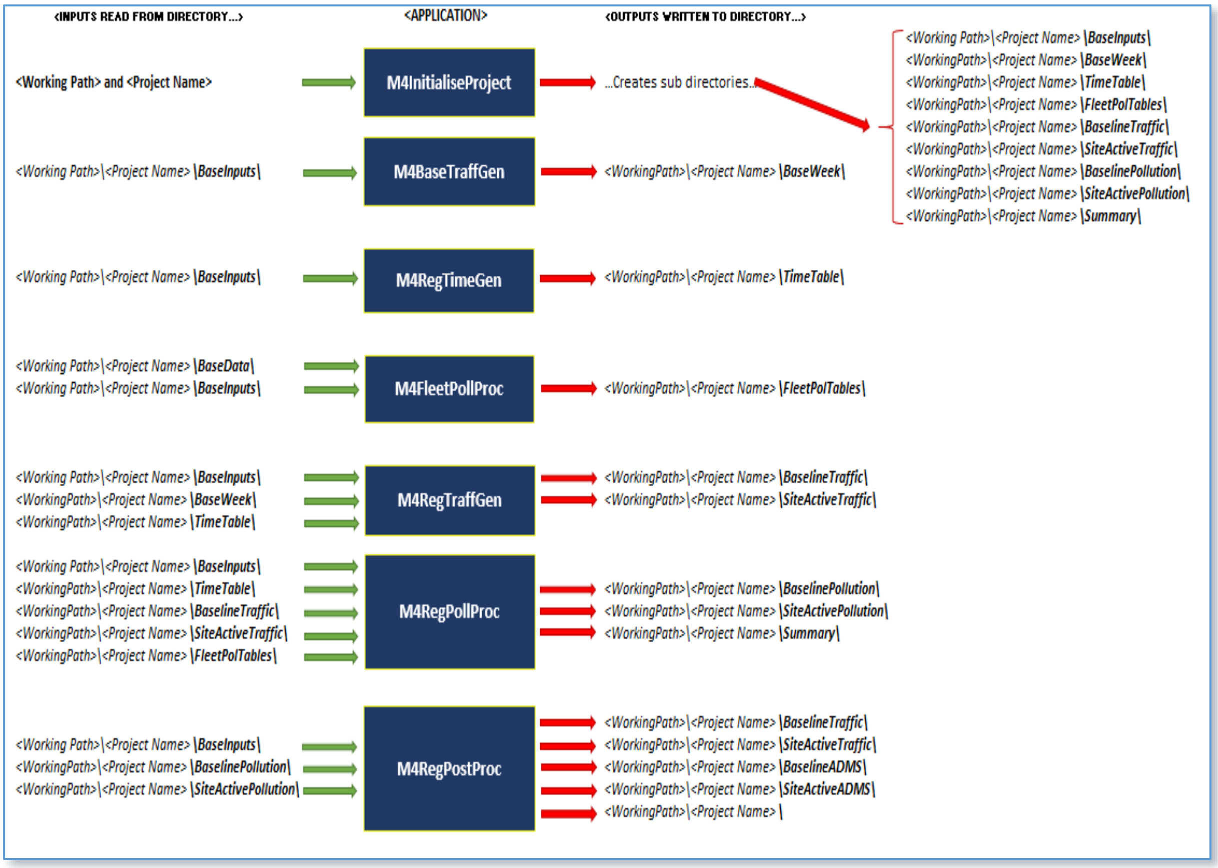


Figure 4: Applications in the UHTIMv2 modelling 'chain'

3.11 Current Versions:

At the time of writing (August 2018), the all seven UHTIM ‘M4’ applications have the same Version number 1.1.0.0. This manual has been explicitly written for this version.

4. Scenario Input Directories:

A UHTIM scenario sits within its own directory: ‘<project>\’. This will generally be created through the use of the ‘M4InitialiseProject.exe’ application. At the start of a scenario run two sub-directories are expected to be present in the ‘<project>\’ directory: ‘<project>\BaseData’ and ‘<project>\BaseInputs’, and each need to contain a number of input files, typically in .csv (comma separated variable) format. These inputs are described below.

4.1 ‘BaseData’ Directory Contents

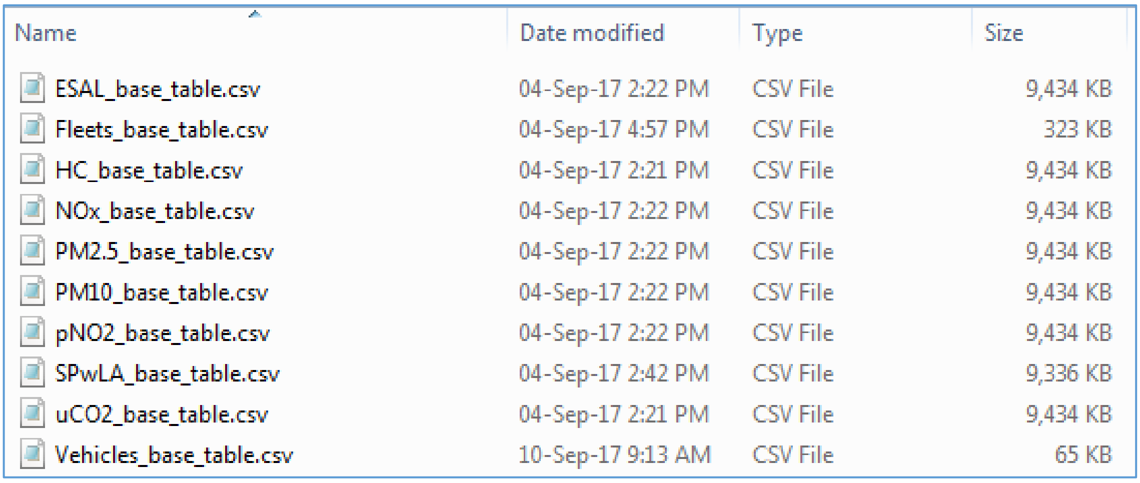
The ‘BaseData’ directory, contains generic data on how emissions are to be calculated. It should contain three sets of ‘.csv’ files:

1. **‘Vehicle_Base_Table.csv’** – which contains definitions for individual vehicle types;

2. **‘Fleets_Base_Table.csv’** – which contains the definitions for all of the user classes required by a scenario;

3. **‘<Pollutant>_Base_Table.csv’** – where <pollutant> is the name of a pollutant (e.g. NOx or PM10). There can be any number of these files, each one representing individual vehicle-level emissions for a particular pollutant, as required by a scenario. Note that the following pollutant names are ‘reserved’ – ‘SpwLA’ for noise (technical Sound Power Levels in A-weighted Decibels), and ‘ESAL’ for ‘Equivalent Standard Axle Loads’.

Sample files are provided in the installation – see Figure 5. Generally, a copy of these files is made, from the installation directory to the new project directory, by the ‘M4InitialiseProject’ application when a new project is created. The resulting, copied <Pollutant> files are used directly by subsequent applications, whilst the ‘Vehicle_Base_Table.csv’ and ‘Fleets_Base_Table.csv’ may be used as templates for further required user customisation (i.e. to add in additional User Classes required for site activities) – see the section “‘BaseInputs’ Directory Contents”.



Name	Date modified	Type	Size
ESAL_base_table.csv	04-Sep-17 2:22 PM	CSV File	9,434 KB
Fleets_base_table.csv	04-Sep-17 4:57 PM	CSV File	323 KB
HC_base_table.csv	04-Sep-17 2:21 PM	CSV File	9,434 KB
NOx_base_table.csv	04-Sep-17 2:22 PM	CSV File	9,434 KB
PM2.5_base_table.csv	04-Sep-17 2:22 PM	CSV File	9,434 KB
PM10_base_table.csv	04-Sep-17 2:22 PM	CSV File	9,434 KB
pNO2_base_table.csv	04-Sep-17 2:22 PM	CSV File	9,434 KB
SPwLA_base_table.csv	04-Sep-17 2:42 PM	CSV File	9,336 KB
uCO2_base_table.csv	04-Sep-17 2:21 PM	CSV File	9,434 KB
Vehicles_base_table.csv	10-Sep-17 9:13 AM	CSV File	65 KB

Figure 5: Sample/Default ‘BaseData’ Directory Files

The structure of each file is discussed separately in the following sections:

4.1.1 Vehicle_Base_Table.csv:

The 'Vehicle_Base_Table.csv' file consists of one header line, followed by any number of data lines. An individual data line should contain the following information for each vehicle type:

1. **Veh_ID:** <Integer> A single, unique value for the vehicle type;
2. **Key:** <String> A single, unique string (e.g. 'Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Pre-Euro|') that will also be used to identify this vehicle type in the 'Fleet' and '<Pollutant>' base tables.
3. **Name:** <String> A user-defined name for this vehicle type – the default datasets provided just set the 'Name' to be the same as the 'Key' value;
4. **Class:** <String> Defines the type of vehicle chassis. Allowable values are 'Car', 'LGV' (Light Goods Vehicle), 'HGV' (Heavy Goods Vehicle), 'PSV' (Public Service Vehicle) and 'PTW' (Powered Two Wheeler). If the vehicle type definition spans multiple chassis types, or the distinction isn't required, then 'Any' may be used;
5. **Fuel:** <String> Defines the type of fuel used by the vehicle. Allowable values are: 'Petrol', 'Diesel', 'LPG', 'CNG', 'E85', 'Biodiesel', 'Hybrid_Petrol', 'Hybrid_Diesel', 'Electric', and 'Hydrogen'. If the fuel type isn't relevant, then 'Any' may be used.
6. **Euro:** <String> Defines the nominal EURO class of the vehicle. Allowable values are 'PreEuro', 'Euro1', 'Euro2', 'Euro3', 'Euro4', 'Euro5', 'Euro6' for light-duty vehicles, and 'PreEuro', 'EuroI', 'EuroII', 'EuroIII', 'EuroIV', 'EuroV' and 'EuroVI' for heavy-duty vehicles. Euro 5 and 6 vehicles may be further qualified by the Euro subcategory (e.g. 'Euro6c') if required. If the vehicle doesn't need to comply with a Euro class (e.g. an electric vehicle) or the Euro class is not known then 'NA' or 'Unknown' may be used. If the vehicle type actually refers to all Euro types, or isn't relevant, then 'Any' may be used;
7. **Min_Speed:** <Integer> The minimum speed (km/h) for emissions calculations using this type of vehicle. Below this speed, emission rates will be clamped to those at the minimum speed value.
8. **Max_Speed:** <Integer> The maximum speed (km/h) for emission calculation for this type. Above this speed, emission rates will be clamped to those at the maximum speed value (e.g. many HDVs in the UK are limited to 85km/h, even if the speed of the road is higher).
9. **PCU:** <Float> The Passenger Car-Equivalent Unit that should be used for this vehicle type within the traffic model. A Passenger Car Equivalent is "essentially the impact that a mode of transport has on traffic parameters compared to a single car" (Wikipedia) and is used extensively in the speed/flow model calculations. The values used in the default datasets are: Car = 1.0, LGV = 1.1, Rigid HGVs = 1.89, Articulated HGVs = 2.50, PSVs = 2.0, PTWs = 0.33).

NB: All UHTIM applications expecting traffic flows as inputs expect those inputs in terms of absolute numbers of vehicles, rather than PCUs. Internally, PCU values are only used in the traffic assignment models in 'M4BaseTraffGen.exe' and 'M4RegTraffGen.exe'.

Figure 6 shows an excerpt from the default 'Vehicle_Base_Table.csv' file, including the header line and first and last four data lines. Note that the (lengthy) 'Key' and 'Name' values are derived from the hierarchical categorisation of vehicles by 'Class, Chassis, Weight, Fuel, Engine Capacity and Euro Class' used in the UK Emissions Factor Toolkit. Individual lines have also been wrapped due to length. A full list of the vehicle types in the default file may be found in Appendix B.

```
Veh_ID,Key,Name,Class,Fuel,Euro,Min_Speed,Max_Speed,PCU
1,Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Pre-Euro|,Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Pre-
Euro|,Car,Petrol,PreEuro,5,140,1.00
2,Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_1|,Car|Car|0.0-2.5t|Petrol|0.0-
1.4l|Euro_1|,Car,Petrol,Euro1,5,140,1.00
3,Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_2|,Car|Car|0.0-2.5t|Petrol|0.0-
1.4l|Euro_2|,Car,Petrol,Euro2,5,140,1.00
```

```
4,Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_3|,Car|Car|0.0-2.5t|Petrol|0.0-
1.4l|Euro_3|,Car,Petrol,Euro3,5,140,1.00
…
565,PTW|M/Cycles(4-stroke)|All|Petrol|750+cc|Pre-Euro|,PTW|M/Cycles(4-
stroke)|All|Petrol|750+cc|Pre-Euro|,PTW,Petrol,PreEuro,5,140,0.33
566,PTW|M/Cycles(4-stroke)|All|Petrol|750+cc|Euro_1|,PTW|M/Cycles(4-
stroke)|All|Petrol|750+cc|Euro_1|,PTW,Petrol,Euro1,5,140,0.33
567,PTW|M/Cycles(4-stroke)|All|Petrol|750+cc|Euro_2|,PTW|M/Cycles(4-
stroke)|All|Petrol|750+cc|Euro_2|,PTW,Petrol,Euro2,5,140,0.33
568,PTW|M/Cycles(4-stroke)|All|Petrol|750+cc|Euro_3|,PTW|M/Cycles(4-
stroke)|All|Petrol|750+cc|Euro_3|,PTW,Petrol,Euro3,5,140,0.33
```

Figure 6: Excerpt from default 'Vehicle_Base_Table.csv' file

4.1.2 Fleets_Base_Table.csv:

The 'Fleets_Base_Table.csv' file consists of one header line, followed by any number of data lines. An individual data line should contain information on how the proportion of a particular vehicle type (as defined in the 'Vehicles_Base_Table.csv' file) changes in a particular user class fleet mix, year-by-year. Each line contains the following data:

1. **Fleet_ID:** <Integer> An integer identifier for the user class associated with this line. ***NB: There can only be a maximum of 256 user classes in a particular simulation***;
2. **Key:** <String> A string identifier for the user class to be associated with this line;
3. **Name:** <String> A string identifier for the user class to be associated with this line. This doesn't have to be the same as the 'Key';
4. **Vehicle:** <String> This should be the key value of the vehicle type associated with this line. It should be identical to the key defined in the 'Vehicles_Base_Table.csv'. Note that a particular fleet doesn't need to contain an entry for ALL vehicles defined, just those required;
5. **Start:** <Integer> The start year of the fleet proportions dataset.
6. **End:** <Integer> The end year of the fleet proportions dataset.

NB: The start and end year should be the same on every data line.

7. **<Data>:** <Float> For each individual year between the start and end years (inclusive), a proportion should be defined that gives the vehicle type contribution to the fleet in that year. This can be any numeric value as the data for each fleet and year is normalised after loading, but the default fleet data provided has been scaled to add up to 1.0 for each year.

Figure 7 shows an excerpt from the default 'Fleets_Base_Table.csv' file. A single, baseline fleet (ID: 1, Key: 'Base', Name: 'Base') is being defined using all of the vehicles in the 'Vehicles_Base_Table.csv', for the years 2008 to 2050. Fleet proportions are provided in scientific number format to five decimal places figures. The excerpt contains the header line, the first three, and last two data lines in the file.

Subsequent fleets could be added to the end of the file, using sequential IDs and different 'Key'/'Name' values (e.g. '2,LGVs,LGVs'… '3.Tankers,Tankers' etc.) for the first three parameters in a data line.

```
Fleet_ID,Key,Name,Vehicle,Start,End,2008,2009,2010,2011,2012,2013,2014,2015,2016,2017,2018,201
9,2020,2021,2022,2023,2024,2025,2026,2027,2028,2029,2030,2031,2032,2033,2034,2035,2036,2037,20
38,2039,2040,2041,2042,2043,2044,2045,2046,2047,2048,2049,2050
1,Base,Base,Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Pre-Euro|,2008,2050,2.27548e-03,1.33727e-
03,7.31005e-04,3.31683e-04,1.29565e-04,2.42256e-
05,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000
e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.000
00e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.0
0000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0
.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00
1,Base,Base,Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_1|,2008,2050,1.04353e-02,7.48901e-
03,5.14107e-03,3.15184e-03,1.93101e-03,1.13715e-03,6.30215e-04,3.16151e-04,1.31636e-
04,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000
e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.000
```

```
00e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.0
0000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0
.00000e+00,0.00000e+00,0.00000e+00
1,Base,Base,Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_2|,2008,2050,3.54275e-02,3.07572e-
02,2.59235e-02,1.88857e-02,1.33930e-02,9.08177e-03,5.87536e-03,3.64623e-03,2.21065e-
03,1.31969e-03,7.05875e-04,3.44296e-04,1.36560e-
04,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000
e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.000
00e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.0
0000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00
…
1,Base,Base,PTW|M/Cycles(4-stroke)|All|Petrol|750+cc|Euro_2|,2008,2050,5.34673e-04,5.15566e-
04,4.88659e-04,4.64845e-04,4.39246e-04,4.15382e-04,3.93971e-04,3.66494e-04,3.32624e-
04,3.04311e-04,2.78004e-04,2.54391e-04,2.28626e-04,1.99996e-04,1.78522e-04,1.25061e-
04,3.89245e-
05,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000
e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.000
00e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.00000e+00,0.0
0000e+00,0.00000e+00,0.00000e+00
1,Base,Base,PTW|M/Cycles(4-stroke)|All|Petrol|750+cc|Euro_3|,2008,2050,8.22794e-04,1.08462e-
03,1.28176e-03,1.53217e-03,1.77036e-03,1.99409e-03,2.20285e-03,2.40184e-03,2.55838e-
03,2.69671e-03,2.81777e-03,2.92344e-03,3.01396e-03,3.08746e-03,3.14545e-03,3.18723e-
03,3.22049e-03,3.21202e-03,3.17123e-03,3.13146e-03,3.09267e-03,3.05484e-03,3.01791e-
03,2.98330e-03,2.94948e-03,2.91641e-03,2.88408e-03,2.85246e-03,2.85246e-03,2.85246e-
03,2.85246e-03,2.85246e-03,2.85246e-03,2.85246e-03,2.85246e-03,2.85246e-03,2.85246e-
03,2.85246e-03,2.85246e-03,2.85246e-03,2.85246e-03,2.85246e-03,2.85246e-03
```

Figure 7: Except from the default 'Fleets_Base_Table.csv' file.

4.1.3 <Pollutant>_Base_Table.csv:

The '<Pollutant>_Base_Table.csv' provides the emission rates for a given pollutant, for each vehicle type defined in the 'Vehicles_Base_Table.csv' file. One file should exist for each pollutant required to be modelled.

Each file has a single header line, followed by one data line per vehicle in the 'Vehicles_Base_Table.csv' file, which gives the emission rates to be applied with defined speed bands, for a given combination of four dimensions: 'Year', 'Road_Type', 'Loading' and 'Gradient'.

The structure of a data line is as follows:

1. **Year:** <Integer> The year to which the data line refers;
2. **Vehicle:** <String> The name of the vehicle to which the data line refers. This must be the same as the key value as defined in the 'Vehicles_Base_Table.csv' file;
3. **Road_Type:** <String> The name of the road type to which the emission rates apply. If the model only requires a single road type use the keyword 'All';
4. **Loading:** <String> The vehicle loading to which the emission rates apply. If the model only requires a single loadfing state, the keyword 'All' may be used;
5. **Gradient:** <String> The gradient to which the emission rates apply. As with 'Road_Type' and 'Loading', the keyword 'All' may be used for generic treatment.

NB: The actual terms used for 'Road_Type', 'Loading' or 'Gradient' are not relevant, as long as exactly the same terms are used in link and traffic demand inputs and descriptions.

6. <Data>: <Float> The emissions rate data in 5km/h increments from 5km/h to 140km/h.

Default tables are provided for the following pollutants:

- **ESAL :** Equivalent Standard Axle Loads – NB: ESAL values don't necessarily change with speed, though values for all speed bands must still be provided in the table.
- **HC :** Hydrocarbon Emissions (all species), in g/km;

- **NOx :** Oxides of Nitrogen Emissions, in g/km;
- **PM2.5 :** Particulate Matter under 2.5 microns aerodynamic diameter, in g/km;
- **PM10 :** Particulate Matter under 10 microns aerodynamic diameter, in g/km;
- **pNO2 :** Primary (tailpipe) emissions of Nitrogen Dioxide, in g/km;
- **SPwLA :** A weighted equivalent sound power levels, in dB/m;
- **uCO2 :** Carbon Dioxide (ultimate Carbon Dioxide – i.e. assuming complete oxidation of all carbon combustion components in the exhaust), in g/km.

Emission rates for the gaseous pollutants (i.e. all except SPwLA and ESAL) have been derived from those values found in the (now out-of-date) Emissions Factor Toolkit version 5.1.3 (DEFRA, 2012) with fleet data derived from National Atmospheric Emissions Inventory (NAEI) data for English rural roads (NAEI, 2011). Additional data for hybrid vehicle technologies comes from Pang and Murrells, 2013. Values for SPwLA have been derived from the CNOSSOS-EU model (Kephalopoulos *et al*., 2012), whist values for ESAL have been calculated using assumed axle loadings (AASHTO, 1986). These models are discussed further in Appendix C.

Currently the UHTIM application ‘M4FleetPollProc’, which handles fleet-averaging of pollution data, only accepts emission rate inputs in 5km/h increments over a speed range from 5km/h to 140km/h – though this could be varied in the future. Likewise, the valid year range is currently fixed to 2008 to 2050 inclusive, but may be changed in future.

The default tables provided with the installation only have a single level for each the dimensions, ‘Road_Type’, ‘Loading’ and ‘Gradient’, though emissions are assumed to change by year, due to technology, degradation and fuel factors, as per the EFT methodology.

At the present time, the ‘Loading’ dimension is ignored by the UHTIM applications. The default EFT rates assume that HGVs are loaded at approximately 56% capacity, at no appreciable gradient, when calculating emissions. If separate loadings are required (e.g. for loaded tankers entering a site, and empty tankers leaving), it would be easiest to define separate vehicle types for the ‘loaded’ and ‘unloaded’ states, define their associated emissions, then create separate ‘loaded’ and ‘unloaded’ user classes in the model. The additional precision gained in the emission calculations would come at the expense of longer runtimes for processing, and additional output files being produced during the scenario run.

Figure 8 shows an excerpt from the default data table for Oxides of Nitrogen (NOx_base_table.csv). The excerpt contains the header line, and the first and last three data lines in the file. As an example, it can be seen that, in 2008, a small petrol car (up to 1.4l engine), with Pre-Euro technology, was assumed to emit 1.43g/km of NOx at 5km/h, and 3.33 g/km at 140km/h.

```
Year,Vehicle,Road_Type,Loading,Gradient,5,10,15,20,25,30,35,40,45,50,55,60,65,70,75,80,85,90,9
5,100,105,110,115,120,125,130,135,140
2008,Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Pre-
Euro|,All,All,All,1.43492e+00,1.43492e+00,1.45949e+00,1.48879e+00,1.52284e+00,1.56163e+00,1.60
516e+00,1.65343e+00,1.70645e+00,1.76420e+00,1.82670e+00,1.89394e+00,1.96592e+00,2.04264e+00,2.
12411e+00,2.21031e+00,2.30126e+00,2.39695e+00,2.49738e+00,2.60255e+00,2.71247e+00,2.82712e+00,
2.94652e+00,3.07066e+00,3.19954e+00,3.33316e+00,3.33316e+00,3.33316e+00
2009,Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Pre-
Euro|,All,All,All,1.42162e+00,1.42162e+00,1.44595e+00,1.47499e+00,1.50872e+00,1.54715e+00,1.59
028e+00,1.63810e+00,1.69062e+00,1.74784e+00,1.80976e+00,1.87638e+00,1.94769e+00,2.02370e+00,2.
10441e+00,2.18982e+00,2.27992e+00,2.37472e+00,2.47422e+00,2.57842e+00,2.68732e+00,2.80091e+00,
2.91920e+00,3.04219e+00,3.16987e+00,3.30226e+00,3.30226e+00,3.30226e+00
2010,Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Pre-
Euro|,All,All,All,1.42162e+00,1.42162e+00,1.44595e+00,1.47499e+00,1.50872e+00,1.54715e+00,1.59
028e+00,1.63810e+00,1.69062e+00,1.74784e+00,1.80976e+00,1.87638e+00,1.94769e+00,2.02370e+00,2.
10441e+00,2.18982e+00,2.27992e+00,2.37472e+00,2.47422e+00,2.57842e+00,2.68732e+00,2.80091e+00,
2.91920e+00,3.04219e+00,3.16987e+00,3.30226e+00,3.30226e+00,3.30226e+00
```

```
…
2048,PTW|M/Cycles(4-stroke)|All|Petrol|750+cc|Euro_3|,All,All,All,1.26123e-01,1.08039e-01,9.09311e-02,7.69022e-02,6.61902e-02,5.87416e-02,5.44355e-02,5.31402e-02,5.47315e-02,5.91004e-02,6.61563e-02,7.58291e-02,8.80696e-02,1.02851e-01,1.20166e-01,1.40034e-01,1.62492e-01,1.87603e-01,2.15450e-01,2.46140e-01,2.79801e-01,3.16586e-01,3.56669e-01,4.00245e-01,4.47536e-01,4.98781e-01,5.54247e-01,6.14219e-01
2049,PTW|M/Cycles(4-stroke)|All|Petrol|750+cc|Euro_3|,All,All,All,1.26123e-01,1.08039e-01,9.09311e-02,7.69022e-02,6.61902e-02,5.87416e-02,5.44355e-02,5.31402e-02,5.47315e-02,5.91004e-02,6.61563e-02,7.58291e-02,8.80696e-02,1.02851e-01,1.20166e-01,1.40034e-01,1.62492e-01,1.87603e-01,2.15450e-01,2.46140e-01,2.79801e-01,3.16586e-01,3.56669e-01,4.00245e-01,4.47536e-01,4.98781e-01,5.54247e-01,6.14219e-01
2050,PTW|M/Cycles(4-stroke)|All|Petrol|750+cc|Euro_3|,All,All,All,1.26123e-01,1.08039e-01,9.09311e-02,7.69022e-02,6.61902e-02,5.87416e-02,5.44355e-02,5.31402e-02,5.47315e-02,5.91004e-02,6.61563e-02,7.58291e-02,8.80696e-02,1.02851e-01,1.20166e-01,1.40034e-01,1.62492e-01,1.87603e-01,2.15450e-01,2.46140e-01,2.79801e-01,3.16586e-01,3.56669e-01,4.00245e-01,4.47536e-01,4.98781e-01,5.54247e-01,6.14219e-01
```
Figure 8: Excerpt from 'NOx_Base_Table.csv' file

4.2 'BaseInputs' Directory Contents:

The 'BaseInputs' directory holds all initial inputs required by the UHTIM applications. These include: the scenario description, baseline traffic information, site activity information, as well as additional files specifying what options individual applications will use, and how certain outputs will be formatted.

The files required are:

- **'Simulation_settings.csv'** – contains basic information on the time period covered by the simulation as well as a number of modelling options;
- **'Vehicles_sim_table.csv'** – contains the individual type definitions required by the scenario. The format is identical to the 'Vehicles_base_table.csv', described in the previous section;
- **'Fleets_sim_table.csv'** – contains the User Class (fleet) aggregations of vehicles required by the scenario. The format is the same as the 'Fleets_base_table.csv', described previously;
- **'Nodes.csv'** – describes the traffic network nodes and their locations;
- **'Links.csv'** – describes the network (road) links which connect between nodes;
- **'Speed_flow_curves.csv'** – describes the per-road-type cost functions used in the traffic assignment models;
- **'Weekly_traffic.csv'** – describes how the traffic assignment model in 'M4BaseTraffGen.exe' should be used to produce a 'typical' week of traffic;
- **'Weekly_scaling.csv'** – provides a matrix of values that allows user class flows on the network to be scaled on a particular day of the week and hour of the day;
- **'Monthly_scaling.csv'** – provides a matrix of values that allow user class flows on the network to be scaled by month of year;
- **'Annual_scaling.csv'** – provides a matrix of values that allows user class flows on the network to be scaled by a factor for a particular year. This may be used to simulate year-on-year traffic growth;
- **'Region.csv'** – describes the Sites, Processes, Phases and site-related Traffic Demands within the Region;
- **'Site_Duplications.csv'** – allows Sites or Processes described in the 'Region.csv' file to be duplicated and repositioned, both spatially and temporally, without having to re-specify every detail again. This is useful if a scenario is to model multiple, but procedurally identical, activities;
- **'ADMS_settings.csv'** - provides a mapping between the pollutant names and descriptions used in the UHTIM model to the standard pollutant descriptions used in the CERC suite of ADMS software applications;

- **‘Pollutant_units_hourly.csv’** – provides scaling factors, decimal place levels and units for each pollutant. These alter the values and formatting of outputs from ‘M4RegPollProc.exe’ at the link level (e.g. hourly mass emissions for pollutants at the link level tend to be in the ‘mg’ to ‘gram’ range, so a large scaling factor, or a high number of decimal places, may be required for ‘sensible’ outputs;
- **‘Pollutant_units_summary.csv’** – provides similar data as to the above, but affecting outputs at the network and site-activity period aggregation levels. These may require smaller scaling factors, and/or number of decimal places for outputs in the ‘kg’ to ‘tonne’ ranges;
- **‘Pollutant_units_ADMS.csv’** – ADMS applications expect emission rates per link to be expressed in terms of g/km/s. This file sets the pollution unit scaling and formatting options for compatibility between UHTIM and ADMS. Both the ‘ADMS_settings.csv’ and ‘ADMS_units.csv’ are used exclusively by the ‘M4RegPostProc.exe’ application;
- **‘<Matrix>.csv** – there may be any number of ‘matrix’ files that describe either: traffic flows between origin and destination node pairs, or explicit traffic flows on individual links. These files are referenced in the ‘Weekly_traffic.csv’ to be used in formulating the ‘typical week’ traffic description by ‘M4BaseTraffGen.exe’.

Figure 9 shows an example of the contents of the ‘BaseData’ directory, using the ‘Test’ scenario provided with the installation.

Name	Date modified	Type	Size
ADMS_settings.csv	29-Jun-18 9:47 AM	CSV File	1 KB
Annual_scaling.csv	18-Sep-17 12:22 PM	CSV File	2 KB
Fleets_sim_table.csv	30-Oct-17 9:30 AM	CSV File	491 KB
Links.csv	26-Jun-18 2:41 PM	CSV File	1 KB
mat_day.csv	26-Jun-18 4:17 PM	CSV File	1 KB
Monthly_scaling.csv	18-Sep-17 12:42 PM	CSV File	1 KB
Nodes.csv	26-Jun-18 3:12 PM	CSV File	1 KB
Pollutant_units_ADMS.csv	27-Jun-18 5:12 PM	CSV File	1 KB
Pollutant_units_hourly.csv	01-Nov-17 3:57 PM	CSV File	1 KB
Pollutant_units_summary.csv	01-Nov-17 3:56 PM	CSV File	1 KB
Region.csv	26-Jun-18 3:14 PM	CSV File	8 KB
Simulation_settings.csv	26-Jun-18 3:36 PM	CSV File	1 KB
Site_duplications.csv	15-Jun-18 4:04 PM	CSV File	1 KB
Speed_flow_curves.csv	31-Aug-17 2:02 PM	CSV File	3 KB
Vehicles_sim_table.csv	10-Sep-17 8:13 AM	CSV File	65 KB
Weekly_scaling.csv	18-Sep-17 12:14 PM	CSV File	4 KB
Weekly_traffic.csv	26-Jun-18 4:23 PM	CSV File	6 KB

Figure 9: Sample/Default ‘BaseInput’ Directory Files

Table 1 summarises which input files are specifically required by individual UHTIM applications.

Table 1: Input files required by each individual UHTIM application

Input \ Application	M4InitialiseProject	M4BaseTrafficGen	M4RegTimeGen	M4FleetPolProc	M4RegTraffGen	M4RegPollProc	M4RegPostProc
Simulation_settings.csv	✗	✓	✓	✓	✓	✓	✓
Vehicles_sim-table.csv	✗	✓	✓	✓	✓	✓	✓
Fleets_sim_table.csv	✗	✓	✓	✓	✓	✓	✓
Speed_flow_curves.csv	✗	✓	✓	✗	✓	✓	✓
Nodes.csv	✗	✓	✓	✗	✓	✓	✓
Links.csv	✗	✓	✓	✗	✓	✓	✓
Weekly_scaling.csv	✗	✓	✓	✗	✓	✓	✗
Monthly_scaling.csv	✗	✓	✓	✗	✓	✓	✗
Annual_scaling.csv	✗	✓	✓	✗	✓	✓	✗
Weekly_traffic.scv	✗	✓	✓	✗	✓	✓	✗
Region.csv	✗	✗	✓	✗	✓	✓	✗
Site_duplications.csv	✗	✗	✓	✗	✓	✓	✗
<Matricies>.csv	✗	✗	✗	✗	✓	✗	✗
Pollutant_units_hourly.csv	✗	✗	✗	✗	✗	✓	✗
Pollutant_units_summary.csv	✗	✗	✗	✗	✗	✓	✗
ADMS_settings.csv	✗	✗	✗	✗	✗	✗	✓
Pollutant_units_ADMS.csv	✗	✗	✗	✗	✗	✗	✓
<Pollutant>_Base_Tables.csv	!	✗	✗	✓	✗	✗	✗

NB: 'M4InitialiseProject.exe' copies '<Pollutant>_Base_Tables.csv' from the installation directory to the project directory. 'M4FleetPollProc.exe' reads the copied tables from the '<Project>\BaseData' directory.

The following sections describe each file in detail.

4.2.1 Simulation_settings.csv:

The 'Simulation_settings.csv' file has a header line, followed by a list of parameters and their values.

The header line is simply:

```
Parameter,Value
```

Currently recognised parameters are:

- **'Start'**: <String> The start time (to the minute) and date of the simulation in a (pseudo) POSIX format ('yyyy-mm-dd hh:mm', e.g. the start of 2018 would be '2018-01-01 00:00');
- **'End'**: <String> The end time and date of the simulation. Note that the UHTIM applications use the time 'hh:59' to represent the end of an hour, e.g. the end of 2018 would be '2018-12-31 23:59);
- **'Use_Annual_Scale_Factors'**: <Boolean> Sets whether or not traffic flow calculations are to take into account the annual scaling factors from the 'Annual_scaling.csv' file. Generally this should be left as 'true';
- **'Use_Monthly_Scale_Factors'**: <Boolean> Sets whether or not traffic flow calculations are to take into account the monthly scaling factors from the 'Monthly_scaling.csv' file. Generally this should be left as 'true';
- **'Use_Interpolation'**: <Boolean> Sets whether pollutant emissions should be calculated using linear interpolation between provided emission rate values ('true'), or whether just the closest speed breakpoint should be selected ('false'). There has been some discussion (e.g. in Highways England Interim Advice Note 185/15) as to whether interpolated emissions from macroscopic traffic models, give a 'false sense of accuracy' regarding emissions, and changes in emissions, with speed variation – with the recommendation that emissions should be calculated rather over speed-bins representing underlying traffic conditions;

- **'Hourly Outputs'**: <Boolean> Sets whether emission results should be output at the hourly level, or whether only summary outputs need to be generated. The former is required for any form of ADMS-based work, but generates a large (i.e. 8,000+!) number of intermediate output files from 'M4RegPollProc.exe';
- **'Traffic_State_Format'**: <String> Sets the output format of intermediate files. Currently this may only be set to 'json', though the intention is to allow output in a binary, compressed format. 'Json' files are human-readable, but relatively slow to parse by the computer, whilst binary files are non-human readable, but much faster to process (what's in the file can be directly copied to memory, without parsing overheads);
- **'Noise_Distance'**: <Float> Sets the reference distance, in metres, from the centre of a road that is used in sound pressure level calculations. The default is 10.0m;
- **'Noise_Source'**: <Float> Sets the height of the vehicle noise source above the road carriageway, in metres. The default value is 0.2m;
- **'Noise_Receiver'**: <Float> Sets the height of the noise receiver above ground level, in metres. The default value is 1.5m;
- **'Noise_Ground'**: <Float> Sets the correction applied to calculated noise levels to account for ground impedance and reflection effects, in decibels (dB). A value of 6.0 implies sound propagation over an acoustically reflective hard surface (e.g. concrete), whilst 0.0 implies a very absorptive surface (e.g. soft snow). The default value is 6.0dB.

4.2.2 Vehicles_sim_table.csv:

The 'Vehicles_sim_table.csv' file has exactly the same structure as the 'Vehicles_Base_Table.csv' file discussed previously. If new vehicle types are added to this file, then they must also have corresponding data line entries added to the various '<Pollutant>_Base_Table.csv' files in the '<project>\BaseData' directory.

4.2.3 Fleets_sim_table.csv:

The 'Fleets_sim_table.csv' file has exactly the same structure as the 'Fleets_Base_Table.csv' file discussed previously. Additional user classes, required by the scenario, should be added to this file.

4.2.4 Nodes.csv:

The 'Nodes.csv' file has the following header line:

```
ID1,Name,Type,X,Y
```

Each data line should contain:

- **ID1**: <Integer> A unique identifier for the node ID;
- **Name**: <String> A unique name for the node;
- **Type**: <String> Three node types are recognised by the traffic assignment models:
    - ***'Centroid'*** – a 'virtual' node used to represent a loading point of traffic onto the network at a location (named after the use of the geometric centroid of large aggregate zones, such as industrial sites or housing estates, as a simplification in transport models);
    - ***'Connection'*** – a location where multiple traffic links join one another, but there isn't necessarily any conflict between flows on those links (e.g. all of the traffic is flowing in the same direction, and no possibility to turn onto a different link exists);
    - ***'Junction'*** – a location where multiple traffic links join one another, and conflict or turning possibilities exist;

- **X**: <Float> Cartesian 'X' coordinate of the node, in metres (e.g. in the UK the 6-digit 'Easting' coordinate);
- **Y**: <<Float> Cartesian 'Y' coordinate of the node, in metres (e.g. in the UK the 6-digit 'Northing' coordinate).

4.2.5 Links.csv:

The 'Links.csv' file has the following header line:

```
A_NODE,B_NODE,Type,CostCurve,PolType,Length,Gradient
```

Each data line should contain:

- **A_Node**: <Integer> The ID of the starting node at the beginning of the road link;
- **B_Node**: <Integer> The ID of the end node of the road link. Note that the 'A_B' node pair defines the link direction, so to model a bi-directional road two links need to be defined – 'A -> B' and 'B -> A';
- **Type**: <String> Two values are accepted:
    - ***'Link'*** - a 'real-world' link between two junction, two connection, or one junction and one connection node. Such links should be defined with a finite capacity in their cost function;
    - ***'Connector'*** – a 'virtual' link between a centroid node and any other node type. These do not have a finite capacity, and hence cost, associated with their use.
- **CostCurve**: <String> The name of the speed-flow cost function to be applied on this link. This should exist as an entry in the 'Speed_flow_curves.csv' file;
- **PolType**: <String> The name of the type of road, if disaggregate emissions factors are being used – i.e. corresponding to the 'Road_Type' dimension in the '<Pollutant>_base_table' files. If only one type of road is defined, use the 'All' keyword. The full EFT tables distinguish three categories of road type – 'Urban', 'Rural' and 'Motorway', further disaggregated by country, though default tables provided by UHTIM are based only on the 'England Rural' category;
- **Length**: <Integer> or <String>. The length of the road in metres. If the string 'NA' is used then the road length will be calculated directly from the start and end node coordinates. If this 'straight-line' distance is inappropriate (for whatever reason) then a defined value may be used to override the calculated one. (Alternately, if geographically accurate links are desired, use shapefile-based, rather than .csv-based link and node inputs, see: 'Alternate file formats: Shapefiles');
- **Gradient**: <String> The name of the gradient category to be applied, if disaggregate emissions factors are being used – i.e. corresponding to the 'Gradient' dimension in the '<Pollutant>_base_table' files. If only one gradient is required (i.e. all roads are flat) use the 'All' keyword.

4.2.6 Speed_flow_curves.csv:

The 'Speed_flow_curves.csv' file has the following header line:

```
Type,ID1,ID2,Name,Description,Val1,Val2,Val3,Val4,Val5,Val6,Va
l7,Val8,Val9,Val10
```

The information required on each data line depends on the type of cost function required. Currently, three types of function are supported: '**COBA'** (UK COst-Benefit Analysis), '**BPR**' (US Bureau of Public Roads) and '**CENT**' (Infinite capacity centroid connections). Different types of function may be feely mixed in the 'Speed_flow_curves.csv' file. Further information on the functions themselves may be found in Appendix D.

For COBA-type functions data lines should contain:

- **Type**: <String> 'COBA';
- **ID1**: <Integer> The primary identifier of a particular cost function. This is somewhat arbitrary at present, but should be unique – e.g. an incremental value given to the particular function (1,2,3 … n, including any previously defined 'BPR' or 'CENT' functions);
- **ID2**: <Integer> A secondary identifier that may be used to group functions. Again, this is somewhat arbitrary, but the example 'Speed_flow_curves.csv' file provided with the installation, uses 'ID2' to cluster broadly similar functions for categories of road (e.g. 1 = Rural roads, 2 = Suburban roads, 3 = Urban roads, 4 = Town and village roads);
- **Name**: <String> A short string identifier for the cost function (max. 5 characters). In the sample file, this is used to give the road type, quality and the lane configuration of the road (e.g. 'R4DM' is a rural, 4-lane duelled, standard motorway, whilst 'VS2D' is a low-quality single carriageway road running through a village). A full list of road types is given in Appendix D;
- Description: <String> A longer string identifier (max. 64 characters) that may be used to better describe the function than the 'Name' field;
- **Val1**: <Float> Speed in km/h of the road at free-flow (i.e. 'S_0' from equations D.1-D.3);
- **Val2**: <Float> Speed in km/h of the road at the first capacity breakpoint at maximum free-flow (i.e. 'S_1' from equations D.1-D.3);
- **Val3**: <Float> Speed in km/h of the road at the second capacity breakpoint at link capacity flow (i.e. 'S_2' from equations D.1-D.3) ;
- **Val4**: <Integer> Flow in pcus/hour/lane, at the first capacity breakpoint ('F' in Equations D.1-D.3);
- **Val5**: <Integer> Flow in pcus/hour/lane, at the second capacity breakpoint ('C' in Equations D.1-D.3);
- **Val6**: <Float> Exponential power of the smooth curve which can be used to approximate the piecewise cost function, as used by some transport models such as SATURN. ***NB: this isn't actually used in UHTIM at present and is only provided in the default files for reference***;
- **Val7**: <Float> The distance between successive road junctions, in kilometres. This is used in the calculation of speed in over-capacity, highly-congested conditions ('d' in Equations D.1-D.3);
- **Val8**: <Float> The width of an individual lane on the carriageway in metres;
- **Val9**: <Float> Nominal number of lanes on the overall carriageway (i.e. both directions of flow);
- **Val10**: <Boolean> 'true' if the road is duelled, 'false' if single carriageway.

For BPR-type functions data lines should contain:

- **Type**: <String> 'BPR';
- **ID1**: <Integer> The primary identifier of a particular cost function. This is somewhat arbitrary at present, but should be unique – e.g. an incremental value given to the particular function (1,2,3 … n, including any previously defined 'COBA' or 'CENT' functions);
- **ID2**: <Integer> A secondary identifier that may be used to group functions. Again, this is somewhat arbitrary, but the example files use 'ID2' to cluster broadly similar functions for categories of road (e.g. 1 = Rural roads, 2 = Suburban roads, 3 = Urban roads, 4 = Town and village roads);
- **Name**: <String> As for COBA functions above. Note that the sample file doesn't use any 'BPR' type functions, so no naming convention is present as an example;
- **Description**: <String> As for 'COBA' functions above;

- **Val1**: <Float> Sets the Free-flow travel time 'Ta' value in seconds/km, for the BPR function (Equation D.4);
- **Val2**: <Float> Sets the Capacity 'Ca' value in pcu/h, for the BPR function (Equation D.4);
- **Val3** … **Val10**: <Strings> These should all be set to the not-applicable string, 'NA'.

For CENT-type functions data lines should contain:

- **Type**: <String> 'CENT';
- **ID1**: <Integer> The primary identifier of a particular cost function. This is somewhat arbitrary at present, but should be unique – e.g. an incremental value given to the particular function (1,2,3 … n, including any previously defined 'COBA' or 'BPR' functions);
- **ID2**: <Integer> The secondary identifier – in the sample file, this is set to a value of '5' to denote a centroid function;
- **Name**, **Description**, **Val1** … **Val10**: <Strings> These should all be set to the not-applicable string, 'NA'.

4.2.7 Weekly_traffic.csv:

The 'Weekly_traffic.csv' file has the following header line:

```
Param1,Value1,Value2,Value3,Value4,Value5,Value6,Value7,Value8
,Value9,Value10,Value11,Value12
```

This is then followed by two lines which define how the typical week is to be described in the 'Day_Type' and 'Time_Type' data lines:

The 'Day_Type' data line has this structure:

- **Param1**: < String> "Day_Type";
- **Value1**: <String> Defines how many traffic profiles are to be defined to cover the individual days of the week. If set to '**All**', the seven days must be defined separately. Other values are '**Single**', which means that all days will use the same traffic profile; '**WDay_WEnd**', which means that two separate profiles, one for Mon-Fri and one for Sat-Sun, will be used; '**WDay_Sat_Sun**', which further separates the weekend profile into individual days, and; '**WDay_Fri_Sat_Sun**', which assumes one profile holds for Mon-Thu, but all other days will have unique profiles.
- **Value2** … **Value12**: <Strings> All of these entries should be set to 'NA'.

The 'Time_Type' data line has this structure:

- **Param1**: <String> "Time_Type";
- **Value1**: <String> Defines into how many individual units each diurnal traffic profile is to be broken into. At present the only allowable value is 'Hourly', with each profile consisting of 24 entries;
- **Value2** … **Value12**: <Strings> All of these entries should be set to 'NA'.

e.g. the following lines:

```
Day_Type,Single,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA
Time_Type,Hourly,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA
```

Inform that the 'typical week' will be defined using a single hourly-diurnal traffic profile.

Next two lines are the start and end dates over which this profile may be applied are defined. These have the format:

- **Param1**: <String> “Start_Date”;
- **Value1**: <String> Start date and time in ‘YYYY-MM-DD HH:MM’ format;
- **Value2** - **Value12**: <Strings> All of these entries should be set to ‘NA’.

- **Param1**: <String> “End_Date”;
- **Value1**: <String> End date and time in ‘YYYY-MM-DD HH:MM’ format;
- **Value2** - **Value12**: <Strings> All of these entries should be set to ‘NA’.

e.g. The following lines:

```
Start_Date,2018-01-01 00:00,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA
End_Date,2018-12-31 23:59,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA
```

Set the profiles within the file to apply over 2018.

The next block of lines inform how many user classes are being used in the traffic profile. The first line is:

- **Param1**: <String> “Fleet_Count”;
- **Value1**: <Integer> The number of user classes in the scenario;
- **Value2** - **Value12**: <Strings> All of these entries should be set to ‘NA’.

This line is then followed by one line naming each user class:

- **Param1**: <String> “Fleet”;
- **Value1**: <String> The name of the user class;
- **Value2** - **Value12**: <Strings> All of these entries should be set to ‘NA’.

e.g. The following lines:

```
Fleet_Count,4,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA
Fleet,Base,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA
Fleet,LGV,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA
Fleet,HGV1,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA
Fleet,HGV2,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA,NA
```

Inform that there are four user classes being used ‘Base’, ‘LGV’, ‘HGV1’ and ‘HGV2’. NB: During a traffic assignment using multiple user classes, individual user classes are loaded onto the network in ‘reverse PCU order’ – i.e. the ‘heaviest’ user class, with the largest PCU value, is loaded first. This is done to allow the assignment to favour the use of major roads for heavy vehicles, with private (car) traffic being assigned last, as this has the best ability to reroute onto minor roads if necessary. A future iteration of the applications may allow custom ordering, or the ability to force ‘fixed’ or ‘preload’ assignments to go first.

Finally, the traffic profiles are defined. The data format of each data line changes depending on how traffic assignment should be performed for a particular user class within the given hour. Possible types of assignment are:

- ***BAS*** – Basic (or all-or-nothing) assignment. This assignment takes an OD matrix for the user class, scales it if necessary, then applies it to the network by loading flows onto links using the shortest paths (Dijkstra's Algorithm), based on the link costs under zero flow conditions.
- ***FIX*** – Fixed route assignment. This assignment reads an incomplete network traffic state (i.e. one whose coverage doesn't include all links in the network) for the user class from file, scales it appropriately, and then applies it directly to traffic links.
- ***FWO*** – Frank-Wolfe iterative assignment. This assignment takes an OD matrix and incrementally loads the flows onto the network. An initial loading is made using the overall demand in the matrix, under all-or-nothing conditions. For subsequent iterations, a 'direction' (up or down) for assignment of flows on links, the (approximate) ideal size of the proportion of demand to be loaded in that iteration (via 'Golden Section' search), and new network costs and shortest-paths are calculated under that loading. This is repeated until the majority of the demand in the matrix has been assigned to the network. Ideally, results from iterations should eventually assign 100% of the demand, and converge to a unique, cost-optimal, network solution. Realistically, some network configurations don't necessarily converge well within a reasonable time frame. Hence further parameters are provided to limit the number of iterations used in the assignment, the amount of demand that must be assigned from the matrix and the acceptable convergence of changes in flows between iterations, recognising the fact that this will lead to sub-optimal costs and non-equilibrium flows on the network;
- ***INC*** – Incremental assignment. This assignment scales an OD matrix if necessary, then divides the demand from the matrix into four equal parts. Each portion is then applied to the network sequentially, with network costs and shortest paths recalculated after each, prior to the next assignment.
- ***PRE*** – Preload assignment. This is similar to the 'fixed route' assignment, but expects a complete traffic state to be used, i.e. there must be an entry for the user class on every link, even if the flow is zero.
- ***SCA*** – Scaled assignment. This assignment takes the results for the assignment in another period, scales it appropriately, and applies the resulting flows directly to the network;
- ***ZER*** – Zero assignment. This simply sets all flows on the network for this user class to zero.

The 'BAS', 'FWO' and 'INC' traffic assignment options are further discussed in Appendix E.

The 'Param1' to 'Value4' elements of an assignment data line should contain:

- **Param1**: <String> "Entry" – This indicates the line is a traffic profile entry;
- **Value1**: <Integer> The integer code for the day to which this profile refers (see Table 2);
- **Value2**: <Integer> The hour of the day, from 0 to 23;
- **Value3**: <String> The user class to which this profile refers;
- **Value4**: <String> The type of assignment to be used, e.g. 'BAS' or 'FIX';

4.2.7.1 Basic Assignment:

For basic assignment of a user class, the remaining elements are:

- **Value5**: <Float> The scaling factor to be applied to the traffic demand;
- **Value6**: <String> The filename (minus file extension) of the traffic demand file that is to be read from the '<project>\BaseInput' directory;
- **Value7**: <String> The type of traffic demand file used for input. This may be 'csv' (see Section '<Matrix>.csv' for the file format), 'json' (see Section 'Alternate file formats: Json files') or 'bin' (not currently used, but reserved for future compressed binary file formats);
- **Value8**: <String> Output file format. This should currently be set to 'json' only. (Output of binary or csv files is again, a future option). Generally, traffic assignments producer two separate output files, one containing the network flows for the user class, the other, the network speeds;
- **Value9** – **Value12**: <Strings> These elements should be set to 'NA'.

e.g. The line:

```
Entry,0,0,Base,BAS,1.0,mat_100,csv,json,NA,NA,NA,NA
```

Will create a traffic assignment for the user class 'Base', for 00:00 to 01:00, on days with day code '0', using the basic assignment methodology, loading demand from '<project>\BaseInputs\mat_100.scv', then scaling it by a factor of 1.0, before applying results to the network. Output will be written as 'json' files.

4.2.7.2 Fixed Route Assignment:

For fixed-route assignment of a user class, a data line should be formatted as:

- **Value5**: <Float> The scaling factor to be applied to the traffic demand;
- **Value6**: <String> The filename (minus file extension) of the traffic demand file that is to be read from the '<project>\BaseInput' directory;
- **Value7**: <String> The type of traffic demand file. This may be 'csv' (see Section '<Matrix>.csv' for the file format), 'json' (see Section 'Alternate file formats: Json files') or 'bin' (not currently used, but reserved for future compressed binary file formats);
- **Value8**: <String> Output file format. This should currently be set to 'json' only. (Output of binary or csv files is again, a future option).
- **Value9**: <String> A setting for how the traffic demand should be applied to the network. If set to 'NA' the demand is simply added to the network. However, other possible operations are available, see Table 3.
- **Value10** – **Value12**: <Strings> These elements should be set to 'NA'.

e.g. The line:

```
Entry,0,0,Base,FIX,1.0,routes,csv,json,NA,NA,NA,NA
```

Would do the same as the basic assignment example above, but use fixed routes loaded from '<project>\BaseInputs\routes.csv'.

4.2.7.3 Frank-Wolfe Assignment:

For fixed-route assignment of a user class, a data line should be formatted as:

- **Value5**: <Float> The scaling factor to be applied to the traffic demand;
- **Value6**: <String> The filename (minus file extension) of the traffic demand file that is to be read from the '<project>\BaseInput' directory;
- **Value7**: <String> The type of traffic demand file. This may be 'csv' (see Section '<Matrix>.csv' for the file format), 'json' (see Section 'Alternate file formats: Json files') or 'bin' (not currently used, but reserved for future compressed binary file formats);
- **Value8**: <String> Output file format. This should currently be set to 'json' only. (Output of binary or csv files is again, a future option).
- **Value9**: <Integer> Sets the maximum number of iterations that the FW algorithm will perform ('n_{max}' – see Appendix E) when trying to reach equilibrium traffic conditions. Default value is 20.
- **Value10**: <Integer> Sets the maximum number of iterations the 'Golden Section' search algorithm will use (see Appendix E) to refine the proportion of demand to be assigned in a given main iteration of the FW algorithm. Default value is 20.
- **Value11**: <Float> Sets the convergence criteria ('ε' – see Appendix E) for changes in flows between successive main iterations of the FW algorithm. Default value is 0.001;
- **Value12**: <Float> Sets the convergence criteria for changes in the costs between successive internal iterations, as produced by the 'Golden Section' search algorithm. Default value is 0.001.

e.g. The line:

```
Entry,0,7,Base,FIX,0.80,mat_100,csv,json,25,50,0.001,0.001
```

Would perform a Frank-Wolfe assignment for 07:00 to 08:00 on days with code '0', loading demand from '<project>\BaseInputs\mat_100.scv', scaled by '0.8'. Actual assignment will be based on a maximum of 25 iterations of the algorithm, each using a maximum of 50 internal iterations to refine the amount of demand to load. Outputs will be written to 'json' files.

4.2.7.4 Incremental Assignment:

For incremental assignment of a user class, a data line should be formatted as:

- **Value5**: <Float> The scaling factor to be applied to the traffic demand;
- **Value6**: <String> The filename (minus file extension) of the traffic demand file that is to be read from the '<project>\BaseInput' directory;
- **Value7**: <String> The type of traffic demand file. This may be 'csv' (see Section '<Matrix>.csv' for the file format), 'json' (see Section 'Alternate file formats: Json files') or 'bin' (not currently used, but reserved for future compressed binary file formats);
- **Value8**: <String> Output file format. This should currently be set to 'json' only. (Output of binary or csv files is again, a future option).
- **Value9** … **Value12**: <Strings> These elements should be set to 'NA'.

e.g. The line:

```
Entry,0,0,Base,INC,1.0,mat_100,csv,json,NA,NA,NA,NA
```

Would perform the same operation as in the basic assignment example above, but using incremental assignment.

4.2.7.5 Preload Assignment:

For preload assignment of a user class, a data line should be formatted as:

- **Value5**: <Float> The scaling factor to be applied to the traffic demand;
- **Value6**: <String> The filename (minus file extension) of the traffic demand file that is to be read from the '<project>\BaseInput' directory;
- **Value7**: <String> The type of input traffic demand file. This may be 'csv' (see Section '<Matrix>.csv' for the file format), 'json' (see Section 'Alternate file formats: Json files') or 'bin' (not currently used, but reserved for future compressed binary file formats);
- **Value8**: <String> Output file format. This should currently be set to 'json' only. (Output of binary or csv files is again, a future option).
- **Value9**: <String> A setting for how the traffic demand should be applied to the network. If set to 'NA' the demand is simply added to the network. However, other possible operations are available, see Table 3.
- **Value10** … **Value12**: <Strings> These elements should be set to 'NA'.

e.g. The line:

```
Entry,0,0,Base,PRE,0.10,network_state,csv,json,NA,NA,NA,NA
```

Would load the file '<projects>\BaseInputs\network_state.csv', scale it by a factor of 0.1 (10%) and then apply it directly onto the network.

4.2.7.6 Scaled Assignment:

For fixed-route assignment of a user class, a data line should be formatted as:

- **Value5**: <Float> The scaling factor to be applied to the traffic demand;
- **Value6**: <String> The filename (minus file extension) of the traffic demand file that is to be read from the '<project>\BaseInput' directory;
- **Value7**: <String> This is the type of input Traffic Demand file. It may only be 'json' (see Section 'Alternate file formats: Json files') or 'bin' (not currently used, but reserved for future compressed binary file formats);
- **Value8**: <String> Output file format. This should currently be set to 'json' only. (Output of binary or csv files is again, a future option).
- **Value9**: <Integer> The day code (see Table 2) for the time period of the pre-existing assignment this assignment is to be scaled from;
- **Value10**: <Integer> The time code (0-23 for the time period of the pre-existing assignment this assignment is to be scaled from);
- **Value11,Value12**: <Strings> These elements should be set to 'NA'.

When running 'M4BaseTraffGen' initially calculates network conditions for all non-scaled assignment periods in a week, and writes these results to file, before going back and 'filling in the blanks' for the remaining scaled assignment periods, by reading in the pre-calculated data for another hour, and re-scaling it. Value9 and Value10 in a scaled assignment must therefore reference another non-scaled assignment, though that non-scaled assignment can come from a period that is, in reality, later in the week. e.g: The line:

```
Entry,0,5,Base,SCA,0.25,NA,json,json,0,7,NA,NA
```

Would set the traffic demand on the network for the 'base' user class at 05:00 to 06:00, for whatever days shared day code '0' to 0.25 (25%) of whatever the calculated flow for 'base' was on the same day(s) for 07:00 to 08:00.

4.2.7.7 Zero Assignment:

For zero assignment a data line should contain:

- **Value5** … **Value7** <Floats> These elements should be set to 'NA';
- **Value8**: <String> Output file format. This should currently be set to 'json' only. (Output of binary or csv files is again, a future option);
- **Value9** … **Value12**: <Strings> These should all be set to 'NA'.

Table 2: Numeric day codes for different week description options

Day Code	Sun	Mon	Tue	Wed	Thu	Fri	Sat
All	0	1	2	3	4	5	6
Single	0	0	0	0	0	0	0
WDay_WEnd	1	0	0	0	0	0	1
WDay_Sat_Sun	2	0	0	0	0	0	1
WDay_Fri_Sat_Sun	3	0	0	0	0	1	2

Table 3: Available arithmetic and mathematical operations on network traffic states [1]

Operation String	Op. ID	Description
ADD (or NA)	1	Arithmetically adds the values defined in the <matrix> file to the existing network values for the user class.
SUB	2	Subtracts the values defined in the <matrix> file to the existing network values for the user class.
MUL	3	Multiplies the existing network values for the user class by the values defined in the <matrix> file.
DIV	4	Divides the existing network values for the user class by the values defined in the <matrix> file.
POW	5	Raises the existing values to the power of the values defined in the <matrix> file.
LAD	6	Logarithmically adds the values defined in the <matrix> file to the existing network values for the user class.
LSC	7	Logarithmically scales the values defined in the <matrix> file to the existing network values for the user class.

[1] NB: for general traffic assignment, only ADD (or NA) is (or at least should be) used, as the matrix values are assumed to refer to traffic flows. The other possible operations arise from the use network traffic states to store and manipulate other values, such as speeds, pollution levels or noise levels (e.g. decibel noise values are logarithmic in nature, and therefore require different addition and scaling functions to be defined).

4.2.8 Weekly_scaling.csv:

The 'Weekly_scaling.csv' file has the following header line:

```
Fleet,Day,00:00,01:00,02:00,03:00,04:00,05:00,06:00,07:00,08:0
0,09:00,10:00,11:00,12:00,13:00,14:00,15:00,16:00,17:00,18:00,
19:00,20:00,21:00,22:00,23:00
```

Each data line should contain:

- **Fleet**: <String> The name of the user class to which the line refers. This should be a 'Key' value from the 'Fleets_sim_table.csv' file;
- **Day**: <String> A three-letter code identifying the day-of-week (i.e. Mon, Tue, Wed, Thu, Fri, Sat, Sun). Each user class defined in 'Fleets_sim_table.csv' should therefore have seven data line entries;
- **00:00** … **23:00**: <Float> The hourly scaling factor for this user class and day that will be applied to the baseline, typical weekly values.

The sample file provided with the installation sets all scaling values to 1.0.

4.2.9 Monthly_scaling.csv:

The 'Montly_scaling.csv' file has the following header line:

```
Fleet,Jan,Feb,Mar,Apr,May,Jun,Jul,Aug,Sep,Oct,Nov,Dec
```

Each data line should contain:

- **Fleet**: <String> The name of the user class to which the line refers. This should be a 'Key' value from the 'Fleets_sim_table.csv' file;
- **Jan** … **Dec**: <Float> The scaling factor for this user class that will be applied to the baseline values in the month.

The sample file provided with the installation sets all scaling values to 1.0.

4.2.10 Annual_scaling.csv:

The 'Annual_scaling.csv' file has the following header line:

```
Fleet,2008,2009,2010,2011,2012,2013,2014,2015,2016,2017,2018,2
019,2020,2021,2022,2023,2024,2025,2026,2027,2028,2029,2030,203
1,2032,2033,2034,2035,2036,2037,2038,2039,2040,2041,2042,2043,
2044,2045,2046,2047,2048,2049,2050
```

Each data line should contain:

- **Fleet**: <String> The name of the user class to which the line refers. This should be a 'Key' value from the 'Fleets_sim_table.csv' file;
- **2008** … **2050**: <Float> The scaling factor for this user class that will be applied to the baseline values in the year.

The sample file provided with the installation sets all scaling values to 1.0.

4.2.11 Region.csv:

The 'Region.csv' is the most complex of all the UHTIM input files, given that it encompasses all aspects of the region hierarchy in a single structure. The 'Region.csv' header line is as follows:

```
Item,SiteID,ProcessID,PhaseID,Name,Start_Date,End_Date,Directi
on,Origin,E_or_D,N_or_V,Description
```

The 'Item' element defines as to what type of object, within the Region hierarchy, the data line refers to. Possible options are:

- **Region** – the top level object in the hierarchy. There can only be one of these data lines, directly after the header line;

- **Fleet** – defines a user class being used elsewhere in the 'Region.csv' file. There can be as many fleet data lines as required, as long as they all immediately follow the region line. ***NB: The maximum number of user classes (baseline or activity-related) per region is 256***;
- **Site** – There can be as many site lines as necessary in the 'Region.csv' file. The first site definition should immediately follow the fleet definitions. The position of subsequent site definition will depend on the complexity of the sites, as all elements of a site should be defined in the file before the definition of the next site is started. ***NB: The maximum number of sites per region is 65535***;
- **Process** – There can be as many processes as necessary attached to a parent Site. The first Process should be defined immediately after its parent site's definition. Subsequent Processes should be entered after definition of all elements of the previous Process have been completed. ***NB: The maximum number of processes per site is 65535***;
- **Phase** - There can be as many Phases as necessary attached to a parent Process. The first Process should be defined immediately after its parent site's definition. Subsequent Processes should be entered after definition of all elements of the previous Process have been completed. ***NB: The maximum number of phases per process is 65535***;
- **Profile** – This data line defines the site access policy for a Traffic Demand associated with a phase. For each profile data line there should be a corresponding 'Traffic' line, and there could be one or more 'OD' or 'Link' lines;
- **Traffic** – This data line defines the active period for a Traffic Demand;
- **OD** – This data line defines a particular Origin and Destination for a route taken by a vehicles associated with a Traffic Demand, as well as the volume of traffic using the route;
- **Link** – This data line defines the flow on a particular link associated with a Traffic Demand. NB: Multiple 'OD' lines may be required, and multiple 'Link' lines almost certainly will be required to fully define a Traffic Demand.
  NB: A current limitation of Region processing within the application is that there must be one inbound and one outbound set of data for 'Profile', 'Traffic', 'OD' or 'Link' per 'Phase', even if the actual vehicle flow in that direction is zero.

The structures of each type of data line are as follows:

For the 'Region' line:

- **Item**: <String> 'Region';
- **SiteID**, **ProcessID**, **PhaseID**: <Strings> These should be set to 'NA';
- **Name**: <String> A short name for the region;
- **Start_Date**, **End_Date**: <Strings> Both should be set to 'NA'. The region's start and end times are assumed to be the same as those set in the 'Simulation_settings.csv' file;
- **Direction**, **Origin**, **E_or_D**, **N_or_V**: <Strings> All should be set to 'NA';
- **Description**: <String> The long name and/or description of the region.

e.g.:

```
Region,NA,NA,NA,Region_1,NA,NA,NA,NA,NA,NA,Test Region
```

For 'Fleet' lines:

- **Item**: <String> 'Fleet';
- **SiteID, ProcessID, PhaseID**: <Strings> These should be set to 'NA';
- **Name**: <String> The name of a user class;

- **Start_Date, End_Date, Direction, Origin, E_or_D, N_or_V, Description**: <Strings> All of these elements should be set to 'NA'.

e.g.

```
Fleet,NA,NA,NA,LGV,NA,NA,NA,NA,NA,NA,NA
```

For 'Site' Lines:

- **Item**: <String> 'Site';
- **SiteID**: <Integer> The Site's ID number;
- **ProcessID, PhaseID**: <Strings> These should be set to 'NA';
- **Name**: <String> The short name of the Site;
- **Start_Date, End_Date**: <Strings> Define the period over which the Site is active. All subsequent Processes, Phases and Traffic Demands for the Site should fit into this period. Dates and times should be provided in 'YYYY-MM-DD HH:MM' format;
- **Direction**: <String> Should be set to 'NA';
- **Origin**: <Integer> The ID of the centroid node in the traffic network to which this Site is to be attached;
- **E_or_D**: <Integer> The Cartesian x-coordinate (i.e. Easting) of the Site;
- **N_or_V**: <Integer> The Cartesian y-coordinate (i.e. Northing) of the Site;
- **Description**: <String> The long name or description of the Site.

e.g.:

```
Site,1,NA,NA,Wellpad_1,2018-01-01 00:00,2018-06-11
23:59,NA,501,450000,450000,Wellpad_1_at_Site_1
```

For 'Process' Lines:

- **Item**: <String> 'Process';
- **SiteID**: <Integer> The parent Site's ID;
- **ProcessID**: <Integer> The ID of the Process;
- **PhaseID**: <String> This should be set to 'NA';
- **Name**: <String> The short name of the Process;
- **Start_Date, End_Date**: <Strings> Define the period over which the Process is active. All subsequent Phases and Traffic Demands for the Process should fit into this period. Dates and times should be provided in 'YYYY-MM-DD HH:MM' format;
- **Direction, Origin, E_or_D, N_or_V**: <Strings> All should be set to 'NA';
- **Description**: <String> The long name or description of the Process.

e.g.:

```
Process,1,1,NA,Pad_Construction,2018-01-01 00:00,2018-02-04
23:59,NA,NA,NA,NA,Pad_Construction_At_Site_1
```

For 'Phase' Lines:

- **Item**: <String> 'Phase';
- **SiteID**: <Integer> The parent Site's ID;
- **ProcessID**: <Integer> The parent Process' ID;
- **PhaseID**: <Integer> The ID of the Phase;
- **Name**: <String> The short name of the Phase;

- **Start_Date, End_Date**: <Strings> Define the period over which the Phase is active. All subsequent Traffic Demands for the Phase should fit into this period. Dates and times should be provided in 'YYYY-MM-DD HH:MM' format;
- **Direction, Origin, E_or_D, N_or_V**: <Strings> All should be set to 'NA';
- **Description**: <String> The long name or description of the Phase.

e.g.:

```
Phase,1,1,1,Pad_Construction_Concrete,2018-01-01 00:00,2018-
01-05 23:59,NA,NA,NA,NA,Concrete_Pour_for_Wellpad_1_at_Site_1
```

For 'Profile' lines:

- **Item**: <String> 'Profile';
- **SiteID**: <Integer> The parent Site's ID;
- **ProcessID**: <Integer> The parent Process' ID;
- **PhaseID**: <Integer> The parent Phase's ID;
- **Name**: <String> The name of the user class associated with this Traffic Demand;
- **Start_Date**: <String> The days on which site access is to be allowed for this Traffic Demand (i.e. the Site Access Policy) – see Table 4;
- **End_Date**: <String> The times of day at which site access is to be allowed for this Traffic Demand – see Table 4;
- **Direction**: <String> The string 'In' denotes that the Traffic Demand is one inbound to the site, whilst 'Out' denotes a Demand that is outbound from the site;
- **Origin**: <String> This string denotes the loading level, as defined in the <pollutant>_base_table.csv files, to be applied in emissions calculations. NB: In the current versions of the UHTIM applications this string isn't used, so this string should be set to 'All' – loaded versus unloaded emissions should be handled by defining separate user classes for inbound and outbound values, if required.
- **E_or_D, N_or_V, Description**: <Strings> All should be set to 'NA';

e.g.:

```
Profile,1,1,1,LGV,WDay,Interpeak,In,All,NA,NA,NA
```

Table 4: Traffic Access Policies: Allowable Strings for Days and Times

String	Description
AMPeak	*From 07:00 to 10:00 inclusive*
PMPeak	*From 16:00 to 19:00 inclusive*
InterPeak	*From 10:00 to 16:00 inclusive*
Interpeak	*As above.*
BothPeaks	*Same as 'AMPeak+PMPeak'*
DualPeaks	*As above.*
12hDay	*From 06:00 to 18:00 inclusive*
12hNight	*From 18:00 to 06:00 inclusive*
LDay	*From 07:00 to 19:00 inclusive (based on the European Noise Directive's (END) definition of a day)*
LEve	*From 19:00 to 23:00 inclusive (based on the END's definition of an evening)*
LNig	*From 23:00 to 07:00 inclusive (based on the END's definition of the overnight period)*
18hDay	*From 06:00 to 00:00 inclusive (based on the UK's definition of a day in 'Calculation of Road Traffic Noise')*
6hNig	*From 00:00 to 06:00 inclusive (based on the UK's definition of a night in 'Calculation of Road Traffic Noise'*
0h … 23h	*Individual hours may be entered if required, e.g. '6h' = 06:00 to 07:00 inclusive*
24h	*All hours*
Sun … Sat	*Individual days may be entered using the first three letters of the day 'e.g. Wed = Wednesday)*
WDay	*Same as 'Mon+Tue+Wed+Thu+Fri'*
WEnd	*Same as 'Sat+Sun'*
MonToThu	*Same as 'Mon+Tue+Wed+Thu'*
Mon_Thu	*Save as above*
Week	*All days*

NB: The strings used to define the site access policy can be composited together using the '+' symbol, e.g. the string '3h+6h+10h' would yield access times of 3-4am, 6-7am and 10-11am; the string 'Wed+Fri' would give access days of Wednesday and Friday, etc.

For 'Traffic' lines:

- **Item**: <String> 'Traffic';
- **SiteID**: <Integer> The parent Site's ID;
- **ProcessID**: <Integer> The parent Process' ID;
- **PhaseID**: <Integer> The parent Phase's ID;
- **Name**: <String> The name of the user class associated with this Traffic Demand;
- **Start_Date, End_Date**: <String> The start and end date for the period associated with this Traffic Demand. The period should nest within the parent Phase's period. Dates and times should be provided in 'YYYY-MM-DD HH:MM' format;
- **Direction**: <String> As per the 'Profile' entry, this string should indicate direction of traffic 'In' to or 'Out' of the site. It should match the direction defined in the associated 'Profile' line;
- **Origin**: As per the 'Profile' entry, this string should define the vehicle loading level, but currently should just be set to 'All';
- **E_or_D, N_or_V, Description**: <Strings> This should be set to 'NA';

e.g.:

```
Traffic,1,1,1,LGV,2018-01-01 00:00,2018-01-05
23:59,In,All,NA,NA,NA
```

For 'OD' and 'Link' lines:

- **Item**: <String> 'OD' or 'Link';

- **SiteID**: <Integer> The parent Site's ID;
- **ProcessID**: <Integer> The parent Process' ID;
- **PhaseID**: <Integer> The parent Phase's ID;
- **Name**: <String> The name of the user class associated with this Traffic Demand;
- **Start_Date, End_Date**: <String> The start and end date for the period associated with this Traffic Demand. The period should nest within the parent Phase's period, and be the same as that defined in the associated 'Traffic' line. Dates and times should be provided in 'YYYY-MM-DD HH:MM' format;
- **Direction**: <String> As per the 'Profile' entry, this string should indicate direction of traffic 'In' to or 'Out' of the site. It should match the direction in the associated 'Traffic' and 'Profile' lines;
- **Origin**: <Integer> The Origin node ID for 'OD', the link 'A' node ID for 'Link';
- **E_or_D**: <Integer> The Destination node ID for 'OD', the link 'B' node ID for 'Link';
- **N_or_V**: <Integer> The demand volume in Vehicles – this should be the number of vehicles expected across the entire period from 'Start_Date' to 'End_Date';
- **Description**: <Strings> All should be set to 'NA';

e.g.:

```
OD,1,1,1,LGV,2018-01-01 00:00,2018-01-05
23:59,In,500,501,200,NA

Link,1,1,1,LGV,2018-01-01 00:00,2018-01-05 23:59,In,1,2,550,NA
```

The first line sets the Traffic Demand to use a shortest-path route assignment between nodes 500 and 501, with a total of 200 vehicles arriving at site over the 1st to the 5th of January 2018. The second explicitly sets the demand on link 1_2 to 550 vehicles over the same period.

Supposing a Site Access Policy had been set in the corresponding 'Profile' line of 'Mon_Thu' and 'AMPeak' this would lead to 16.67 veh/h being applied to the network in the first instance above, in those hours where the profile was active (Mon_Thu = 4 days, AMPeak = 3 hours, Total = 12 hours over the week, 200veh/12hours = 16.67 veh/h).

Consideration should also be given to the start and end dates. In the example above 1st Jan 2018 was a Monday, and the 5th a Friday, so the access policy allowed access across the week in full. If the dates had been set to 3rd Jan to 5th Jan, then all traffic would be 'compressed' into the Wednesday and Thursday of the week (at a rate of 33veh/h from 06:00 to 10:00 on both days). If, say, the 5th of Jan was specified as both the start and end date, there are two issues: 1) The traffic must be compressed into a single day (at a rate of 66.67veh/h from 06:00 to 10:00), and 2) As the 5th is a Friday, it *should* be excluded due to the access policy, but then that would mean no vehicles could arrive in the site – the access policy is therefore ignored in favour of the vehicles actually reaching the site.

4.2.12 Site_Duplications.csv:

The 'Site_Duplications.csv' file has a header line in the following format:

```
Action,Old_Site,New_Site,Name_Root,Start_Time,New_Node,Old_Ori
g_ID,Old_Dest_ID,New_Orig_ID,New_Dest_ID
```

The precise details required for data lines depends on the type of duplication action needed. Supported actions are:

- ***Duplicate*** – this action duplicates an entire site, including all Processes, Phases and Traffic demands, and allows movement of the new site both spatially and temporally;
- ***Dup_Process*** – this action duplicates a process (and associated Phases and Traffic Demands) at an already existing site, allowing movement of the new process temporally;
- ***PTS_Change*** – this action allows start and end node changes to be made to the OD pairs an existing traffic demand, e.g. if a site is duplicated, then linked to another node in the network, the origin and destination nodes possibly (probably) need to be updated for all of the new Site's Traffic Demands.

A 'Duplicate' data line has the following structure:

- **Action**: <String> 'Duplicate';
- **Old_Site**: <Integer> The numeric ID of the site to be duplicated;
- **New_Site**: <Integer> The numeric ID to be given to the new site;
- **Name_Root**: <String> A partial name to be given to the new site. The full name will be '<Name_Root>_<New_Site>', e.g. if 'Name_Root' is 'Wellpad' and the 'New_Site' ID is '53', then the full name of the new site will be 'WellPad_53';
- **Start_Time**: <String> The date and time at which the new site is to become active, in 'YYYY_MM_DD HH:MM' format. The overall time period for the site should still fit within that defined in the 'Simulation_settings.csv' file for the scenario;
- **New_Node**: <Integer> The ID of the node to be associated with the site. The site will be given the same Cartesian coordinates as the node;
- **Old_Orig_ID, Old_Dest_ID, New_Orig_ID, New_Dest_ID**: <Strings> All of these parameters are not used, and should be set to 'NA'.

e.g: The line:

```
Duplicate,1,2,Wellpad,2019-03-01 00:00,501,NA,NA,NA,NA
```

Would create a new site 'Wellpad_2', whose activities start on the 1st of March 2019, based on the existing site with ID 1. The new site will be attached to the network at Node '501', so unless Site 1 was also attached to Node 501, there would probably need to be a couple of subsequent 'PTS_Change' actions required to update Traffic Demand origins and destinations.

A 'Dup_Process' data line has the following structure:

- **Action**: <String> 'Dup_Process';
- **Old_Site**: <Integer> The numeric ID of the site for which a process is being duplicated;
- **New_Site**: <String> This is not used, and should be set to 'NA';
- **Name_Root**: <String> This is not used. And should be set to 'NA';
- **Start_Time**: <String> The date and time at which the new process is to become active, in 'YYYY_MM_DD HH:MM' format. The overall time period subsequently defined should still fit into the start and end dates of the parent site;
- **New_Node**: <String> This is not used, and should be set to 'NA';
- **Old_Orig_ID**: <Integer> This should be the numeric identifier of the Process to be duplicated;
- **Old_Dest_ID**: <String> This is not used, and should be set to 'NA';
- **New_Orig_ID**: <Integer> This should be the numeric identifier to be assigned to the new process;
- **New_Dest_ID**: <String> This is not used, and should be set to 'NA';

e.g. The line:

```
Dup_Process,2,NA,NA,2019-03-01 00:00,NA,1,NA,5,NA
```

Would create a new Process with ID '5' at Site '2', based on the existing process '1'. The new process would start on the 1st of March 2019, and have the same duration as process '1'.

A 'PTS_Change' data line has the following structure:

- **Action**: <String> 'PTS_Change';
- **Old_Site**: <String> This is not used, and should be set to 'NA';
- **New_Site**: <Integer> The numeric ID of the site for which Traffic Demand Origins or Destinations need to be changed;
- **Name_Root**: <String> This is not used. And should be set to 'NA';
- **Start_Time**: <String> This is not used, and should be set to 'NA';
- **New_Node**: <String> This is not used, and should be set to 'NA';
- **Old_Orig_ID**: <Integer> This should be the numeric identifier of the 'A' (Origin) node to be changed;
- **Old_Dest_ID**: <Integer> This should be the numeric identifier of the 'B' (Destination) node to be changed;
- **New_Orig_ID**: <Integer> This should be the new numeric identifier to be applied to the 'A' nodes;
- **New_Dest_ID**: <Strings> This should be the new numeric identifier to be applied to the 'B' nodes;

e.g.: The line

```
PTS_Change,NA,2,NA,NA,NA,500,502,501,503
```

Would set all Traffic Demands at Site 2, that start at Node 500, and end at Node 502, to start at Node 501 and end at Node 503. Given that inbound and outbound values are handled as separate movements, a line specifying the alternate direction would also be needed, i.e.:

```
PTS_Change,NA,2,NA,NA,NA,502,500,503,501
```

Note that, at present, Traffic Demands using defined routes on given links, rather than using assignment via OD matrices cannot be altered in this way.

When an object is shifted temporally, the durations of associated elements (Processes, Phases, Demands etc.) are not altered, just the start and end dates and times shifted. One may need to be careful when providing different start dates, as it is possible to generate invalid or undesirable time periods in certain instances, when site access policies associated with Traffic Demands are considered. For example, if a site has a policy of only allowing a particular Traffic Demand on Weekdays, but the effect of a temporal shift would move the Demand to a weekend, then a warning will be generated by 'M4RegTraffGen.exe' when the scenario is run (the traffic demand will be applied at the weekend though).

If no duplication of Sites or Processes or no changes to Site Traffic Demands are required (i.e. all data needed for the scenario is contained in the 'Region.csv' file, then no additional data lines need to be added after the header. However, the file still needs to be present in the '<project>\BaseInputs' directory.

4.2.13 ADMS_settings.csv:

The 'ADMS_settings.csv' file has a header line, followed by a list of parameters and their values.

The header line is simply:

```
Parameter,Value
```

Currently recognised parameters are:

- **Use_Vehicles**: <Boolean> This parameter refers to whether outputs should be written so as to allow ADMS to calculate emissions for itself, based on link-based traffic values. The only valid value at the current time is 'false', given that UHTIM's purpose is to calculate emissions for itself.
- **Road_Width**: <Float> The default value of road width in metres, that is to be written for ADMS canyon model inputs. The default value is 10 metres, though conceivably a future version of UHTIM could write a width as provided by the road type or COBA curves, for example;
- **Canyon_Height**: <Float> The default height value of buildings surrounding the road for the ADMS canyon model. By default this is set to 0 (i.e. open roads outside canyons);
- **Buffer_Zone**: <Float> The additional size of buffer that will be applied to network bounds when calculating suggested output grid sizes for ADMS (e.g. a value of 200 applied to a network with coordinate bounds of lower-left (0,0), upper-right (1000,1000), will result in a suggested grid based on coordinates (-200,-200) to (1200,1200);
- **Desired_Grid**: <Float> The size of x-y grid in metres, as required for ADMS outputs. e.g. if a 100m grid is specified on the above (-200,-200) to (1200,1200) grid then UHTIM will return a suggested number of grid points of '7' for both dimensions;
- **Start_Hour**: <Integer> This value defines the starting hour for writing sequential data into ADMS .hfc files. It should be set to '0' if the version of ADMS in question assumes hours in the .hfc file run from '0' to '23', and '1' if ADMS expects '1' to '24';
- **EIT_Version_Header**: <String> Header line to be written to .eit outputs. This may change with future versions of ADMS, but is currently set to "EITVersion1" for ADMS-Urban 4.1;
- **GPT_Version_Header**: <String> Header line to be written to .fpt outputs. This may change with future versions of ADMS, but is currently set to "GPTVersion1" for ADMS-Urban 4.1;
- **SPT_Version_Header**: <String> Header line to be written to .spt outputs. This may change with future versions of ADMS, but is currently set to "SPTVersion1" for ADMS-Urban 4.1;
- **TFT_Version_Header**: <String> Header line to be written to .tft outputs. This may change with future versions of ADMS, but is currently set to "TFTVersion1" for ADMS-Urban 4.1;
- **VGT_Version_Header**: <String> Header line to be written to .vgt outputs. This may change with future versions of ADMS, but is currently set to "VGTVersion2" for ADMS-Urban 4.1;

NB: If Future versions of ADMS change the structure of output files, then updates will be needed to 'M4RegPostProc.exe' to account for any changes.

- **Emissions_Dataset**: <String> This is the traffic dataset name used to describe emissions in the .spt outputs. It is currently set to "Traffic dataset name | EFT v6.0.1 (2 VC)" as a string recognisable by ADMS when importing data from the .spt file, though it is actually irrelevant, given that traffic values are not being used in emissions calculations.
- **Road_Type**: <String> As with 'Emissions_Dataset' above, this value is used by ADMS when emissions are being calculated from traffic values, and is therefore not relevant for UHTIM. A default value of "England (rural)" is recognisable by ADMS when importing .spt files.
- **Emitter_Type**: <String> This is the emitter type in ADMS. A default value of "Road" is used when importing .spt files.

The remaining parameters in the 'ADMS_settings.csv' file set the mapping between whatever a particular pollutant is called within ADMS, and the pollutants defined in the UHTIM '<pollutant>_base_table.csv' files. If no UHTIM base table has been defined for a particular pollutant then the 'NA' string should be used. The following list is based on the default pollutant pallet in ADMS Urban 4.1. The 'Parameter' field is the ADMS name, the 'Value' field the UHTIM name.

- **NO2**: <String> NA
- **NOx**: <String> NOx
- **VOC**: <String> HC
- **O3**: <String> NA
- **SO2**: <String> NA
- **PM2.5**: <String> PM2.5
- **PM10**: <String> PM10
- **CO**: <String> NA
- **BENZENE**: <String> NA
- **BUTADIENE**: <String> NA
- **TSP**: <String> NA

4.2.14 Pollutant_units_hourly.csv:

The 'Pollutant_units_hourly.csv' file has the following header line:

```
Pollutant,Units,ScaleFactor,Precision,UseSciFormat
```

Each subsequent data line should contain:

- **Pollutant**: <String> The name (abbreviated name) of a pollutant being used by the scenario (i.e. one of the pollutants defined by a '<Pollutant>_base_table.csv' file (e.g. NOx, PM10 etc.);
- **Units**: <String> The output units for this pollutant (e.g. 'g', 'kg', 't' etc.);
- **ScaleFactor**: <Float> The scaling factor to be applied to hourly outputs. As mass based emissions are initially calculated in grams, a scaling factor of '0.001' yields kilograms, and '0.000001' yields tonnes;
- **Precision**: <Integer> The number of decimal places outputs shall be written to;
- **UseSciFormat**: <Boolean> Sets whether outputs should be written in decimal format (e.g. 1.234) or scientific format (e.g. 1.234E+00).

Whilst 'ESAL' and 'SPwLA' aren't mass-based emissions, they still need a data line entry in the file, if they are being used in a scenario, with the 'ScaleFactor' parameter set to 1.0.

4.2.15 Pollutant_units_summary.csv:

The 'Pollutant_units_summary.csv' file has exactly the same format as the 'Pollutant_units_hourly.csv' file. The same caveat regarding 'ESAL' and 'SPwLA' applies.

4.2.16 Pollutant_units_ADMS.csv:

The 'Pollutant_units_ADMS.csv' file has the same format as the 'Pollutants_units_hourly.csv' file. However, the 'Pollutant' string in each data line should reflect one of ADMS' palette of pollutants (see 'ADMS_settings.csv' for default names). The 'ScaleFactor' value should be set to '2.7778e-7' to correctly convert from 'g' to 'g/km/s'. A high number of decimal places (e.g. 5+) and use of scientific format is recommended to allow accurate import of emissions to ADMS.

'ESAL' and 'SPwLA' are not ADMS pollutants, and are ignored.

4.2.17 <Matrix>.csv:

A '<Matrix>.csv file defines traffic values between OD-pairs, or on specific links. It can be used to define both incomplete (some links missing) and complete network states (all link values defined), as well as complete or sparse OD matrices.

The file has the following header line:

```
Param1,Value1,Value2
```

This is then followed by a default header block:

```
ID1,1,NA
ID2,0,NA
Key,UNDEFINED!,NA
Units,veh,NA
```

The temporal coverage of the matrix is then defined in two lines, with the date and time for start and end points set in the 'Value1' field, 'Value2' should be set to 'NA' e.g.:

```
Start,2018-01-01 00:00,NA
End,2018-12-31 23:59,NA
```

Next the PCU value is set in 'Value1'. As the UHTIM applications expect all traffic inputs to be in vehicles, this line should look as follows:

```
PCU_Value,1,NA
```

Finally, all subsequent data lines should contain 'A_Node' (Param1) and 'B_Node' (Value1) identifiers, followed by the flow value (Value2), e.g. the following example defines four values from Node '500' to nodes '501', '502', '503' and '505':

```
500,501,300
500,502,300
500,503,300
500,505,100
```

If both the 'A' and 'B' node are centroids (i.e. both virtual), then the line refers to the flow along a route between OD matrix elements. If the 'A' and 'B' nodes are junctions or connections (i.e. both physical), then the line refers to an actual flow on a link. It is not valid to mix 'virtual' and 'physical' node IDs on a data line, nor to mix OD and link flow elements within the file.

4.3 Alternate File Formats:

As well as allowing input from .csv files, depending on command line parameters or input file settings, certain other types of file may be used as inputs to (or outputs from – see 'Outputs' section) UHTIM applications. These are:

- **Binary files**: Non-human readable files containing bytes of 'raw' data in a structured format – NB: Binary files are not yet used by the UHTIM applications, but the intention is to enable their use to speed up input and output in key areas – such as writing outputs from 'M4RegPollProc', which currently uses numerous small 'Json' files;
- **Json files**: Human readable files containing bespoke data, formatted in a structured way. These files may be used as inputs for Traffic Demands, and may describe partial or complete

network states. Json files are also used as outputs from the various applications, which are to be read by another application in the modelling chain: e.g. hourly flow or pollution outputs from the 'M4BaseTraffGen', 'M4RegTraffGen' and 'M4RegPollProc' applications, or the timetable produced by 'M4RegTImeGen' are all .json files;

- **Shape files**: Network links and nodes may be loaded from ESRI Shape files. These 'files' actually consist of a number of component files (e.g. .shp, .dbf, .shx, .prj files), sharing a common 'root' name. At a bare minimum a '.shp' geometry file, a '.dbf' database file and a '.shx' index file are required. None are human readable. 'M4RegPostProc' may also produce shapefiles as part of its outputs.

Json and Shape files are discussed further below:

4.3.1 JSON Files:

Only two type of JSON file are described here – the 'TrafficState' and 'PartialTrafficState' files that can be used to describe either link-based values for a complete network, or values on a series of links or an OD matrix, respectively. The 'values' themselves are usually traffic values when considered as inputs, but UHTIM applications also can write speed and pollutant information in the same format.

Individual UHTIM applications may write input/output .json files in a number of other formats. These files are described in the relevant 'Outputs' sections.

4.3.1.1 'TrafficState.json' files

A traffic state json file should contain the following elements:

- **Type:** <String> "TrafficState";
- **ID1:** <Integer> The first part of the traffic state's ID. This could be a day code (see Table 2) when the file is being used for user defined input. Alternately, for outputs, UHTIM applications use unique values that have specific meanings (e.g. 3000000 is a network traffic flow state, 3000001 is a network speed state, 3000003 is a pollution state, 3000002 is an internal calculation result). In this instance the day code usually forms part of the filename;
- **ID2:** <Integer> The second part of the traffic state's ID. This is the hour code (0 … 23) when the file is being used as input. Alternately, for UHTIM outputs, a repeat of the 'ID1' value is used;
- **Key:** <String> String identifier for the information contained in the traffic state. When used as input, the string isn't strictly necessary, but should act as an aide memoire as to what the file contains. For outputs, however, UHTIM applications will set the key value to 'Current_Values', 'Current_Speeds' or a pollutant name;
- **Units:** <String> String identifier for the units of the values in the file (e.g. 'veh', 'km/h', 'g', 'kg', 't', 'dBA', 'axles' etc.;
- **Start:** <String> The starting time and date of the data in the file, in 'YYYY-MM-DD HH:MM' format;
- **End:** <Sting> The end time and date of the data in the file.

NB: For files that refer to data without a specific period, or that can refer to multiple periods and are ambiguous, then the default values of "2000-01-01 00:00" and "2000-12-31 23:59" are used.

- **Mask:** <String> This is a string representation of a 128-bit integer that is used internally by UHTIM applications to index periods. For input it should be set to '0';
- **Base_Year:** <Integer> For input traffic data this should be the year in which the traffic data is relevant. For outputs, UHTIM applications use a default value of '2000' in outputs.

- **Default_Op:** <Integer> This is a mathematical operation ID, as defined in table 3. Usually the value of '1' for addition is used;
- **Precision:** <Integer> The number of decimal places to which values are stored;
- **UseSci:** <Boolean> Sets whether values are in normal ('false') or scientific ('true') format;
- **Fleet_Count:** <Integer> The number of user classes. For traffic flow input this should be '1'. For outputs, the file may refer to a single user class, or all user classes in the model;
- Fleets: <String Array> An array of the names of the user classes. For inputs this is irrelevant as the values in the state are assumed to be just numbers of 'generic' vehicles. For outputs fleets are ordered alphabetically;
- **PCU_Count:** <integer> The number of values of PCU conversion factors – this should always be the same as the fleet count;
- **PCU_Values:** <Float Array> An array of values used to convert the link-based values from raw flow values to PCU values. The array should have the same order as the fleets. For input, and speed or pollutant outputs, the array values should all be '1.0'. For output values, the values will be those calculated by 'M4FleetPollProc' when averaging fleet data;
- **Link_Count:** <Integer> The number of links in the network;
- Links: <String Array> An array containing the link names (i.e. A_B node IDs), sorted in order of A node, then B node;
- **Data_Count:** <Integer> The number of link-based values to following in the 'Data' array. This should equal 'number of links x number of user classes';
- **Data:** <Float Array> The link-based values. Values are ordered by link, then by user_class (e.g. for a 2 link array (IDs: 1_2, 2_1) of four fleets (Base,HGV1,HGV2,LGV), where both links carry 1000 base vehicles, 100 LGVs, 50 HGV1s and 25 HGV2s, the json-formatted data array would be:

```
["1000,50,25,100,1000,50,25,100"]
```

Figure 9 gives a sample traffic state file as an example, based on flow output from a baseline traffic assignment run using four user classes and 18 links. NB: As this is a baseline result, may flow values are zero, as only the 'Base' user class has been assigned.

```
{
  "Type": "TrafficState",
  "ID1": 3000000,
  "ID2": 3000000,
  "Key": "Current_Values",
  "Units": "veh",
  "Start": "2000-01-01 00:00:00",
  "End": "2000-12-31 23:59:59",
  "Mask": "151115727451822204387327",
  "Base_Year": 2000,
  "Default_Op": 1,
  "Precision": 4,
  "UseSci": false,
  "Fleet_Count": 4,
  "Fleets": [
    "Base,HGV1,HGV2,LGV"
  ],
  "PCU_Count": 4,
  "PCU_Values": [
    "1.0802,1.8900,2.5000,1.1000"
  ],
  "Link_Count": 18,
  "Links": [
    "1_2,1_3,1_4,1_500,2_1,2_3,2_502,3_1,3_2,",
    "3_4,3_501,4_1,4_3,4_503,500_1,501_3,502_2,503_4"
  ],
  "Data_Count": 72,
  "Data": [
    "94.7177,0.0000,0.0000,0.0000,14.4179,0.0000,0.0000,0.0000,160.5996,",
    "0.0000,0.0000,0.0000,240.8994,0.0000,0.0000,0.0000,94.7177,0.0000,",
    "0.0000,0.0000,146.1816,0.0000,0.0000,0.0000,240.8994,0.0000,0.0000,",
    "0.0000,14.4179,0.0000,0.0000,0.0000,146.1816,0.0000,0.0000,0.0000,",
    "212.0635,0.0000,0.0000,0.0000,240.8994,0.0000,0.0000,0.0000,160.5996,",
    "0.0000,0.0000,0.0000,212.0635,0.0000,0.0000,0.0000,240.8994,0.0000,",
    "0.0000,0.0000,240.8994,0.0000,0.0000,0.0000,240.8994,0.0000,0.0000,",
    "0.0000,240.8994,0.0000,0.0000,0.0000,240.8994,0.0000,0.0000,0.0000"
  ]
}
```


Figure 9: Sample traffic state json file.

4.3.1.2 'PartialTrafficState.json' files

Partial Traffic State files are almost identical to full traffic state files, except:

- They are not used as outputs from UHTIM applications;
- The '**Type**' field should be set to the string 'PartialTrafficState';
- A partial traffic state does not have a 'Fleet_Count' or 'Fleets' defined, rather the '**Key**' string should be set to the name of the user class being referred to. Again, this might not need to be an actual fleet name if the file is just being used to represent generic values (e.g. the same PTS file is being used to generate LGV and HGV values on links, using different scalings);
- A Partial Traffic State has a '**Flow_Mode**' <Integer> entry to denote
- A Partial Traffic State has a single '**PCU_Value**' <Float> entry;
- The '**Data_Count**' values should be the number of subsequent link-based value entries in the partial traffic state;
- The '**Data**' values should be structured as an array of triplet elements formatted as 'A_ID <Integer>,B_ID <Integer>,Value <Float>.

Figure 10 gives an example of a 'Partial Traffic State' file, defining an OD matrix of a single OD pair (500_501) with a flow of 1000 vehicles of user class 'UC1' between those nodes.

```
{
  "Type": "PartialTrafficState",
  "ID1": 1,
  "ID2": 0,
  "Key": "UC1",
  "Start": "2017-01-01 00:00:00",
  "End": "2017-12-31 23:59:00",
  "Mask": "9903595872146768107073961983",
  "Base_Year": 2017,
  "Default_Op": 1,
  "Flow_Mode": 1,
  "PCU_Value": 1.05,
  "Precision": 4,
  "UseSci": false,
  "Data_Count": 1,
  "Data_Values": [
      "500,501,1000.0000"
  ]
}
```

Figure 10: Sample 'Partial Traffic State' file.

4.3.2 Shape Files:

For a shape file to be read as input as a substitute for the 'Nodes.csv' file, the following fields must be defined in the .dbf file:

- **A_Node**: <Integer> The ID of the Node;
- **Name**: <String> The node's name;
- **Type**: <String> The node type – see 'Nodes.csv'.

The X and Y coordinates of the node will be read from the '.shp' file.

For links, the .dbf file must contain the fields:

- **A_Node**: <Integer> Start node ID for the Link;
- **B_Node**: <Integer> End node ID;
- **Name**: <String> Name of the link;
- **Type**: <String> The link type string – see 'Links.csv';
- **Cost_Cur**: <String> The link's cost curve string - see 'Links.csv';
- **Pol_Type**: <String> The link's pollution type string – see 'Links.csv';
- **Gradient**: <String> The link's gradient string – see 'Links.csv'.

5. Outputs:

In this section the outputs from each of the UHTIM applications is described. As mentioned in the 'Component Applications' section, each application outputs data into specific sub-directories. These data are then used as inputs to subsequent applications.

5.1 M4InitialiseProject.exe:

The outputs from 'M4InitialiseProject' should be:

- The creation of the '<project> directory, based on the specified path and project name, if not already present;
- The creation of (or potentially, the removal of all files from) the following sub-directories:
  - '<project>\BaseData'
  - '<project>\BaseInputs'
  - '<project>\BaselineADMS'
  - '<project>\BaselinePollution'
  - '<project>\BaseLineTraffic'

- o `'<project>\BaseWeek'`
  - o `'<project>\FleetPolTables'`
  - o `'<project>\SiteActiveADMS'`
  - o `'<project>\SiteActivePollution'`
  - o `'<project>\SiteActiveTraffic'`
  - o `'<project>\Summary'`
  - o `'<project>\Timetable'`
- A copy of the 'Vehicles_Base_Table.csv', 'Fleets_Base_Table.csv' and '<pollutants>_Base_Table.csv' made from those files provided with the installation.

5.2 M4FleetPollProc.exe:

The outputs from 'M4FleetPollProc.exe' should be the fleet-weighted emissions tables for each user class required by the scenario. This will be placed into the '<project>\FleetPolTables' directory.

Each pollutant will have its own fleet-weighted emissions file, called '<pollutant>_processed_fleets.json'.

Each .json file should contain:

- **Object_Count** : <Integer> The number of emissions tables (i.e. user classes) in the file;
- **Objects** : <Object_Array> The emission tables themselves;

Each emissions table has the following properties:

- **Type** : <String> "PollutantTable";
- **ID1** : <Integer> Sequential ID of the emissions table in the file;
- **ID2** : <Integer> Secondary ID, set to '0';
- **Key** : <String> The name of the user class;
- **Pollutant** : <String> The name of the pollutant';
- **Units** : <String> The units of emission;
- **Start_Year** : <Integer> The starting year of the emission table;
- **End_Year** : <Integer> The end year of the emissions table;
- **Min_Speed** : <Integer> The initial speed in the table, in km/h (default value is 5km/h);
- **Max_Speed** : <Integer> The final speed in the table, in km/h (default value is 140 km/h);
- **Speed_Step** : <Integer> The speed step size between successive entries in the table, in km/h (default value is 5km/h);
- **Speed_Bins** : <Integer> The number of values in each row of the table (i.e. ((Max_Speed – Min_Speed) / Speed_Step) + 1) (default is '28');
- **Precision** : <Integer> The number of decimal places to which values are stored (default is '4');
- **UseSci** : <Boolean> Sets whether values are stored in numeric 'false' or scientific 'true' format' (default is 'false');
- **Vehicle_Count** : <Integer> The number of vehicles/user classes in the table – set to '1';
- **Vehicles** : <String> The names of the vehicles/user classes in the table – this is set to the same as the 'Key' value;
- **Road_Type_Count** : <Integer> The number of road types in the table – this should be the same as the number of road types in the '<pollutant>_Base_Table.csv' files;
- **Road_Types** : <String Array> The array of road types names;
- **Loading_Count** : <Integer> The number of loading types in the table – this should be the same as the number of loadings in the '<pollutant>_Base_Table.csv' files;

- **Loadings** : <String Array> The names of the loading states;
- **Gradient_Count** : <Integer> The number of gradient bands in the table – this should be the same as the number of gradients in the '<pollutant>_Base_Table.csv' files;
- **Gradients** : <String Array> The names of the loading states;
- **Data_Count** : <Integer> The overall number of data points in the table. This should be the same as: Number of Years * Road_Types * Vehicle_Count * Loading_Count * Gradient_Count * Speed_Bins. The default value, based on the year range 2008 to 2050, is '1204' (43 x 1 x 1 x 1 x 1 x 28 = 1204);
- **Data** : <Float Array> The emissions factor entries, ordered by Year, Road_Type, Vehicle_Count, Loading, Gradient, then speed.

5.3 M4RegTimeGen.exe:

The primary output from 'M4RegTimeGen.exe' is a contiguous, sorted-and-ordered-by-date-and-time, list of 'events' for activities in the region. This list is written as a .json file to '<project>\TimeTable\Timetable.json'.

The .json file is not meant to be editable by the user, but for reference, contains the following information:

- **Type** : <String> "SimulationEventManager"
- **Create_Mask** : <Integer> Represents internal options flags that are used when creating and outputting the timetable. Currently this should only ever be set to a value of '900'

  NB: Different flag values control, for example, whether event ends, or non-traffic related activities need to be output. Possible (hexadecimal) flag values are:

  - **0x1 : BASE_PRELOAD** – Write activities that require a new baseline traffic state to be generated via a specified preload assignment, to the timetable. (Not used);
  - **0x2 : BASE_ODMATRIX** – Write activities that require a new baseline traffic state to be generated via non-preload assignment, to the timetable. (Not used);
  - **0x4 : BASE_STATE** - Write activities that require a new baseline traffic state to be read from the '<Project>\BaseWeek' directory, to the timetable;
  - **0x8 : BASE_PARTIAL** – Write activities that require a partial state update (i.e. only affecting specified routes), read from the '<Project>\BaseWeek' directory, to the time table. (Not Used);
  - **0x10** : **SITES** – Write site start activities to the timetable. (Not used);
  - **0x20** : **PROCESSES** – Write process start activities to the timetable. (Not used);
  - **0x40** : **PHASES** – Write phase start activities to the timetable. (Not used);
  - **0x80 : PHASE_ODMATRIX** – Write traffic demand activities that require any network traffic assignment, to the timetable;
  - **0x100 : PHASE_PARTIAL** – Write traffic demand activities that require a partial traffic state (i.e. affecting specified routes), to the timetable;
  - **0x200 : POINT_EVENTS** – Write events that require a traffic scaling check to be performed (e.g. monthly or annual scaling), to the timetable.

  The default, decimal value of '900' represents the OR-ing together of the BASE_STATE, PHASE_ODMATRIX, PHASE_PARTIAL and POINT_EVENT flags (hexadecimal 0x384 = decimal 900).

- **Use_Files** : <Boolean> Sets whether individual event records should be stored in memory by UHTIM applications, or are to be read from disk when needed. Currently this should only ever be set to 'false';
- **Object_Count** : <Integer> The number of events in the subsequent event array;
- **Objects** : <Object Array> The events themselves;

An 'event' is defined to be a period of time and an associated list of active activities in that time period. A new event record is created every time some activity in the region starts or ends. Hence a particular activity may span multiple event periods, and be referenced in each, if there are shorter activities that occur simultaneously within the duration of the longer even. Depending on the options set in the 'Simulation_Settings.csv' file, regarding traffic scaling periods, event records may also be generated when there is a change in the month or year.

Each event has the following properties:

- **ID** : <Integer> The sequential ID of the event;
- **Start** : <String> The start date and time of the event in 'YYYY-MM-DD HH:MM:SS' format;
- **End** : <String> The end date and time of the event in 'YYYY-MM-DD HH:MM:SS' format;
- **Object_Count** : <Integer> The number of activities associated with the event;
- **Objects** : <Object Array> The events themselves.

Each activity within the event is described by:

- **Type** : <String> The type of activity. Possible values are given in Table 5:
- **TypeID** : <Integer> Numeric value representing the type. Possible values are listed in Table 5. The 'TypeID' value affects the order of processing of events by UHTIM applications – generally current activities that are ending get higher priority (i.e. lower 'TypeID') when processing than new activities that are just starting;
- **Key** : <String> This may be the user class to which the activity refers, or either 'UNDEFINED!' or 'MonthEventMarker' in the case of 'BaseStateStart' or 'MonthEventMarker' event types;
- **ID1** : <64-bit Integer> This value encodes the ID of the site, process, phase and traffic movement of the activity. The encoding is as follows:
  - **Bits 56-63 :** User Class ID (based on position of the user class name in an alphabetically-sorted array);
  - **Bits 48-55** : Direction ID (inbound '1' or outbound '2');
  - **Bits 32-47** : Site ID;
  - **Bits 16-31** : Process ID;
  - **Bits 0-15** : Phase ID.
- **ID2** : <64-bit Integer> This values encodes the start and end date and time of the activity (NB: The start and end times of the underlying activity may not be the same as the start and end times of the event). The encoding is as follows:
  - **Bits 32-63 :** End time and date, in seconds since the start of epoch (defined as: "2000-01-01 00:00:00");
  - **Bits 0-31:** Start time and date, in seconds since the start of epoch.

Table 5: Activity 'Types' and identifying 'TypeID' values

Event Type	Event ID	Event Type	Event ID
UNKNOWN!	0	NA	0
PhaseODMatrixEnd	1	FinalPeriodEndMarker	24
PhasePartialInboundEnd	2	SimulationEndMarker	23
PhasePartialOutboundEnd	3	PhaseODMatrixStart	22
PhaseEnd	4	PhasePartialInboundStart	21
ProcessEnd	5	PhasePartialOutboundStart	20
SiteEnd	6	PhaseStart	19
BasePreloadEnd	7	ProcessStart	18
BaseODMatrixEnd	8	SiteStart	17
BaseStateEnd	9	BasePreloadStart	16
BasePartialEnd	10	BaseODMatrixStart	15
YearEventMarker	11	BaseStateStart	14
MonthEventMarker	12	BasePartialStart	13

NB: Greyed 'end' activities are created automatically and used internally by the UHTIM software, but are not explicitly written to the 'Timetable.json' file by default, as their existence can be inferred from comparison of activities in consecutive events (i.e. if an activity exists in one event, but not in a subsequent event, it's end must have occurred at the boundary between those events) .

'M4RegTimeGen.exe' will also produce a 'Region.json' file in the '<project>\TimeTable' directory. This is done as a check that the 'Region.csv' file can be read and parsed correctly – but serves no further purpose.

5.4 M4BaseTrafficGen.exe:

'M4BaseTrafficGen.exe' produces the 'baseline' traffic flow patterns for the 'typical week'. Data is output to the '<project>\BaseWeek' directory, in the form of 'TrafficState' .json files, each containing a single user class (see Section 'TrafficState.json files').

There will be one file produced for every day type and hour in the typical week, as defined in the 'Weekly_traffic.csv' input file (see Section 'Weekly_traffic.csv'). Individual filenames are based on the following structure:

```
<Day Code>_<Hour>_<User Class>.json
```

Where:

- **Day Code** : <Integer> The Day Code value from Table 2;
- **Hour** : <Integer> Hour of day from 0 to 23;
- **User Class** : <String> Name of the user class to which the traffic state refers.

e.g.:

After a successful run with diurnal profiles specified for each day separately, and using four user classes ('Base', 'HGV1', 'HGV2', 'LGV') the output '<project>\BaseWeek' directory should contain 672 .json files (7 x 24 x 4 = 672) named as in Figure 11:

```
0_0_Base.json
0_0_HGV1.json
0_0_HGV2.json
0_0_LGV.json
0_1_Base.json
0_1_HGV1.json
0_1_HGV2.json
0_1_LGV.json

…
```

```
6_22_Base.json
6_22_HGV1.json
6_22_HGV2.json
6_22_LGV.json
6_23_Base.json
6_23_HGV1.json
6_23_HGV2.json
6_23_LGV.json
```

Figure 11: Example filenames for outputs from 'M4BaseTraffGen.exe'

5.5 M4RegTrafficGen.exe:

Like 'M4BaseTraffGen', 'M4RegTraffGen.exe' may produce a large number of traffic state .json files as output. Unlike 'M4BaseTraffGen', outputs from 'M4RegTraffGen' contain multiple user classes in a single file, and separate files are written as to whether they refer to flow or speed data. These files are further separated into sub-directories by whether they refer to 'Baseline' or 'Site Active' traffic, and in which timetabled event period they occur.

e.g.: Supposing a scenario has four events defined in its 'TimeTable.json' file:

1. Event 1 -> 2018-01-01 00:00 to 2018-01-04 23:59;
2. Event 2 -> 2018-01-05 00:00 to 2018-01-31 23:59;
3. Event 3 -> 2018-02-01 00:00 to 2018-02-04 23:59;
4. Event 4 -> 2018-02-05 00:00 to 2018-01-18 23:59.

The same timetable is used to structure the outputs for both 'Baseline' and 'SiteActive' traffic, in order to facilitate direct comparison between the two situations. The names of event period sub-directories are structured as follows:

```
Period_<ID>_<Start Date and Time>_<End Date and Time>
```

The start and end dates and times are formatted as strings in 'YYYYMMDDHHMMSS' format (note no separating characters between date and time elements). Based on the four event periods in the example, outputs from 'M4BaseTraffGen' will therefore be placed in the directories shown in Figure 12:

```
• <project>\BaselineTraffic
    o <project>\BaselineTraffic\Period_1_20180101000000_20180104235900
    o <project>\BaselineTraffic\Period_2_20180105000000_20180131235900
    o <project>\BaselineTraffic\Period_3_20180201000000_20180204235900
    o <project>\BaselineTraffic\Period_4_20180205000000_20180218235900
• <project>\SiteActiveTraffic
    o <project>\SiteActiveTraffic\Period_1_20180101000000_20180104235900
    o <project>\SiteActiveTraffic\Period_2_20180105000000_20180131235900
    o <project>\SiteActiveTraffic\Period_3_20180201000000_20180204235900
    o <project>\SiteActiveTraffic\Period_4_20180205000000_20180218235900
```

Figure 12: 'M4RegTraffGen.exe' output directory structure example

Individually each directory will contain a series of .json files, with names based on the following structure:

```
<Day Code>_<Hour>_<Type Code>.json
```

Where:

- **Day Code** : <Integer> The day of the week (0-6, as per the 'All' data line in Table 2);
- **Hour** : <Integer> The hour of the day (0-23);
- **Type Code** : <Character> 'F' is the file contains flow information, or 'S' for speed information.

The actual day codes used for filenames will reflect the days in the period – e.g. Period 1 in the above example will contain files with day codes: 1,2,3 and 4 – reflecting that the 1st of Jan 2018 was a Monday, and the 4th, a Thursday.

5.6 M4RegPollProc.exe:

Two sets of outputs are produced by 'M4RegPollProc.exe': hourly link-based pollutant emissions data and aggregate period summary data, based on the hourly data.

5.6.1 Hourly Outputs:

'M4RegPollProc.exe' produces hourly 'Baseline' and 'SiteActive' outputs, further broken-down by timetabled event periods, in a similar fashion to 'M4RegTraffGen'. There are, however, two key differences: 1) A further level of sub-directories is added to reflect the pollutant, and 2) A particular .json file contains the link-based outputs for that pollutant.

e.g. based on the four period, example above for 'M4RegTraffGen', assuming two pollutants 'NOx' and 'CO2', outputs will be written to the sub-directories shown in Figure 13.

Individual pollution results files within the directories will be named according to the following structure:

```
<Pollutant>_<Day Code>_<Hour>.json
```

Where:

- **Pollutant** : <String> The name of the pollutant;
- **Day Code** : <Integer> The day of the week (0-6, as per the 'All' data line in Table 2);
- **Hour** : <Integer> The hour of the day (0-23).

Pollutant emission values in the files are scaled by the relevant values defined in the 'Pollutant_units_hourly.csv' file.

- <project>\BaselinePollution
  - <projects>\BaselinePollution\CO2
    - <projects>\BaselinePollution\CO2\Period_1_20180101000000_20180104235900
    - <projects>\BaselinePollution\CO2\Period_2_20180105000000_20180131235900
    - <projects>\BaselinePollution\CO2\Period_3_20180201000000_20180204235900
    - <projects>\BaselinePollution\CO2\Period_4_20180205000000_20180218235900
  - <projects>\BaselinePollution\NOx
    - <projects>\BaselinePollution\NOx\Period_1_20180101000000_20180104235900
    - <projects>\BaselinePollution\NOx\Period_2_20180105000000_20180131235900
    - <projects>\BaselinePollution\NOx\Period_3_20180201000000_20180204235900
    - <projects>\BaselinePollution\NOx\Period_4_20180205000000_20180218235900
- <project>\SiteActivePollution
  - <projects>\SiteActivePollution\CO2
    - <projects>\SiteActivePollution\CO2\Period_1_20180101000000_20180104235900
    - <projects>\SiteActivePollution\CO2\Period_2_20180105000000_20180131235900
    - <projects>\SiteActivePollution\CO2\Period_3_20180201000000_20180204235900
    - <projects>\SiteActivePollution\CO2\Period_4_20180205000000_20180218235900
  - <projects>\SiteActivePollution\NOx
    - <projects>\SiteActivePollution\NOx\Period_1_20180101000000_20180104235900
    - <projects>\SiteActivePollution\NOx\Period_2_20180105000000_20180131235900
    - <projects>\SiteActivePollution\NOx\Period_3_20180201000000_20180204235900
    - <projects>\SiteActivePollution\NOx\Period_4_20180205000000_20180218235900

Figure 13: 'M4RegPollProc.exe' output directory structure example

5.6.2 Period Summary Data:

'M4RegPollProc.exe' summarises hourly pollutant data by calculating totals for each event period and writing these to file. Summaries for both 'Baseline' and 'Site Active' conditions are written into a single file 'summary.csv' in the '<project>\Summary' sub-directory.

The summary file consists of a single header line:

```
Pollutant,Scenario,Period,Fleet,Start,End,Hours,Value,Units
```

Followed by any number of data lines.

- **Pollutant** : <String> The name of the pollutant;
- **Scenario** : <String> Either 'Baseline' or 'SitesActive';
- **Period** : <Integer or String> The integer ID of the event period, or 'NA' for the overall total from all periods;
- **Fleet** : <String> The user class to which the line refers, or 'TOTAL' for the sum of data from all user classes within the period;
- **Start** : <String> The start of the event period in 'YYYY-MM-DD HH:MM' format';
- **End** : <String> > The end of the event period in 'YYYY-MM-DD HH:MM' format';
- **Hours** : <Integer> The total number of hours between the start and end times (useful for calculating rates);
- **Value** : <Float> The total emission of pollutant in the period (scaled using the value in the 'Pollutant_units_summary.csv' file);
- **Units** : <String> The units of emission (as defined in the 'Pollutant_units_summary.csv' file).

For example the lines:

```
CO2,Baseline,NA,TOTAL,2018-01-01 00:00,2018-12-31 23:59,8760,2547.24,tonnes
CO2,SitesActive,NA,TOTAL,2018-01-01 00:00,2018-12-31 23:59,8760,2557.32,tonnes
```

Reveal that over the full year 2018, activities at this Region's sites would be expected to increase CO_2 emissions by 10.08 tonnes (or approximately 0.4%).

5.7 M4RegPostProc.exe:

'M4RegPostProc.exe' can produce a large number and variety of outputs, depending on the command line settings (see section: 'Command Line Arguments'). Typically, the application is used to output files of a format that can then be used as input to the ADMS suite of applications.

5.7.1 ADMS Import Files:

ADMS can import data from a series of .csv-like files, using specific extensions:

- **.spt files** – main source properties. For UHTIM this means a list of the network road links as sources with defined canyon width and height pulled from the 'ADMS_settings.csv' file;
- **.vgt files** – vertex information, taken from the 'Links.csv' (or 'Links.shp') file;
- **.eit files** – pollutant emissions information for all sources. NB: 'M4RegPostProc' sets all link emissions values for every pollutant to be 1.0 g/km/s. This is because the .hfc file contains the actual emission rate for a given day/hour, and is used to scale emissions correctly within ADMS;
- **.tft files** – Pollution flow information. These files are left blank by 'M4RegPostProc' as emissions rates are being specified directly by the '.eit' and '.hfc' files;

- **.gpt files** – source group information. ‘M4RegPostProc’ assigns all network links to the ADMS source group ‘Road’;
- **.hfc files** – time-varying emissions factors. This is a more complex file than the other ADMS imports, and contains hourly emission scaling factors (actually the hourly emission rates themselves – scaled appropriately using values from the ‘Pollutant_units_ADMS.csv’ file) for named ‘link profiles’, followed by a list of mappings between individual links and link profiles. ‘M4RegPostProc’ assumes a 1-to-1 mapping between links and profiles.

‘M4RegPostProc’ produces one set of these files for each pollutant in the ‘Baseline’ and ‘Site Active’ cases, for each individual year covered by a scenario. If the ‘Use_Vehicles’ option is set ‘TRUE’ in the ‘ADMS_settings.csv’ file, then outputs will be further subdivided by user class. If this option is set to ‘FALSE’, outputs will be for all user classes combined, called ‘All’.

Note that, whilst ADMS can handle multiple pollutants in a single run, only one set of time-varying emission scalings from the ‘.hfc’ file can be applied to per-pollutant emission rates defined in the ‘.eit’ file, in a given run. As UHTIM, uses the .hfc file ***as the actual time-varying emission file and keeps emissions in the .eit file constant***, this necessitates individual ADMS runs for each pollutant. Hence, ‘M4RegPostProc’ produces ‘duplicate’ files for convenience, as all files in a particular subdirectory can be imported to ADMS in a single go using the ‘File -> Import’ option, then setting the correct ‘.hfc’ file on the ‘Sources’ tab.

For further information on the content and structure of the above files, please refer to the ADMS User Guide (e.g. ADMS-Urban User Guide Section 5: ‘Import and Export’). For information on how ADMS handles time-varying emissions may also be found in the user guide (e.g. ADMS-Urban User Guide Section 4.1: ‘Time-varying emissions’.

ADMS file outputs from ‘M4RegPostProc’ are handled in similar fashion to those from ‘M4RegTraffGen’ or ‘M4RegPollProc’, in that files are placed in sub-directories created within parent ‘Baseline’ and ‘SiteActive’ directories. Figure 14 provides the two pollutant example (CO2 and NOx), for the composite ‘All’ user class, for the year 2018.

Individual files within the sub-directories are named:

<User Class>_<Pollutant>_<Year>.<File Type>

Where:

- **User_Class** : <String> The name of the User Class, or ‘All’ for the sum from the composite of all user classes;
- **Pollutant** : <String> The name of the pollutant;
- **Year** : <Integer> The year;
- **File Type** : <Three character string> The ADMS file extension.

- <project>\BaselineADMS
  - <projects>\BaselineADMS\CO2
    - <projects>\BaselineADMS\CO2\All
      - <projects>\BaselineADMS\CO2\All\2018
        - <projects>\BaselineADMS\CO2\All\2018\Period_1_20180101000000_20180104235900
        - <projects>\BaselineADMS\CO2\All\2018\Period_2_20180105000000_20180131235900
        - <projects>\BaselineADMS\CO2\All\2018\Period_3_20180201000000_20180204235900
        - <projects>\BaselineADMS\CO2\All\2018\Period_4_20180205000000_20180218235900
  - <projects>\BaselineADMS\NOx
    - <projects>\BaselineADMS\NOx\All
      - <projects>\BaselineADMS\NOx\All\2018
      - <projects>\BaselineADMS\NOx\All\2018\Period_1_20180101000000_20180104235900
      - <projects>\BaselineADMS\NOx\All\2018\Period_2_20180105000000_20180131235900
      - <projects>\BaselineADMS\NOx\All\2018\Period_3_20180201000000_20180204235900
      - <projects>\BaselineADMS\NOx\All\2018\Period_4_20180205000000_20180218235900
- <project>\SiteActiveADMS
  - <projects>\SiteActiveADMS\CO2
    - <projects>\SiteActiveADMS\CO2\All
      - <projects>\SiteActiveADMS\CO2\All\2018
      - <projects>\SiteActiveADMS\CO2\All\2018\Period_1_20180101000000_20180104235900
      - <projects>\SiteActiveADMS\CO2\All\2018\Period_2_20180105000000_20180131235900
      - <projects>\SiteActiveADMS\CO2\All\2018\Period_3_20180201000000_20180204235900
      - <projects>\SiteActiveADMS\CO2\All\2018\Period_4_20180205000000_20180218235900
  - <projects>\SiteActiveADMS\NOx
    - <projects>\SiteActiveADMS\NOx\All
      - <projects>\SiteActiveADMS\NOx\All\2018
      - <projects>\SiteActiveADMS\NOx\All\2018\Period_1_20180101000000_20180104235900
      - <projects>\SiteActiveADMS\NOx\All\2018\Period_2_20180105000000_20180131235900
      - <projects>\SiteActiveADMS\NOx\All\2018\Period_3_20180201000000_20180204235900
      - <projects>\SiteActiveADMS\NOx\All\2018\Period_4_20180205000000_20180218235900

Figure 14: 'M4RegPostProc.exe' ADMS output directory structure example

5.7.2 Bounds '.bds' files:

In addition to the 'standard' ADMS import files, 'M4RegPostProc.exe' produces a further, '.bds', file. This contains network bounding box information that may be useful when manually setting-up ADMS output grids. The .bds file contains a header, and six lines of information:

1. The full extents of the network, including all 'virtual' nodes and links, and the link count;
2. As above, but with bounding coordinates rounded to the nearest grid size, as defined in the 'ADMS_settings.csv' file, and a suggestion of the number of X and Y points for that grid resolution to be used in ADMS;

3. and 4. As 1. and 2. above, but only including 'real' nodes and links, and surrounded by a buffer area, with size defined in the 'ADMS_settings.csv' file;

5. and 6. As 3. And 4. above, minus the buffer region.

If the '-dumpbounds' command line option is set (see section: 'Command Line Arguments'), then bounds information will also be written as a series of polygon features to the ADMS sub-directories.

5.7.3 Flow and Speed Summary Files:

'M4RegPostProc.exe' can also process flow and speed information from the '<project>\BaselineTraffic' and '<project>\SiteActiveTraffic' directories. Output takes the form of '.csv' files written back to the same directories. The structure of the .csv files is the same as the first portion of an ADMS '.hfc' file – i.e. rows in the file represent a single hour in the year, whilst columns represent the data for a particular link in that hour. For 'flow' summaries, the value is simply the total number of vehicles. For 'speed' summaries, the value is the average speed in km/h. Separate files are created for each user class and year. Individual files are named as:

<User Class>_<Type>_<Year>.csv

Where:

- **User_Class** : <String> The name of the User Class, or 'All' for the sum from the composite of all user classes;
- **Type** : <String> Contents of the file – either 'Flow' or 'Speed';
- **Year** : <Integer> The year.

5.7.4 Network: Node and Link Shape Files:

The final set of outputs from 'M4RegPostProc.exe' are shapefiles containing link and node data. Nodes are output as point object features, Links are output as polyline features. Additionally links may be written as polygon features, taking into account road width, if 'COBA' type speed-flow curves are being used. These outputs are written directly to the '<project>' directory. For further information on the structure of the shapefiles see section: 'Alternate File Formats'.

6. Miscellaneous:

6.1 Command Line Arguments:

Each UHTIM application expects several command line arguments, in order to specify input and output directories, for example. Some arguments, like the specification of input directories, are mandatory, whilst others are optional. Command line arguments for each, individual application are listed below:

6.1.1 M4InitialiseProject.exe:

- **-path** : This ***mandatory*** argument tells 'M4InitialiseProject' that the next command line argument sets the directory in which the named project subdirectory is to be created;
- **-name** : This ***mandatory*** argument tells 'M4InitialiseProject' that the next command line argument is the name of the project. All project files will subsequently be placed in <"path"\"name"> to form the <project> directory;
- **-nopause** : The application will not halt and wait for a keypress at the end of a run;
- **-uselogs** : The application will log all on-screen messages to file. The log file will be named "<Project>\log.txt". If the log file already exists, it will be appended to;
- **-delete** : Any files found to already exist in the <Project> directory will be deleted. This helps to prevent errors occurring from inputs based on unwanted directory structures being present from previous failed or successful runs of a scenario, when changes are being made. e.g. 'M4RegPostProc' uses the directory structures created by 'M4RegTraffGen' and 'M4RegPollProc', if these directory structures, or the files they contain, are incorrect, then the results of the post-processing operation will also be erroneous. Care should obviously be taken when using the '-delete' option, that files the user wishes to retain, are not in any affected directories.

e.g.:

```
M4InitialiseProject -path "C:\Projects" -name "Test_Project"
-nopause -uselogs -delete
```

6.1.2 M4FleetPollProc.exe:

- **-path** : This ***mandatory*** option tells 'M4FleetPollProc' that the next command line argument sets the project directory (i.e. '<project>\BaseInputs');
- **-pols** : This ***mandatory*** argument tells 'M4FleetPollProc' that the next command line argument provides the list of pollutants to use in the scenario run. This should be either a comma separated list of pollutants whose input tables are found in the '<project>\BaseData' directory, or the wildcard character '*', if all available pollutants are required;
- **-nopause** : The application will not halt and wait for a keypress at the end of a run;
- **-uselogs** : The application will log all on-screen messages to file. The log file will be named "<Project>\log.txt". If the log file already exists, it will be appended to.

e.g.:

```
M4FleetPollProc -path "C:\Projects\Test_Project" -pols "*"
-nopause -uselogs
```

6.1.3 M4RegTimeGen.exe:

- **-path** : This ***mandatory*** option tells 'M4RegTimeGen' that the next command line argument sets the project directory (i.e. '<project>\BaseInputs');
- **-nopause** : The application will not halt and wait for a keypress at the end of a run;
- **-uselogs** : The application will log all on-screen messages to file. The log file will be named "<Project>\log.txt". If the log file already exists, it will be appended to.

e.g.:

```
M4RegTimeGen -path "C:\Projects\Test_Project" -nopause -uselogs
```

6.1.4 M4BaseTraffGen.exe:

- **-path** : This ***mandatory*** option tells 'M4BaseTraffGen' that the next command line argument sets the project directory (i.e. '<project>\BaseInputs');
- **-nopause** : The application will not halt and wait for a keypress at the end of a run;
- **-uselogs** : The application will log all on-screen messages to file. The log file will be named "<Project>\log.txt". If the log file already exists, it will be appended to;
- **-useshps** : With this option set, 'M4BaseTraffGen' will look in '<project>\BaseInputs' for node and link files in .shp format (see section 'Alternate File Formats : Shape Files'), rather than the default .csv files.

e.g.:

```
M4BaseTraffGen -path "C:\Projects\Test_Project" -nopause
-uselogs -useshps
```

6.1.5 M4RegTraffGen.exe:

- **-path** : This ***mandatory*** option tells 'M4RegTraffGen' that the next command line argument sets the project directory (i.e. '<project>\BaseInputs');
- **-nopause** : The application will not halt and wait for a keypress at the end of a run;
- **-uselogs** : The application will log all on-screen messages to file. The log file will be named "<Project>\log.txt". If the log file already exists, it will be appended to;

- **-useshps** : With this option set, 'M4RegTraffGen' will look in '<project>\BaseInputs' for node and link files in .shp format (see section 'Alternate File Formats : Shape Files'), rather than the default .csv files.

e.g.:

```
M4RegTraffGen -path "C:\Projects\Test_Project" -nopause
-uselogs -useshps
```

6.1.6 M4RegPollProc.exe:

- **-path** : This ***mandatory*** option tells 'M4RegPollProc' that the next command line argument sets the project directory (i.e. '<project>\BaseInputs');
- **-pols** : This ***mandatory*** argument tells 'M4RegPollProc' that the next command line argument provides the list of pollutants to use in the scenario run. This should be either a comma separated list of pollutants whose input tables are found in the '<project>\BaseData' directory, or the wildcard character '*', if all available pollutants are required;
- **-nopause** : The application will not halt and wait for a keypress at the end of a run;
- **-uselogs** : The application will log all on-screen messages to file. The log file will be named "<Project>\log.txt". If the log file already exists, it will be appended to;
- **-useshps** : With this option set, 'M4RegPollProc' will look in '<project>\BaseInputs' for node and link files in .shp format (see section 'Alternate File Formats : Shape Files'), rather than the default .csv files.

e.g.:

```
M4RegPolGen -path "C:\Projects\Test_Project" -pols "*"
-nopause -uselogs -useshps
```

6.1.7 M4RegPostProc.exe:

- **-path** : This ***mandatory*** option tells 'M4RegPostProc' that the next command line argument sets the project directory (i.e. '<project>\BaseInputs');
- **-ADMS** : With this option set, 'M4RegPostProc' will use the files and directory structure output by 'M4RegPollProc' to produce further output files that are compatible as ADMS imports;
- **-speedflow** : With this option set, 'M4RegPostProc' will produce summary files (separate files per user class, and overall Pollution) for all speed and flow information, as produced by 'M4RegPollutionGen', and save them in the '<project>\BaselineTraffic' and '<project>\SiteActiveTraffic' directories. The files are structured in a similar manner to ADMS .hfc files;
- **-nopause** : The application will not halt and wait for a keypress at the end of a run;
- **-uselogs** : The application will log all on-screen messages to file. The log file will be named "<Project>\log.txt". If the log file already exists, it will be appended to;
- **-useshps** : With this option set, 'M4RegPostProc' will look in '<project>\BaseInputs' for node and link files in .shp format (see section 'Alternate File Formats : Shape Files'), rather than the default .csv files;
- **-dumplinks** : With this option set, network links will be written to the '<project>' directory as a shapefile called 'links.shp';
- **-dumpnodes** : With this option set, network nodes will be written to the '<project>' directory as a shapefile called 'nodes.shp';

- -**dumpbounds**: If ADMS outputs are being written, then this option will also write bounds information as ESRI shapefiles to the same sub-directories;
- **-connectors** : With this option set, the 'links.shp' and 'nodes.shp' files written with the options above will also include 'virtual' elements such as centroids and centroid connectors, as well as 'physical' elements;
- **-aspolys** : This option also writes a 'link_polygons.shp' file, containing the physical links as polygon features, with feature width set based on the number of road lanes, if the feature has a corresponding 'COBA' type speed-flow curve.

e.g.:

```
M4RegPostProc -path "C:\Projects\Test_Project" -ADMS
-speedflow -nopause -uselogs -useshps -dumplinks -dumpnodes
-connectors -aspolys
```

6.2 Windows Console and Command Line Interface:

The windows console and command line interface may be accessed by:

- Typing 'cmd' in the Windows search box at the bottom of the start menu on Windows 7, then clicking on the found 'cmd.exe' to start the application. Alternately 'Win+R' will bring up the 'Run' dialog into which you can type 'cmd' – see Figure 15:

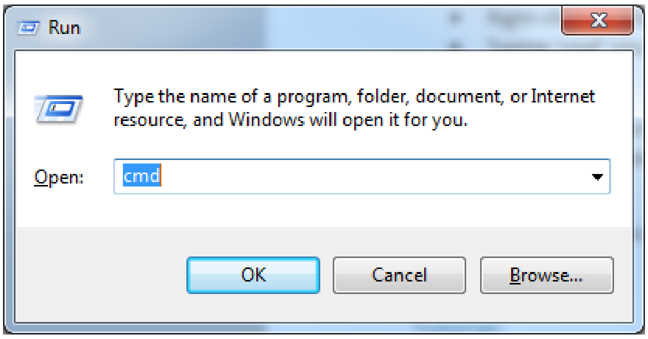


Figure 15: Accessing the Windows Command Prompt via the 'Run' dialog.

- Right-clicking 'Start' and choosing 'Command Prompt' in Windows 8;
- Typing 'cmd' into the Windows search box on the taskbar in Windows 10.

Once open the command prompt should appear something like Figure 16 below:

Figure 16: The Windows command prompt

A discussion of the functionality of the command prompt is outside of the scope of this document. There are a large number of online tutorials that cover the basics required to run applications from the prompt, and navigate through drive and directory structures.

6.3 Windows Batch Files:

As the UHTIM applications are Windows console applications, that need to be run in a sequence for a given scenario, they naturally lend themselves to being launched via 'batch' (.bat) files, called from the command line.

Three example batch files are provided with the installation. The assumption is made that the UHTIM applications have been installed into the directory 'C:\UHTIMv2', and that the user wishes their projects to also be stored in sub-directories in this installation directory. If this is not the case, then the parameters suggested in the batch file(s) below may need editing.

1. **'Test_Sample.bat'** : This batch file simply contains the following command line:

```
Start Test_Complete_Run "C:\UHTIMv2" "Test" "C:\UHTIMv2"
```

This batch file demonstrates the syntax for calling one of the other two batch files with the '<project>' directory as the first parameter (i.e. "C:\UHTIMv2"), the project name (i.e. "Test") as the second parameter, and the installation directory (i.e. "C:\UHTIMv2"), where the original, default '<BaseInput>' and '<BaseData>' directories are found, as the third parameter.

2. **'Test_Complete_Run.bat'** : This batch file should be run only for the sample test scenario above, to check that installation has been performed correctly, as it uses a copy of all of the default '<BaseInput>' files for running the scenario. Figure 17 shows the content of the 'Test_Complete_Run.bat' file.

```
@ECHO ON
SET PRJ_PATH="%~1\%~2"
SET PRJ_IN_PATH="%~1\%~2\BaseInputs"
SET BASE_IN_PATH="%~3\BaseInputs"
SET LOGFILE="%~1\%~2\log.txt"
@ECHO STARTING RUN AT %date% %time% > %LOGFILE%
M4InitialiseProject.exe -path %1 -name %2 -nopause -uselogs -delete
If %ERRORLEVEL% NEQ 0 GOTO :ERROR
XCOPY /s %BASE_IN_PATH% %PRJ_IN_PATH% /u /y
If %ERRORLEVEL% NEQ 0 GOTO :ERROR
M4FleetPollProc.exe -path %PRJ_PATH% -pols "*" -nopause -uselogs
If %ERRORLEVEL% NEQ 0 GOTO :ERROR
M4BaseTraffGen.exe -path %PRJ_PATH% -nopause -uselogs
If %ERRORLEVEL% NEQ 0 GOTO :ERROR
M4RegTimeGen.exe -path %PRJ_PATH% -nopause -uselogs
If %ERRORLEVEL% NEQ 0 GOTO :ERROR
M4RegTraffGen.exe -path %PRJ_PATH% -nopause -uselogs
If %ERRORLEVEL% NEQ 0 GOTO :ERROR
M4RegPollProc.exe -path %PRJ_PATH% -pols "*" -nopause -uselogs
If %ERRORLEVEL% NEQ 0 GOTO :ERROR
M4RegPostProc.exe  -path  %PRJ_PATH%  -adms  -speedflow  -nopause  -uselogs  -
dumplinks -dumpnodes -dumpbounds -connectors -aspolys
If %ERRORLEVEL% NEQ 0 GOTO :ERROR
@ECHO ENDING RUN AT %date% %time% >> %LOGFILE
@ECHO OFF
EXIT /B /0
:ERROR
@echo ERROR RUN FAILED AT %date% %time% >> %LOGFILE
EXIT /B /1
```

Figure 17: Content of the 'Test_Complete_Run.bat' batch file

3. **‘Post_Initialisation_Run.bat’** : This is the general batch file that should be used with user-defined content in the ‘<BaseInput>’ directory (i.e. pretty much every scenario run that isn’t just testing using the default installation files). It differs from ‘Test_Complete_Run.bat’ only in the lack of the ‘xcopy’ command, that transfers default files from the installation directory to the project directory, after ‘M4InitialiseProject.exe’ is called.

6.4 Messages: Information, Warnings and Errors:

When running the UHTIM applications generate messages that are passed to the console window, and to ‘<project>\log.txt’, if the correct command line argument is set.

Each generated message is prepended by a code indicating the message’s status. Possible statuses are:

- ***[CMD_ARGS]*** : These messages are generated when a UHTIM application processes a command line argument. They may be used to check that the parameters the user has passed to the application are correct. In the Windows Console these messages appear as cyan text on a black background;
- ***[INFO]*** : These messages are just general status updates, produced during normal operation of the application. They are intended to let the user know what’s going on with the application, where processing has reached, and to confirm settings or parameters. In the Windows Console these messages appear as green text on a black background;
- ***[WARNING!]*** : These messages indicate a potential issue or problem encountered during the running of the application, though one that wasn’t serious enough to halt processing entirely. The user should check warnings to ensure that the behaviour indicated in the message was as anticipated (e.g. warning messages are generated by ‘M4InitialiseProject.exe’ when deleting files, so that the user can check that the correct directories were targeted for file removal). In the Windows Console warnings appear as yellow text on a black background;
- ***[ERROR!]*** : These messages indicate a serious problem with the application or the input data, that has caused processing to halt. Typically errors are generated by missing or erroneous input data (e.g. wrong directory paths being specified) or incorrect use of the applications (e.g. running applications out-of-sequence). Errors appear as red text on a black background;
- ***[FATAL ERROR!]*** : These messages should be rare, and indicate a failure of an internal mechanism of an application, such as memory not being allocated when requested, or loss of precision in a mathematical calculation. Such errors always halt processing. Fatal errors appear as black text on a red background.

A full list of warning and error message states is outside the scope of this document, as there are over 900 situations throughout the applications which could generate either warning or error messages. Hopefully the messages should be either self-explanatory, or at least give some indication of how potential issues could be rectified.

As a final recourse, if a situation cannot be resolved by the user, please use the contacts at the front of this document to reach the UHTIM developers.

7. Tutorial:

7.1 Introduction:

This section presents a small tutorial on setting up a scenario. It should be read in conjunction with examination of the corresponding input files found within the '<installation path>\tutorial\BaseInputs' directory (though the user might want to take a copy of those files for safekeeping!)

7.2 Scenario Region:

The topographical layout of the scenario region and its associated road network is given in Figure 18. Corresponding Cartesian coordinates (values in metres with origin at node 1) are given in Figure 19. The base condition is of a small village lying just to the north of a rural dual carriageway (running through nodes (500), 1, 3, 8 and (505)). The village (at node 6) can be accessed via two junctions (nodes 3 and 8), with slip roads terminating at a further junction (node 5).

The proposed development would see well pads being built at Site 1 (node 4) and Site 2 (node 7). Access to the pads would be via additional site access roads from the village junction (node 5).

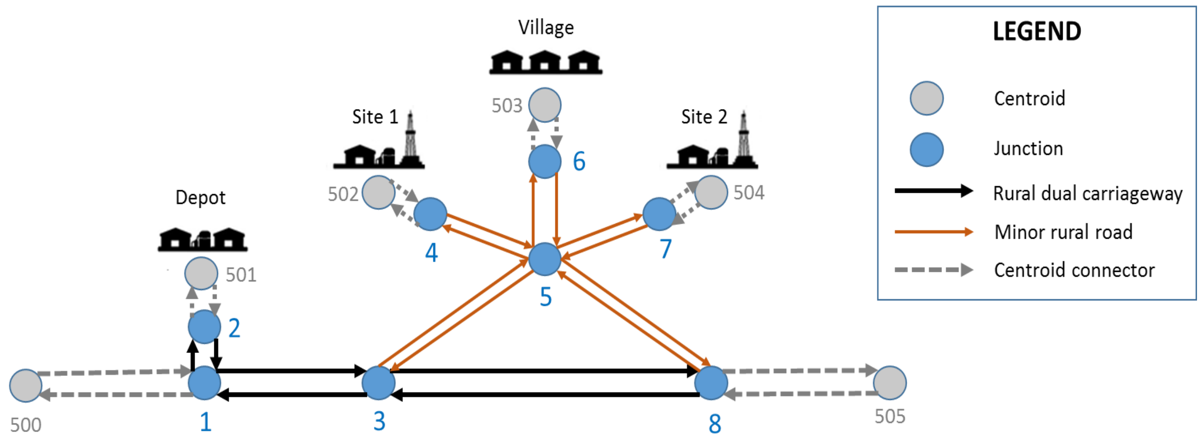


Figure 18: Tutorial region: Topographical layout (not to scale)

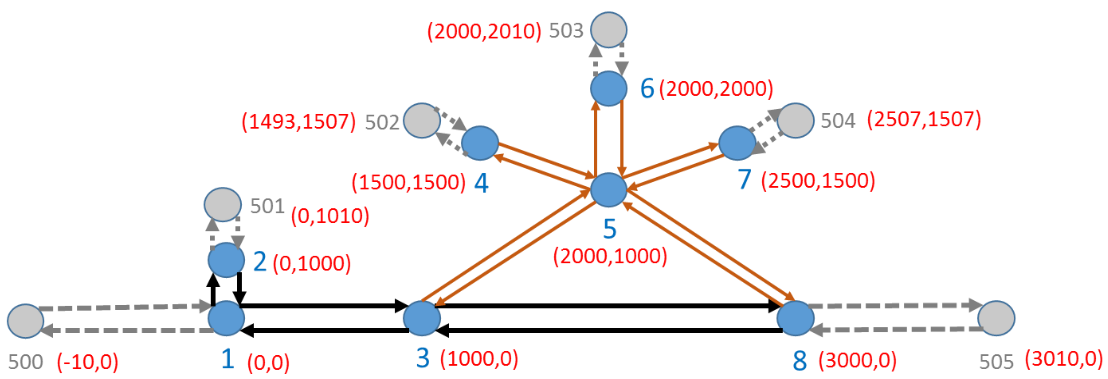


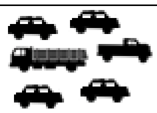
Figure 19: Tutorial region: Network coordinates (not to scale)

Regarding road types and costs on the links it is assumed that the roads will be modelled using COBA speed-flow curves. All dual carriageway links are to be modelled as road type 'R2DA' (rural, 2-lane dual carriageway to UK 'A' road standard), whilst the minor roads are of type 'R2SC' (rural, single carriageway roads to 'C' road standard. The speed-flow curves for these roads may be seen in figure

D.1 in the Appendices. All network data may be found in the ‘<installation path>\tutorial\Nodes.csv’ and ‘<installation path>\tutorial\Links.csv’ files.

Four user classes (Table 6) will be used for modelling traffic in the scenario. One fleet (‘Base’) will be used to represent general traffic, whilst site traffic will be separated into three categories: LGVs, HGV1 and HGV2. (NB: In reality, more than four classes could be used if the exact type of vehicle performing a task was known, and a suitable analogous entries could be found/entered in the ‘<installation path>\tutorial\Vehicles_sim_table.csv’ and ‘<installation path>\tutorial\Fleets_sim_table.csv’ files.

Table 6: Tutorial region: User Classes (Base 2018)

User Class	User Class 1	User Class 2	User Class 3	User Class 4
Name/Key	Base	LGV	HGV1	HGV2
Visual Description:				
Textual Description:	General traffic , mostly Light Duty Vehicles (approximately 6% Heavy Duty Vehicles)	Staff transportation and light construction and mainteneace traffic.	Heavy plant (construction, lifting, drilling) and soild materials transportation	Tankers for water, proppant and flowback/produced water transportation
Vehicles:	Full rural fleet	All LGVs class I to III	All rigid HGVs	All articulated HGVs
PCU Value:	Approx: 1.08	1.1	1.89	2.50
CO_2 Emission	171 g/km	183 g/km	570 g/km	931 g/km
NO_x Emission	0.29 g/km	0.45 g/km	1.03 g/km	1.05 g/km
PM_{10} Emission	0.030 g/km	0.031 g/km	0.094 g/km	0.11 g/km
$PM_{2.5}$ Emission	0.018 g/km	0.019 g/km	0.054 g/km	0.064 g/km
ESALs	0.15	0.05	1.45	3.72
SPwLA	98.3 dBA/m	101.52 dBA/m	104.21 dBA/m	104.21 dBA/m

[1] PCU Values and mass emissions in the above table are per individual (fleet-weighted) vehicle values. They have been calculated at a mean speed of 50 km/h, using PITHEM/EFT 5.1.3 (Goodman *et al.,* 2016). ESAL and SPwLA values have been calculated by UHTIMv2 at the same speed.

It is assumed that traffic flows, in the form of Annual Average Daily Total (AADT) flows, between Origin-Destination pairs are available – see Table 7. Data for the matrix may be found in the ‘<installation path>\tutorial\mat_AADT.csv’ file.

Table 7: Tutorial region: Baseline AADT traffic flows (User Class 1) between OD pairs (Origins = rows, Destinations = columns)

	500	501	502	503	504	505
500	-	20	0	800	0	10000
501	20	-	0	0	0	20
502	0	0	-	0	0	0
503	800	0	0	-	0	800
504	0	0	0	0	-	0
505	10000	20	0	800	0	-

As flows on links aren’t explicitly known, some form of traffic assignment process must be used to ‘fill in’ data for the hourly flows across the base week. The tutorial makes a number of simplifying assumptions here:

1. That the base week will be modelled using a single diurnal profile for every day;
2. That an initial network assignment for the hour 16:00 – 17:00 will be performed using the Frank-Wolfe iterative process, using a demand matrix scaled from the AADT matrix;

3. That flows in other hours will be produced by simply scaling the 16:00 – 17:00 flow values appropriately.

Table 8 gives the scaling factors used to produce the diurnal flows. The first column gives the scaling of the flow in an hour compared to the average weekly profile, as calculated from DfT data (see Appendix A and Figure A.2). This implies that typically, for example, only 0.8% of the flow in a day occurs between midnight and 1am, whilst 7.7% occurs between 4pm and 5pm – the peak hour of the day. Only one value is needed from the first column – that for the selected assignment hour.

The second column in table 8 gives the flow in that hour, relative to the selected assignment hour, e.g. flow levels in the hour 3pm to 4pm will be 92% of the flow levels in the assignment hour. Values from this column are used for scaling every hour, except the initial assignment hour.

Table 8: Tutorial region: Diurnal Variation Scaling Factors

Hour	Scaling relative to Average Daily Total	Scaling relative to modelled hour	Hour	Scaling relative to Average Daily Total	Scaling relative to modelled hour
00:00	0.00807	0.1054	**12:00**	0.0644	0.8414
01:00	0.00553	0.0722	**13:00**	0.0647	0.8452
02:00	0.00454	0.0593	**14:00**	0.0664	0.8673
03:00	0.00493	0.0644	**15:00**	0.0706	0.9211
04:00	0.00743	0.0970	**16:00**	0.0766	1.0000
05:00	0.01690	0.2207	**17:00**	0.0753	0.9835
06:00	0.03828	0.4997	**18:00**	0.0611	0.7973
07:00	0.06024	0.7865	**19:00**	0.0442	0.5767
08:00	0.06353	0.8294	**20:00**	0.0320	0.4174
09:00	0.05828	0.7609	**21:00**	0.0239	0.3123
10:00	0.05967	0.7790	**22:00**	0.0182	0.2374
11:00	0.06286	0.8207	**23:00**	0.0123	0.1608

Obviously the tutorial's treatment of daily traffic flow assignment is very simplistic, as no variation between days, or in flow patterns during a day (e.g. possibly more flow/congestion from the village in the AM-peak, and the converse in the PM-peak) are being taken into account. The tutorial does, however, demonstrate how diurnal profile may be built from incomplete assignment data. The final base weak creation is contained in the '<installation path>\tutorial\Weekly_traffic.csv' file.

Likewise the tutorial doesn't scale flows by month or year. Both the '<installation path>\tutorial\Annual_scaling.csv' and '<installation path>\tutorial\Monthly_scaling.csv' contain default scaling factors (all values set to 1.0).

7.3 Site Activities:

Table 9 gives the processes, phases and traffic demands associated with a single pad and well combination, from initial pad development to fracking and completion. The overall traffic demands and phase durations are based on the New York State 'Early Horizontal Well Development' data presented in Appendix F.15, though data should be taken as indicative only.

Overall it is assumed that a single well at a given site generates 831 LGV, 548 HGV1 and 600 HGV2 round trips over the 120 days to completion. The traffic demand level peaks during the arrival of fracking water and sand on site, reaching approximately 106 vehicles/day. The average demand per well is approximately 16.5 vehicles/day.

Times and durations in Table 9 are given in days, with the start of each process and phase given as an offset from the start of activities on site. Note that the UHTIM applications expect that actual dates are provided, so the '<installation path>\tutorial\Region.csv' tutorial file assumes that activities start on the 1st of January 2018 (2018-01-01 00:00) and run till the 30th of April 2018 (2018-04-30 23:59). Data in the file is assumed to apply to Site 1.

For simplicities sake, it is assumed all traffic to the sites will be generated from, and return to, the depot at node 501. The depot is linked to the dual carriageway at node 1. Obviously a more realistic/holistic scenario would assume vehicles traveling from different locations to the site, possibly moving on to secondary sites (e.g. to deliver waste water to a processing facility), before returning to their 'home' location.

Table 9: Individual Site Activities

Name	Proc. ID	Phase ID	Start Day	Duration, Days	User Classes	Demand	Direction	Access Policy
Drill Pad Construction	1	1	0	35	LGV HGV1	90 45	I/O I/O	All, Daytime All, Daytime
Rig Mobilisation	2	1	35	5	LGV HGV1	140 95	I I	All, Daytime All, Daytime
Drilling Rig Fluids	2	2	40	2	HGV1	45	I/O	All, Daytime
Non-Rig Equipment	2	3	40	2	HGV1	45	I/O	All, Daytime
Drilling (Rig crew etc.)	2	4	40	21	LGV HGV1	140 50	I/O I/O	All, Daytime All, Daytime
Rig Demobilisation	2	5	61	5	LGV HGV1	140 95	O O	All, Daytime All, Daytime
Completion Equipment Mobilisation	3	1	66	1	HGV1	5	I	All, Daytime
Completion General	3	2	67	13	LGV	326	I/O	All, Daytime
Completion Chemicals	3	3	67	2	HGV1	20	I/O	All, Daytime
Hydraulic Fracturing Equipment (on-site tanks)	3	4	70	5	HGV1	175	I/O	All, Daytime
Hydraulic Fracturing Water Haulage	3	5	75	5	HGV2	500	I/O	All, Daytime
Hydraulic Fracturing Sand	3	6	75	5	HGV1	23	I/O	All, Daytime
Completion Equipment Demobilisation	3	7	80	1	HGV1	5	O	All, Daytime
Waste and produced water disposal	4	1	80	35	HGV2	100	I/O	All, Daytime
Final pad preparations	5	1	115	5	LGV HGV1	50 45	I/O I/O	All, Daytime All, Daytime
Miscellaneous	6	1	0	120	LGV	85	I/O	All, 24h
TOTAL (Round trip movements)	NA	NA	0	120	LGV HGV1 HGV2	831 548 600	NA	NA

7.4 Other Parameters and Files:

The '<installation path>\tutorial\Simulation_settings.csv' file includes a start date of 1st Jan 2018 (2018-01-01 00:00) and an end date of the 31st December 2018 (2018-12-31 23:59). The initial '<installation path>\tutorial\Site_duplications.csv' file is empty. No account of the second site at node 504 is being taken into account.

7.5 Running the tutorial scenario:

Double-clicking clicking on the 'Test_Tutorial.bat' file should start the UHTIM modelling chain, ***if the Installation path is 'C:\UHTIMv2' only***. If the installation path is different then the .bat file will need to be amended. However, as noted previously, it would be more advisable to take a copy of both the .bat file, and the tutorial directory, and rename both, prior to making a run. i.e.:

1. Make a copy of '<installation path>\tutorial\' and rename it '<installation path>\my_tutorial1\' (or similar). ***NB: Subsequent instructions in the tutorial will assume that the scenario directory has been called 'my_tutorial1'***;
2. Make a copy of the 'Test_Tutorial.bat' file, rename that copy to 'Test_My_Tutorial1.bat';
3. Amend the contents of the batch file from:

```
Start Post_Initialisation_Run "C:\UHTIMv2" "Tutorial" "C:\UHTIMv2"
```

To:

```
Start Post_Initialisation_Run "<Installation path>" "My_Tutorial1" "<Installation path>"
```

4. Start the run by clicking on the new batch file.

The windows command prompt should appear, with each UHTIM application being called in turn – see Figure 17.

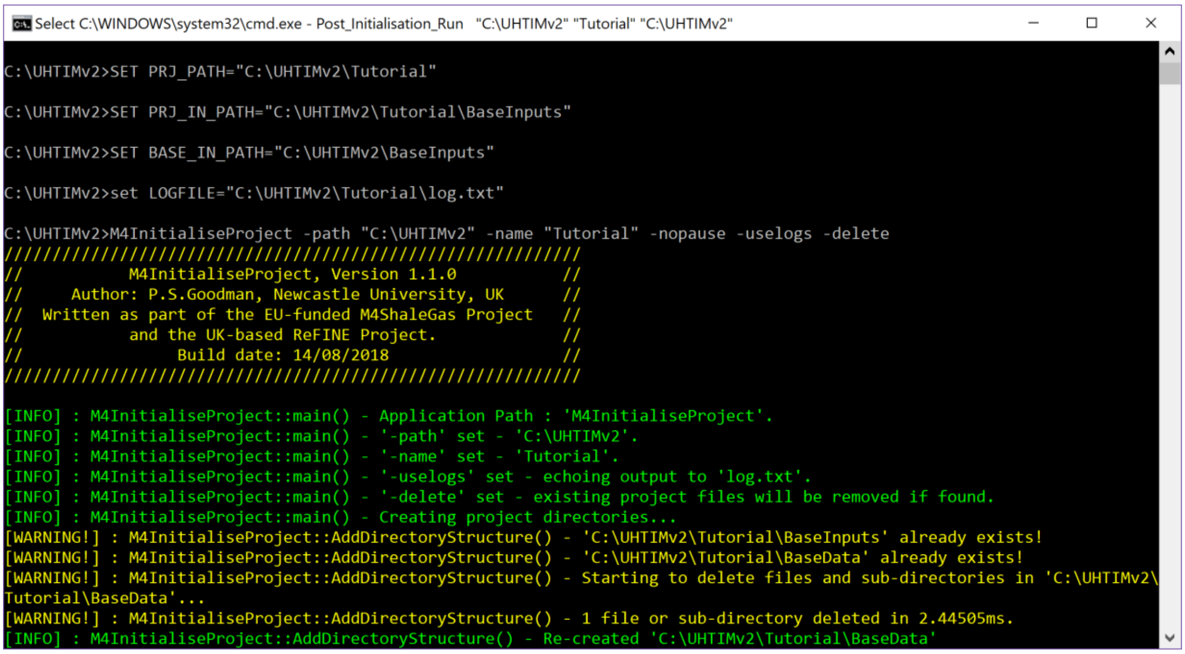


Figure 17: UHTIM Tutorial running from the windows command prompt, with installation path 'C:\UHTIMv2' and scenario directory 'Tutorial'

Depending on the speed of the machine, the tutorial should take between 5 minutes and ½ hour to run. On a modern Dell XPS laptop (i7-7500U processor @ 2.70 – 2.90 GHz, SSD storage) a run completes in 9 minutes 30 seconds, whilst on an older Core 2 Duo machine, at nominally the same clock speed (E6300 @ 2.80GHz, physical HDD), completion is in 20 minutes. Speed of disk access influences runtimes for simple scenarios far more than CPU speed, given the large number of small files generated during a run. Likewise the slowest individual application is 'M4RegPostProc.exe' when producing summary ADMS, or flow and speed outputs, due to the high number of disk read and writes required.

At the end of the run, the command prompt should remain open, displaying a blue line with the elapsed time taken by the last application (‘M4RegPostProc.exe’) – see Figure 18.

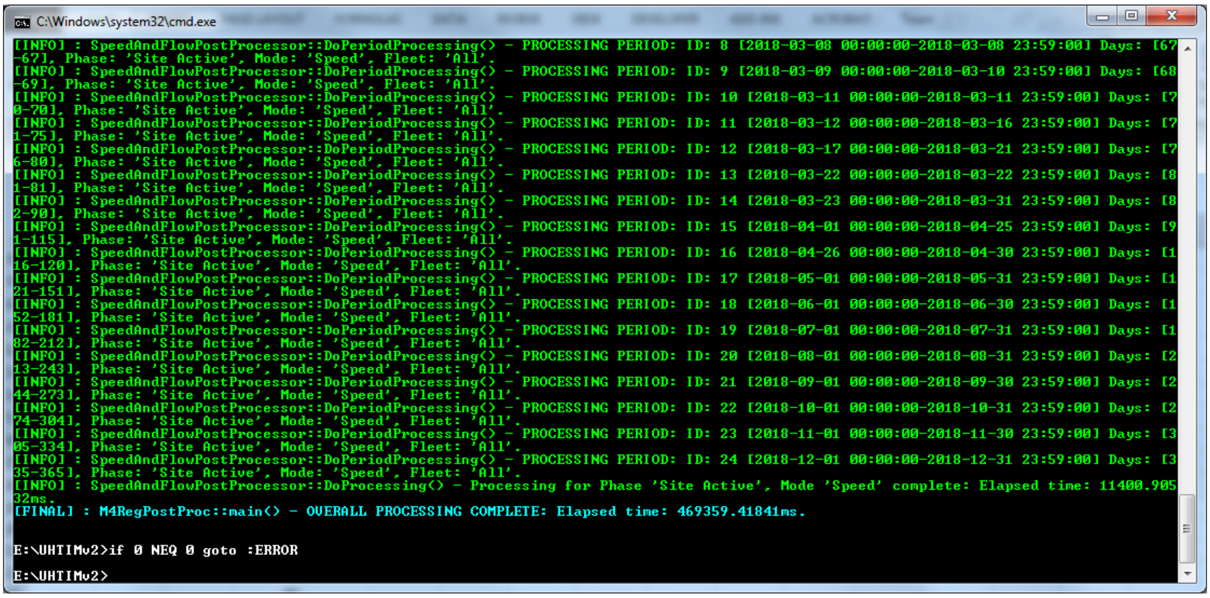


Figure 18: Successful Termination of a scenario run.

7.6 Checking for Warnings and Errors:

Looking in the ‘<Installation Path>\my_tutorial1\log.txt’ file, the user will note a number of ‘WARNING!’ level messages will have been generated (but hopefully no ‘ERROR’ or ‘FATAL’ messages!). Warnings may occur from ‘M4InitProject.exe’ if the tutorial has been run before, to inform the user that the directory structure already exists, and files from the previous run are being deleted.

Warnings will also be generated from ‘M4RegTimeGen.exe’, ‘M4RegTraffGen’ and ‘M4RegPollProc.exe’ when the ‘Region.csv’ file is being read and processed. These errors relate to mis-matches between the defined time periods for phases and the site access policy applied to the traffic demands in phases. For example:

- The error **`'[WARNING!] : Region::ReadFromCSV() - Line 38, Traffic state '1, 2, 2, HGV1, In'. The defined period [2018-02-10 00:00:00 - 2018-02-11 23:59:00] has no days in common with the profile! Profile has been changed to match period.'`** refers to the fact that the 2 days on which the phase is scheduled (Saturday 10th and Sunday 11th February 2018, cannot be satisfied by the access policy which only allows movements on Weekdays – as no other days are available, it is assumed that the activity must take place on those days and the phase/traffic demand date and time settings override the access policy;
- The error **`'[WARNING!] : Region::ReadFromCSV() - Line 67, Traffic state '1, 2, 5, LGV, In'. The defined period [2018-03-03 00:00:00 - 2018-03-07 23:59:00] has fewer days than the profile. Profile rescaled by 1.667!'`** refers to the fact that the number of days allocated to the phase (nominally 5 days from Saturday, 3rd March 2018 to Wednesday, 7th March), can only be partially reconciled to the available traffic policy (access on Weekdays). Hence the expected weekly traffic flow (5 days) is ‘crushed’ into the available 3 days, giving a flow scaling factor of 5/3 = 1.667 on each available day.

Neither of these warnings would occur under a 24/7 site access policy.

7.7 Sample Outputs:

Looking at the '<installation path>\my_tutorial1\Summary\Summary.csv file' the user can extract the results in Table 10.

Table 10: Summary emission results

Parameter	Baseline	Site Active	Difference	Percentage increase[2]
ESAL[1]	2590099 axles	2614726 axles	24627 axles	0.95%
HC	693.58 kg	693.93 kg	0.35 kg	0.05%
NO_x	7593.5 kg	7603.0 kg	9.5 kg	0.12%
$PM_{2.5}$	606.6 kg	607.5 kg	0.9 kg	0.14%
PM_{10}	1036.0 kg	1037.6 kg	1.6 kg	0.15%
pNO_2	2435.2 kg	2437.0 kg	1.8 kg	0.07%
uCO_2	4227.2 t	4235.1 t	7.9 t	0.19%

[1] This value is a fairly meaningless, as it is based on cumulative network totals across all links – the relative and cumulative impact on individual links is of more interest. [2] Percentages are based on calculations from the rounded values in the table. [3] For a similar reason to the ESAL value being suspect, no values are given for noise in the summary file as a 'cumulative noise total' across the network has little meaning – absolute changes on individual links at certain periods of time are far more important.

It can be seen from Table 10 that:

- Introduction of a single well at Site 1 does little to the annual emissions totals overall across the network. This would be expected, given that the site demand of approximately 2000 total round trips over 120 days is small compared to the daily network demand of 23280 vehicles, let alone the annual demand value of approximately 8.5 million vehicles;
- Relatively speaking, the increase in ESAL is the highest of all parameters. Caveats about the validity of network total measures for ESAL aside, this is unsurprising given the '4th power with weight' relationship of individual 'emission' per vehicle, and the number of heavy vehicles involved;
- Lower percentage increases are noted for hydrocarbons (0.05%) and primary NO_2 (0.07%), than for other gaseous pollutants (0.12 - 0.19%). This is due to high HC and primary NO_2 emissions generally being related to petrol and light diesel vehicles respectively, whilst emissions of other pollutants are more driven by heavier diesel vehicles;
- All impacts will be relative to the size of network and overall time period chosen. Impacts on individual links would be expected to be larger – see below.

As a brief 'sanity check to the data in Table 10, the following calculations are offered:

- Approximately 20000 vehicles each day travel 3km through the network along the dual carriageway, whilst 1600 vehicles travel 3.4km to and from node 1 and the village. A further 1600 travel 2.4km to and from node 8 and the village. This results in a 'ballpark' CO2 emission total of 11.85 t/day, or 4324 t/annum, using the emission value of 171 g/km from Table 6 for the baseline fleet – close to the final calculated value of 4227 t/annum. Ballpark values for NO_x, PM_{10} and $PM_{2.5}$ would be 7.3 t/annum, 0.76 t/annum and 0.45 t/annum respectively. These are further away from the actually calculated values due to the greater sensitivity of these emissions to speeds around 40-80 km/h, compared to CO_2;

- A further 2000 vehicles, with an average emission of 486g/km CO_2 (weighted-average of emissions from Table 6, for user classes 'LGV', 'HGV1' and 'HGV2', making the 8.2km round trip between depot and site 1, would add an estimated (2000 x 8.2 x 486 / 1000000) 7.97 tonnes over the site active period – again close to the 7.9 tonne value from the scenario run.

Of course, whilst 'ballpark' figures are relatively easy to calculate for a simple network, the UHTIM software can also be used to give a profile of emissions and emissions rates over time. For example Figure 19 gives cumulative additional CO_2 emissions across the year, whilst Figure 20 gives NO_x emission rates associated with each individual modelled period. The five-day period associated with water deliveries for fracking (17th March to 21st March) represents almost 50% of the total CO_2 emissions associated with the site, and the highest additional NO_x emission rate in the network (25g/h).

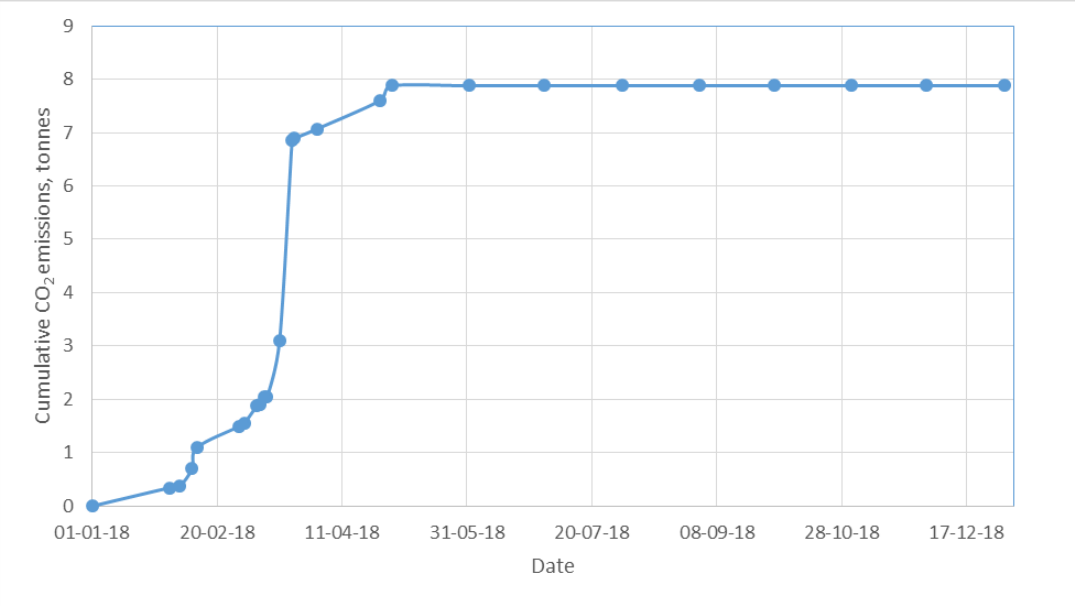


Figure 19: Cumulative additional site-related CO_2 emissions over the year

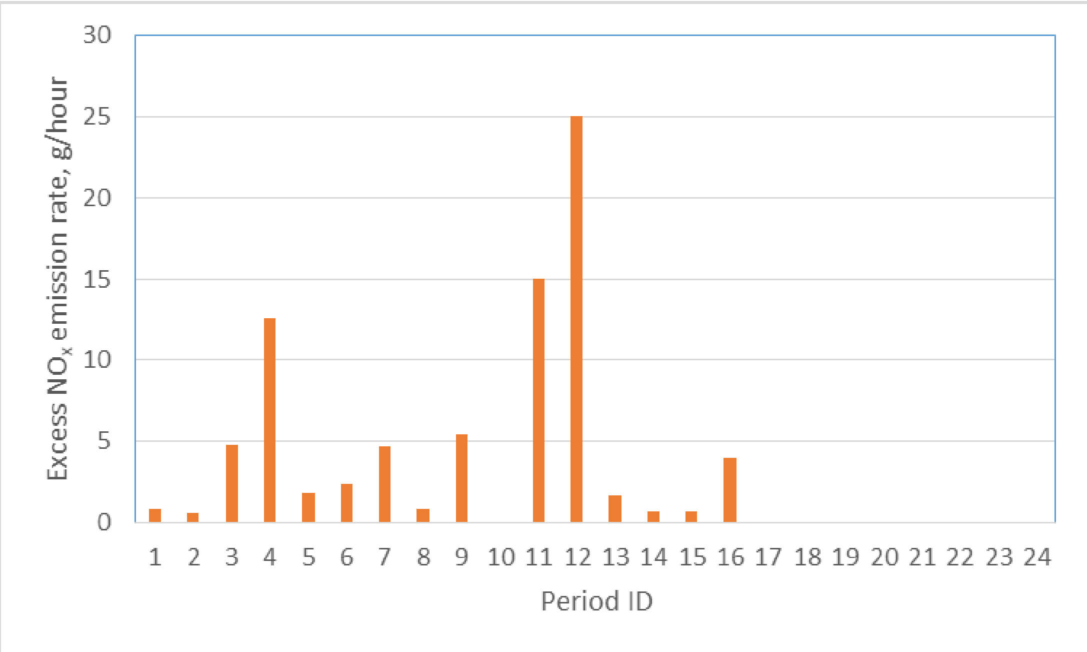


Figure 20: Site-related average additional NOx emissions rates, g/hour

Looking at the produced traffic summary files: ‘HGV1_Flow_2018.csv’, ‘HGV2_Flow_2018.csv’ and ‘LGV_Flow_2018.csv’ in ‘<installation path>\my_tutorial1\’ the additional flows due to the Site can be calculated and checked: e.g. summing data from link 2_1 (outbound from the depot) and link 1_2 (inbound to the depot) gives an assurance that all of the site demand traffic has been allocated to the network. Due to the fractional distribution of vehicles across time periods, and rounding errors, there might be slight discrepancies (in the order of < ±1 vehicle) in the total number of vehicles calculated. Table 11 gives the depot inbound/outbound total flows calculated from the three files.

Table 11: Calculated cumulative depot flows

User Class	Expected Inbound	Expected Outbound	Assigned Inbound (% Err)	Assigned Outbound (% Err)
HGV1	548	548	548.8 (+0.14%)	548.5 (+0.09%)
HGV2	600	600	599.04 (-0.16%)	599.04 (-0.16%)
LGV	831	831	829.2 (-0.22%)	829.6 (-0.17%)

7.8 Expanding the region – Site 2:

If the processes to occur at Site 2 are identical to those at Site 1, then adding the new site may be done via the ‘<installation path>\my_tutorial1\Site_duplications.csv’ file. However, to preserve the original tutorial files:

1. Create a new directory in the installation path called ‘my_tutorial2’;
2. Copy the ‘BaseData’ and ‘BaseInputs’ sub-directories from ‘my_tutorial1’ into this new directory;
3. Create a copy of the ‘<installation path>\my_tutorial1.bat’ file;
4. Rename this copy ‘<installation path>\my_tutorial2.bat’;
5. Open the new .bat file and edit the ‘start’ line so that ‘my_tutorial1’ becomes ‘my_tutorial2’;
6. Open the ‘<installation path>\my_tutorial2\Site_duplications.csv’ file for editing;
7. Add the following lines to the file, and then save:

```
Duplicate,1,2,Wellpad,2018-01-01 00:00,504,NA,NA,NA,NA
PTS_Change,NA,2,NA,NA,NA,501,502,501,504
PTS_Change,NA,2,NA,NA,NA,502,501,504,501
```

   These instructions will allow UHTIM to create ‘Site 2’ from a copy of ‘Site 1’, position it at node 504, and shift incoming and outgoing traffic to the new site node;

8. Run the new scenario by double clicking on the ‘<installation path>\my_tutorial2.bat’ file.

Once the run is complete a brief check of the ‘summary.csv’ and site active traffic files should reveal that the additional emissions totals have approximately doubled (e.g. additional CO_2 emissions are now 15.7 tonnes) due to the traffic assigned to the second site second site. Note that the increase in this instance is linear as all roads in the network are generally operating below capacity in their free flow regimes, leading to relatively minor changes in link speeds, and emissions changes being entirely driven by flow volume increases.

7.9 Expanding in time – Multi-well Sites

As a final example, we will look at duplication sites temporally. This is, once again, achieved via the 'Site_duplications.csv' file. As in the example above:

1. Create a new directory in the installation path called 'my_tutorial3';
2. Copy the 'BaseData' and 'BaseInputs' sub-directories from 'my_tutorial1' into this new directory;
3. Create a copy of the '<installation path>\my_tutorial1.bat' file;
4. Rename this copy '<installation path>\my_tutorial3.bat';
5. Open the new .bat file and edit the 'start' line so that 'my_tutorial1' becomes 'my_tutorial3';
6. Open the '<installation path>\my_tutorial3\Site_duplications.csv' file for editing;
7. Add the following lines to the file, and then save:

```
Duplicate,1,2,Wellpad,2018-01-01 00:00,504,NA,NA,NA,NA
PTS_Change,NA,2,NA,NA,NA,501,502,501,504
PTS_Change,NA,2,NA,NA,NA,502,501,504,501
Duplicate,1,3,Wellpad,2018-05-01 00:00,504,NA,NA,NA,NA
Duplicate,2,4,Wellpad,2018-05-01 00:00,504,NA,NA,NA,NA
Duplicate,1,5,Wellpad,2018-08-28 00:00,504,NA,NA,NA,NA
Duplicate,2,6,Wellpad,2018-08-28 00:00,504,NA,NA,NA,NA
```

   These instructions will allow UHTIM to create 'Site 2' from a copy of 'Site 1', position it at node 504, and shift incoming and outgoing traffic to the new site node. The two sites, with activities starting in January, are then copied two more times each, and given start dates of the 1st of May and 28th August, respectively. This gives at total of six sites in the region, with two site's activities running in parallel, throughout the year.

8. Run the new scenario by double clicking on the '<installation path>\my_tutorial3.bat' file.

As before, looking at the '<installation path>\my_tutorial3\Summary.csv' file should reveal that the CO_2 emissions associated with the sites being active has increased approximately six-fold compared to 'my_tutorial1', to a total of 47.1 tonnes. The overall number of modelled periods has increased to 50, from the initial number of 24.

7.10 Importing to ADMS

The following text is based on using ADMS-Urban 4.0. The interface of other versions of ADMS (e.g. ADMS-Roads, or versions before or after 4.0) may vary slightly.

Before an ADMS run can be undertaken, a .upl file must be created. This may be done using ADMS' 'import file' capabilities:

1. Firstly, open ADMS – see Figure 21;

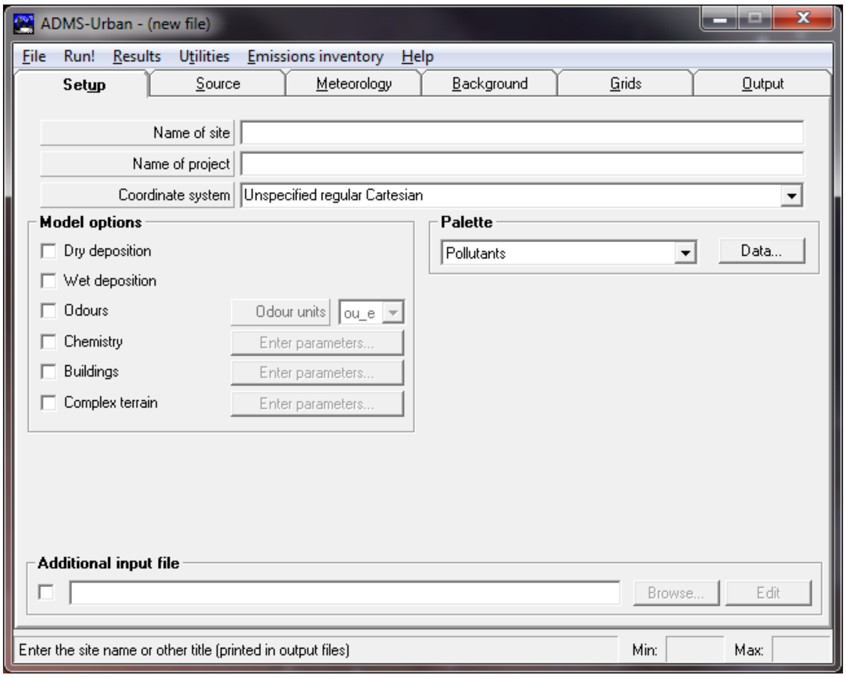


Figure 21: ADMS Main interface

2. Select 'File'->'Import' and the 'Import Wizard' should appear – see Figure 22;

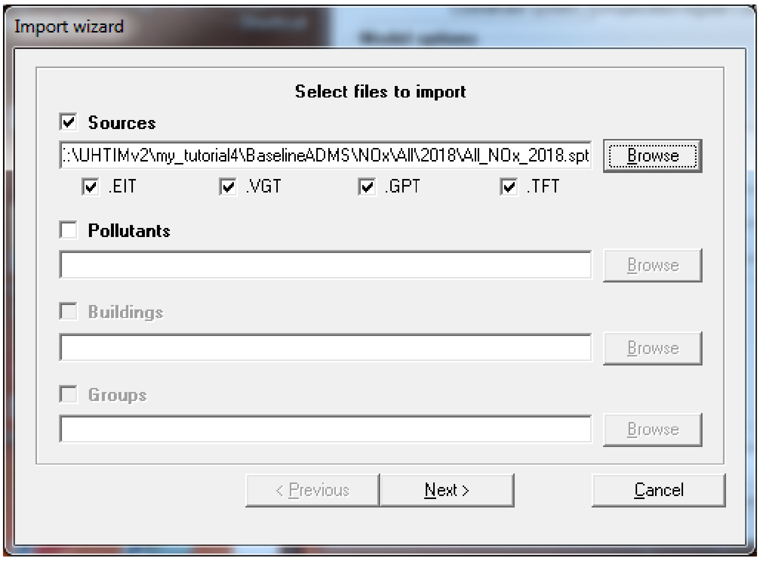


Figure 22: ADMS Import Wizard

3. In the 'Import Wizard', make sure the '.EIT', '.VGT', '.GPT' and '.TFT' checkboxes are ticked;
4. Click the 'Browse' button and navigate to the the correct '.SPT' file in either the '<project_path>\BaselineADMS' or '<project_path>\SiteActiveADMS' sub-directory;

5. Click the ‘Next >’ button, and you should see a confirmation screen for importing a number of sources of type ‘Road’ – see Figure 23;

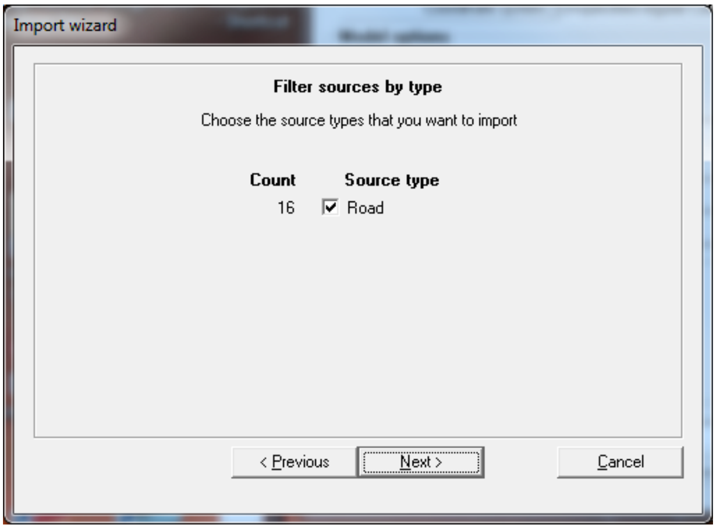


Figure 23: Source Type selection confirmation

6. Click the ‘Next >’ button, and the source selection screen should appear. Hit the ‘Add all >>’ button to transfer sources from the ‘Excluded’ list to the ‘Included’ list, then hit ‘Next >’ – see Figure 24;

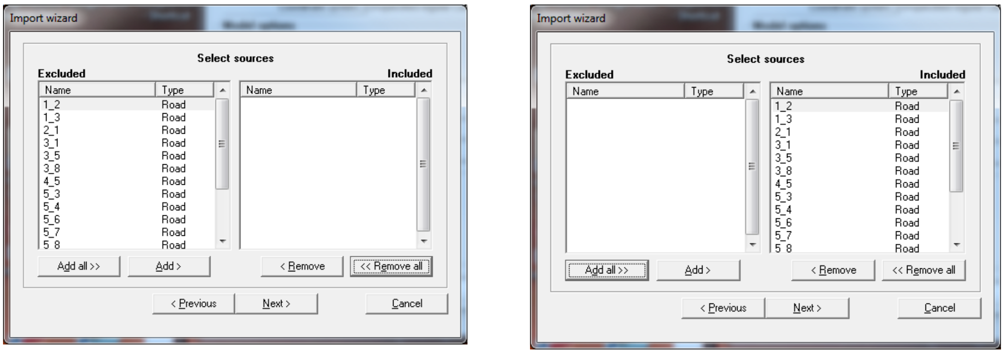


Figure 24: Selecting individual sources – moving roads from ‘excluded’ to ‘included’ lists

7. A final confirmation dialog should appear – see Figure 25. Hit the ‘Import’ button to create the sources in ADMS – you should get confirmation of a successful import.

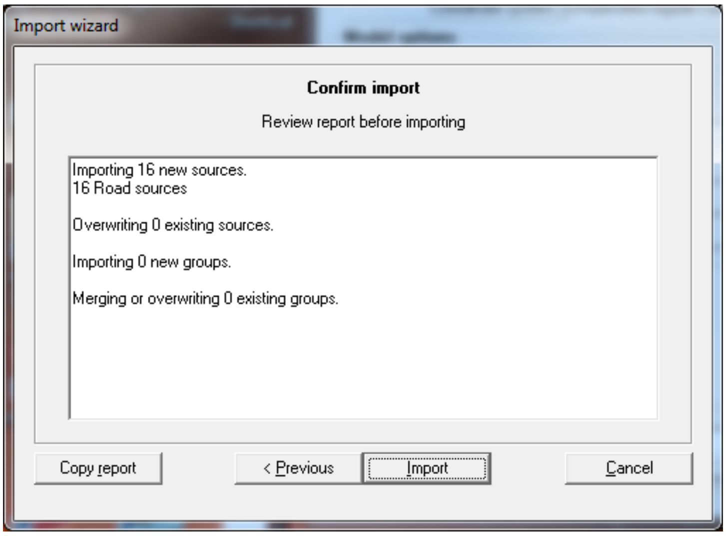


Figure 25: Final Import confirmation

8. The final import step is to add the time-varying emissions factors to the sources. Hit the ‘Source’ tab on ADMS (Figure 26), then check ‘Time varying emission factors’ at the bottom of the page. This should activate the ‘Data source…’ button, and allow selection of the ‘.fac’ file;

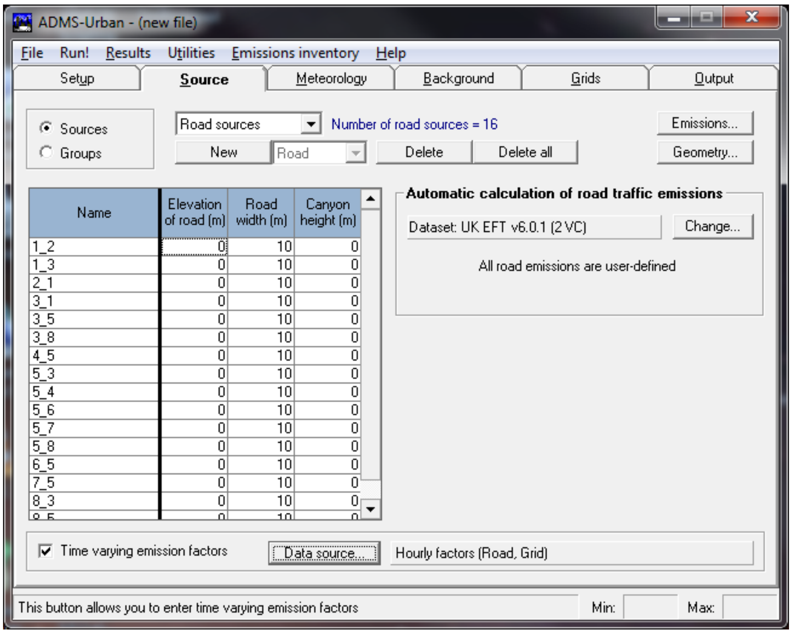


Figure 26: ADMS Source tab

9. In the ‘Time varying emissions factors’ dialog (Figure 27), ensure the ‘File of time varying factors’ radio option is checked, then select the ‘.hfc file’ check box, and ‘Browse…’ to the correct ‘.hfc’ file in either the ‘<project_path>\BaselineADMS’ or ‘<project_path>\SiteActiveADMS’ sub-directory.

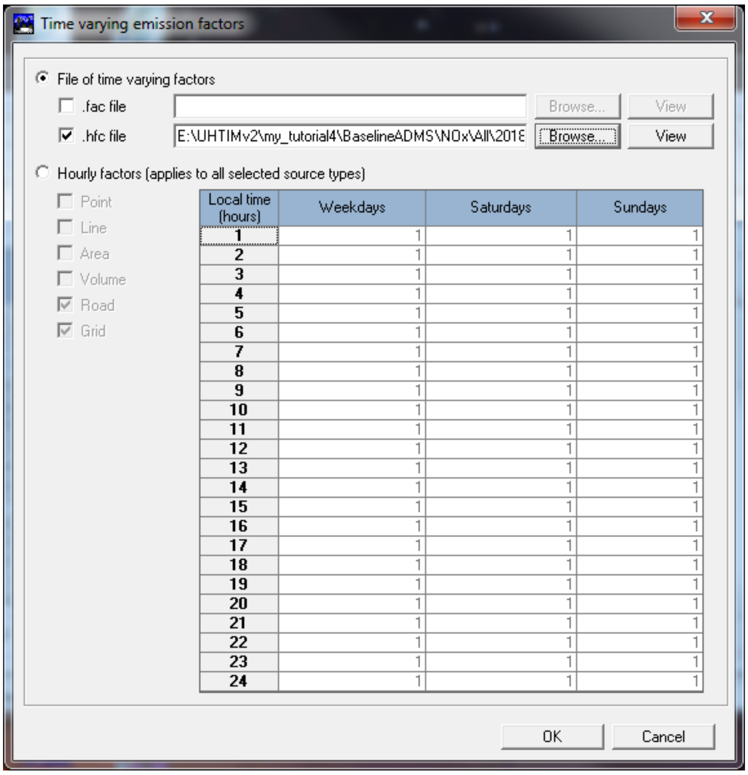


Figure 27: Time varying factors selection

Having completed these stages, the rest of the ADMS run should be set up as normal – i.e. data entry on all other tabs (‘Setup’, ‘Meteorology’, ‘Background’, ‘Grids’ and ‘Output’) needs to be completed. The user may then save the final ‘.upl’ file, and initiate an ADMS run. As noted previously, due to the way UHTIMv2 processes data for ‘.spl’ and ‘.hfc’ files, one ADMS run is required for each pollutant required.

Figures 28 shows sample ADMS long-term annual average grid (.glt) outputs, for NO_x, processed in ESRI ArcGIS, for the Baseline case (top-left) and the Site Active case (top-right) using ‘my_tutorial3’ data from the previous section. A non-linear, geometric colour scale is used for the top images to bring out small concentration changes between the two scenarios. The final image (bottom) presents these changes a bit more clearly using a difference map created by subtracting the ‘Baseline’ data from the ‘Site Active’ data.

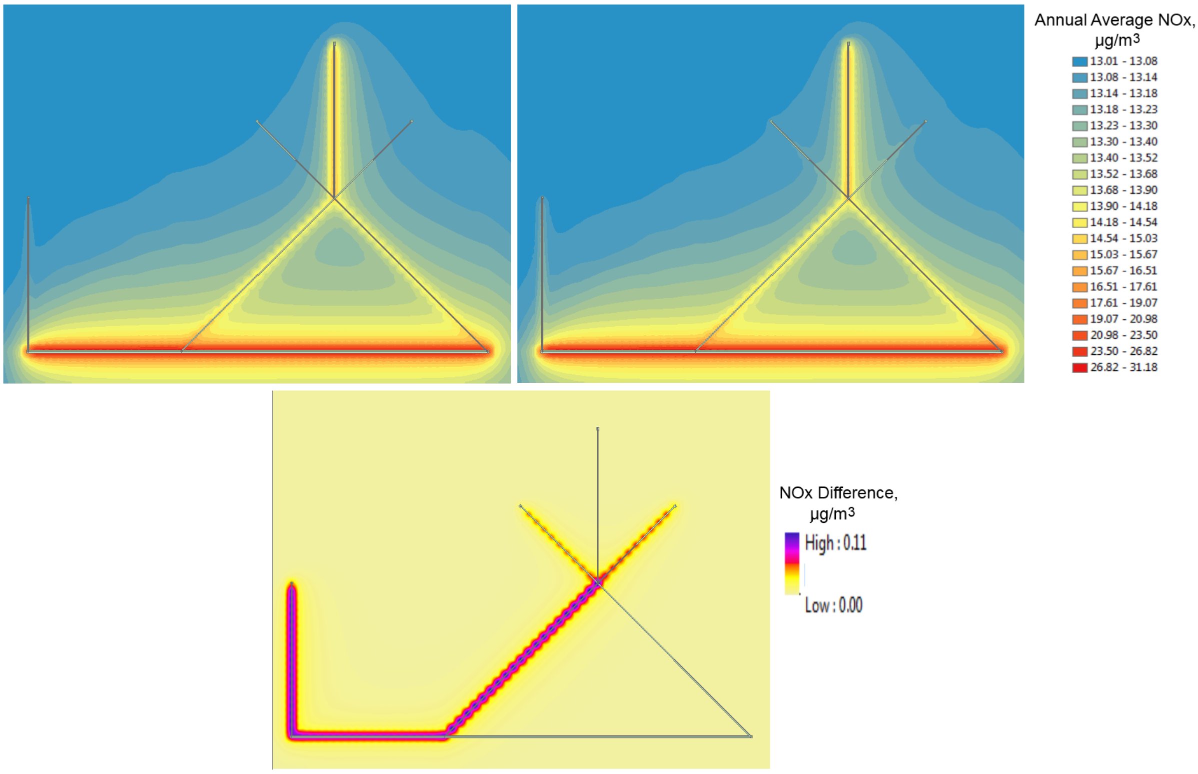


Figure 28: Example ADMS results based on ‘my_tutorial3’ files. Top-left: ‘Baseline’ Annual average NO_x concentrations, Top-Right: ‘Site-Active’ Annual average NO_x concentrations, Bottom: Difference map between the two scenarios.

The run was completed using 2017 Newcastle met data (prevailing wind direction: WSW), and assuming a background NO_x level of 13 µg/m^3. Note that, even in this six-well/two-wells active simultaneously case, the maximum increase in annual level is limited to 0.11 µg/m^3, thought further analysis of the short-term data (e.g. ADMS ‘comprehensive output file’ NetCDF (.nc) data and conversion og NOx data to NO2 data would be required to ascertain if any pollution standard exceedence events actually occurred.

References:

AASHTO. (1986). *Guide for the Design of Pavement Structures*. American Association of State Highway and Transportation Officials. Washington D.C., US.

CERC (2016). ADMS-Urban, Urban Air Quality Management System Version 4.0 User Guide. Cambridge Environmental Research Consultants. Cambridge, UK.

CERC (2018). *ADMS (Air-pollution Dispersion Modelling System) Software*. Cambridge Environmental Research Consultants. Cambridge, UK. Online resource: http://www.cerc.co.uk/index.php [Accessed: 12/07/18].

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Goodman, P.S., Galatioto, F., Thorpe, N., Namdeo, A.K., Davies, R.J. and Bird, R.N. (2016) Investigating the Pollution-related environmental impacts of hydraulic fracturing (Fracking) operations. *Environment International* 2016, **89-90**, pp 248-260.

Goodman, P.S. and Thorpe, N. (2017). *Unconventional Hydrocarbons: Pollution Impacts Model*. Online resource: https://research.ncl.ac.uk/uhtim/ [Accessed: 12/07/2018].

Kephalopoulos, S., Paviotti, M. and Anfosso-Lédée, F. (2012). *Common Noise Assessment Methodologies in Europe. To be used by the EU Member States for strategic noise mapping following adoption as specified in the Environmental Noise Directive 2002/49/EC*. Joint Research Centre (JRC) Institute for Health and Consumer Protection, Ispra, Italy. Report EUR 25379 EN. Online resource: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC72550/cnossos-eu%20jrc%20reference%20report_final_on%20line%20version_10%20august%202012.pdf [Accessed: 12/07/2018].

NAEI. 2011. *Vehicle fleet projections (Base 2011)*. UK National Atmospheric Emissions Inventory. Online resource: http://naei.defra.gov.uk/data/ef-transport?f_datachunk_id=328 [Accessed: 12/07/2018].

Pang, Y. and Murrells, T. (2013). *Emissions factors for alternative vehicle technologies*. National Atmospheric Emissions Inventory. NAEI Reference3 ED57423001. Online resource: http://naei.defra.gov.uk/resources/NAEI_Emisison_factors_for_alternative_vehicle_technologies_Final_Feb_13.pdf [Accessed: 12/07/18].

Worrall, F., Clancy, S.A., Goodman, P.S., Thorpe, N., Willis, S. (2017). *Final Report on Impact of Well Site Infrastructure and Transport*. Deliverable 12.6 of the M4ShaleGas (Measuring, monitoring, mitigating and managing the environmental impact of shale gas) project. Online resource: http://www.m4shalegas.eu/downloads/SP2/M4ShaleGas%20-%20D12.6%20-%20Impact%20of%20well%20site%20infrastructure%20and%20transport%20-%20Dec.%202017.pdf [Accessed 03/07/18].

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strong_ptr

Author: Ralph Shane
Source: Github
Date: 2013
License Terms:
Strong and Weak pointer implementations: strong_ptr - simple reference counted pointer.
Copyright (c) 2013, Ralph Shane <free2000fly at gmail dot com>
This is a non-intrusive implementation that allocates an additional int and pointer for every counted object.
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DeleteDirectory

Author: Andreas Masur
Source: Codeguru.com: http://forums.codeguru.com/showthread.php?239271-Windows-SDK-File-System-How-to-delete-a-directory-and-subdirectories
Date: 2003
License Terms: https://enterprise.dejacode.com/licenses/public/codeguru-permissions/#essentials

GetFilesInDirectory

Author: Andreas Bonini
Source: StackExchange.com
Date: 2008
License Terms: MIT License: https://meta.stackexchange.com/questions/271080/the-mit-license-clarity-on-using-code-on-stack-overflow-and-stack-exchange

ArrayLength

Author: Michael Burr/Google Chromium
Source: StackExchange.com
Date: 2008

License Terms: MIT License: https://meta.stackexchange.com/questions/271080/the-mit-license-clarity-on-using-code-on-stack-overflow-and-stack-exchange

StringFormat

Author: Erik Aronesty
Source: StackExchange.com
Date: 2017
License Terms: MIT License: https://meta.stackexchange.com/questions/271080/the-mit-license-clarity-on-using-code-on-stack-overflow-and-stack-exchange

StringEqual

Author: Kirill V. Lyadvinsky
Source: StackExchange.com
Date: 2015
License Terms: MIT License: https://meta.stackexchange.com/questions/271080/the-mit-license-clarity-on-using-code-on-stack-overflow-and-stack-exchange

DateToJulianDay/JulianDayToDate

Author: US Navy Astronomical Applications Department
Source: http://aa.usno.navy.mil/faq/docs/JD_Formula.php
Date: 2015
License Terms: Public Domain

strnatcmp

Author: Martin Pool
Source: sourcefrog.net
Date: 2004
License Terms:

strnatcmp.c -- Perform 'natural order' comparisons of strings in C. Copyright (C) 2000, 2004 by Martin Pool <mbp sourcefrog net> This software is provided 'as-is', without any express or implied warranty. In no event will the authors be held liable for any damages arising from the use of this software. Permission is granted to anyone to use this software for any purpose, including commercial applications, and to alter it and redistribute it freely, subject to the following restrictions: 1. The origin of this software must not be misrepresented; you must not claim that you wrote the original software. If you use this software in a product, an acknowledgment in the product documentation would be appreciated but is not required. 2. Altered source versions must be plainly marked as such, and must not be misrepresented as being the original software. 3. This notice may not be removed or altered from any source distribution.

Geometric tests and functions

Author: Joseph O'Rourke
Source: Book: Computational Geometry in C (2nd Edition), Cambridge University Press : http://cs.smith.edu/~jorourke/books/ftp.html.
Date: 1998.
License terms: Unknown

BOOST Graph Libraries/BOOST Lexical Cast/BOOST Multiprecison/BOOST Optional

Authors: J Siek, Lie-Quan Lee, Andrew Lumsdaine (Graph), K Henney, A Nasonov, A Polukin (Lexical Cast), J Maddock, C Kormanyos (Multiprecision), FLC Carballal, A Krzeminski (Optional)
Date: 2017
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Shapelib v.1.30

Author: Frank Warmerdam

Date: 1999

Source: http://shapelib.maptools.org

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Appendix A: Potential sources of UK traffic data

A.1: Flow on Primary Roads:

Quarterly and annual traffic flow information from detectors on the UK primary road network may be found at: https://www.dft.gov.uk/traffic-counts/. Figure A.1 shows the DfT's on-line interactive traffic count data selector.

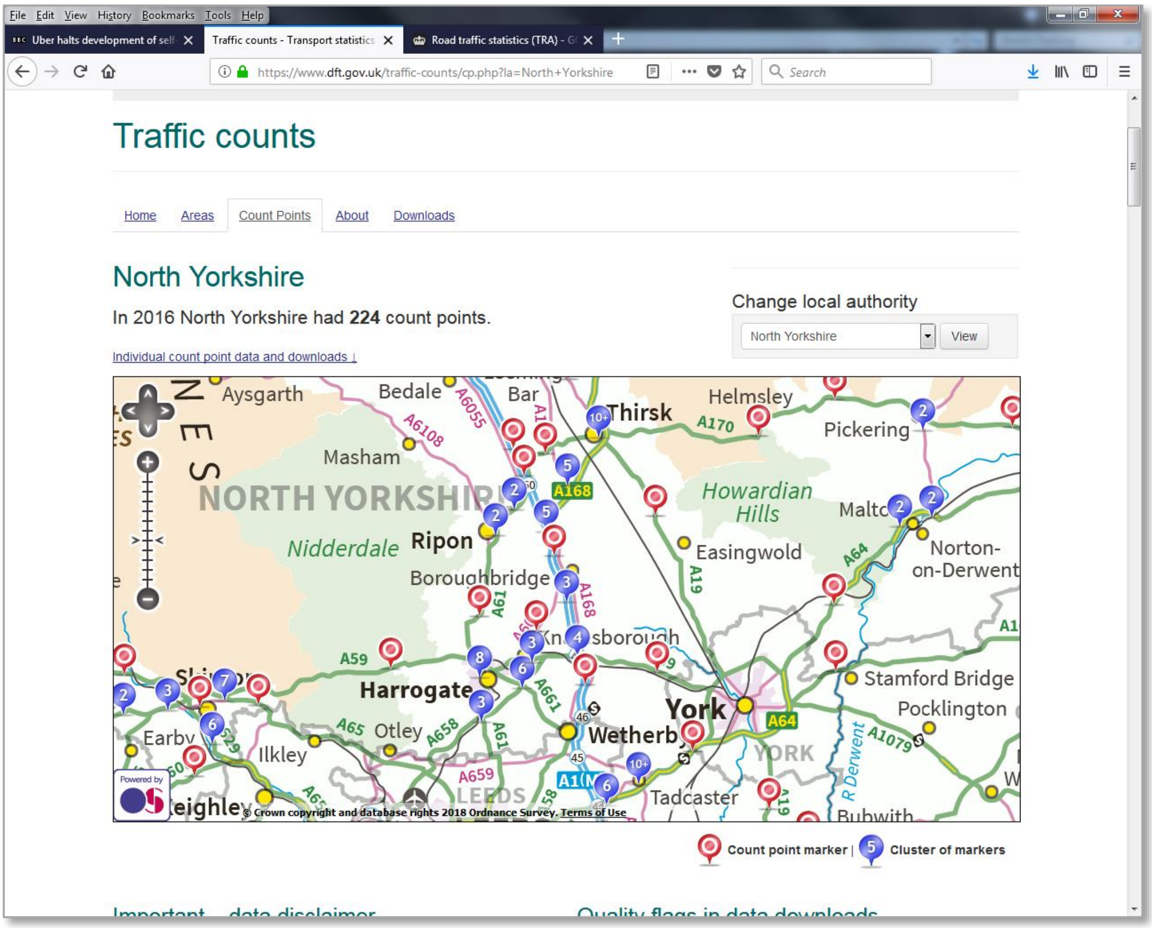


Figure A.1: DfT On-line traffic count data selection tool

The downside to using the tool is that it's coverage is limited to spot locations on the Primary road network, which leaves many secondary and tertiary roads, uncovered. These, unfortunately, are precisely the kinds of road that could be affected by substantive development of unconventional resources.

A.2: Diurnal Traffic Variations:

Diurnal flow variations by day-of-week in annual flows on UK roads may be found at: https://www.gov.uk/government/statistical-data-sets/road-traffic-statistics-tra - specifically Tables TRA0307 and TRA0308.

For example, a sample of the diurnal traffic profiles by day-of-week (DfT Table TRA0307), are presented in Figure A.2. These average profiles are weighted by type of road, across a representative sample of all roads in the UK, and can be used to provide appropriate scaling factors when generating weekly traffic profiles – if more locally-relevant data cannot be sourced.

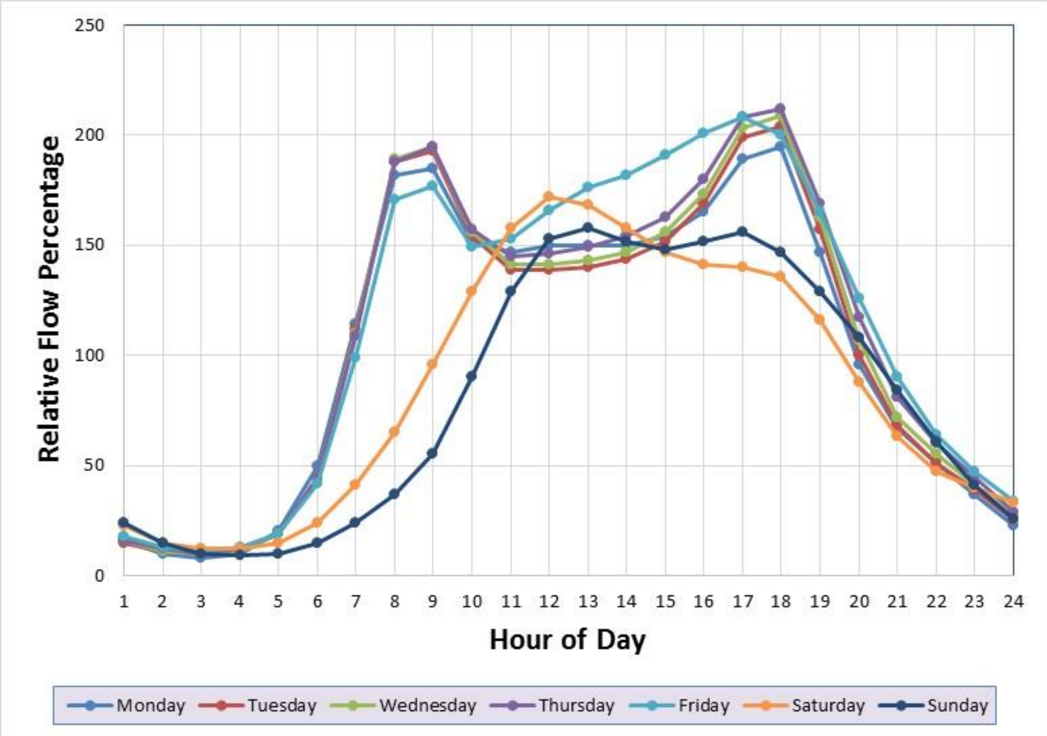


Figure A.2: Sample hourly diurnal traffic profiles (all traffic, all types of road) by day-of-week

Data from Figure A.2 has been used in the calculation of scaling factors for flows in the 'Tutorial' secton.

Appendix B: Vehicle types defined in the default 'Vehicles_Base_Table.csv' file

The following tables give the keys and ID numbers of all vehicles defined in the default installation files. These are derived from the vehicle hierarchy in the Emission Factor Toolkit (EFT) v5.1.3 (DEFRA, 2012), and alternate-fuel vehicles (Pang and Murrells, 2013). The structure of the hierarchy is:

- Chassis Type
    - Chassis sub-type
        - Weight
            - Fuel
                - Engine size
                    - Engine/exhaust technology

Levels in the hierarchy are separated by the '|' character. The EFT and NAEI are discussed in detail in Appendix C.

The following abbreviations are used in the engine/exhaust technology descriptions.

- CAT_FAIL – Catalytic converter failure
- DPF – Diesel particle filter
- DPF_FAIL – Diesel particle filter failure
- DPFRF – Diesel particle filter retrofit
- DPFSCR_RF - Diesel particle filter and selective catalytic reduction retrofit
- EGR – Exhaust gas recirculation
- HEV – Hybrid electric vehicle
- PHEV – Plug-in hybrid electric vehicle
- SCR – Selective catalytic reduction
- SCR_FAIL – SCR catalyst fail
- SCRRF – Selective catalytic reduction retrofit

B.1: Cars

Table B.1 Petrol and Petrol-hybrid Cars

1	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Pre-Euro|	33	Car|Car|0.0-2.5t|Petrol|2.0+l|Pre-Euro|
2	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_1|	34	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_1|
3	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_2|	35	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_2|
4	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_3|	36	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_3|
5	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_4|	37	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_4|
6	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_5|	38	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_5|
7	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_6|	39	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_6|
8	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_1_CAT_FAIL|	40	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_1_CAT_FAIL|
9	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_2_CAT_FAIL|	41	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_2_CAT_FAIL|
10	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_3_CAT_FAIL|	42	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_3_CAT_FAIL|
11	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_4_CAT_FAIL|	43	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_4_CAT_FAIL|
12	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_5_CAT_FAIL|	44	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_5_CAT_FAIL|
13	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_6_CAT_FAIL|	45	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_6_CAT_FAIL|
14	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_4_HEV|	46	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_4_HEV|
15	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_5_HEV|	47	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_5_HEV|
16	Car|Car|0.0-2.5t|Petrol|0.0-1.4l|Euro_5_PHEV|	48	Car|Car|0.0-2.5t|Petrol|2.0+l|Euro_5_PHEV|
17	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Pre-Euro|	91	Car|Car|2.5-3.5t|Petrol|All|Pre-Euro|
18	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_1|	92	Car|Car|2.5-3.5t|Petrol|All|Euro_1|
19	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_2|	93	Car|Car|2.5-3.5t|Petrol|All|Euro_2|
20	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_3|	94	Car|Car|2.5-3.5t|Petrol|All|Euro_3|
21	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_4|	95	Car|Car|2.5-3.5t|Petrol|All|Euro_4|
22	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_5|	96	Car|Car|2.5-3.5t|Petrol|All|Euro_5|
23	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_6|	97	Car|Car|2.5-3.5t|Petrol|All|Euro_6|
24	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_1_CAT_FAIL|	98	Car|Car|2.5-3.5t|Petrol|All|Euro_1_CAT_FAIL|
25	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_2_CAT_FAIL|	99	Car|Car|2.5-3.5t|Petrol|All|Euro_2_CAT_FAIL|
26	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_3_CAT_FAIL|	100	Car|Car|2.5-3.5t|Petrol|All|Euro_3_CAT_FAIL|
27	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_4_CAT_FAIL|	101	Car|Car|2.5-3.5t|Petrol|All|Euro_4_CAT_FAIL|
28	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_5_CAT_FAIL|	102	Car|Car|2.5-3.5t|Petrol|All|Euro_5_CAT_FAIL|
29	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_6_CAT_FAIL|	103	Car|Car|2.5-3.5t|Petrol|All|Euro_6_CAT_FAIL|
30	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_4_HEV|	104	Car|Car|2.5-3.5t|Petrol|All|Euro_4_HEV|
31	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_5_HEV|	105	Car|Car|2.5-3.5t|Petrol|All|Euro_5_HEV|
32	Car|Car|0.0-2.5t|Petrol|1.4-2.0l|Euro_5_PHEV|	106	Car|Car|2.5-3.5t|Petrol|All|Euro_5_PHEV|

Table B.2 Diesel and Diesel-hybrid Cars

49	Car|Car|0.0-2.5t|Diesel|0.0-1.4l|Pre-Euro|	73	Car|Car|0.0-2.5t|Diesel|2.0+l|Pre-Euro|
50	Car|Car|0.0-2.5t|Diesel|0.0-1.4l|Euro_1|	74	Car|Car|0.0-2.5t|Diesel|2.0+l|Euro_1|
51	Car|Car|0.0-2.5t|Diesel|0.0-1.4l|Euro_2|	75	Car|Car|0.0-2.5t|Diesel|2.0+l|Euro_2|
52	Car|Car|0.0-2.5t|Diesel|0.0-1.4l|Euro_3|	76	Car|Car|0.0-2.5t|Diesel|2.0+l|Euro_3|
53	Car|Car|0.0-2.5t|Diesel|0.0-1.4l|Euro_4|	77	Car|Car|0.0-2.5t|Diesel|2.0+l|Euro_4|
54	Car|Car|0.0-2.5t|Diesel|0.0-1.4l|Euro_5|	78	Car|Car|0.0-2.5t|Diesel|2.0+l|Euro_5|
55	Car|Car|0.0-2.5t|Diesel|0.0-1.4l|Euro_6|	79	Car|Car|0.0-2.5t|Diesel|2.0+l|Euro_6|
56	Car|Car|0.0-2.5t|Diesel|0.0-1.4l|Euro_3_DPF|	80	Car|Car|0.0-2.5t|Diesel|2.0+l|Euro_3_DPF|
57	Car|Car|0.0-2.5t|Diesel|0.0-1.4l|Euro_4_DPF|	81	Car|Car|0.0-2.5t|Diesel|2.0+l|Euro_4_DPF|
58	Car|Car|0.0-2.5t|Diesel|0.0-1.4l|Euro_5_DPF_FAIL|	82	Car|Car|0.0-2.5t|Diesel|2.0+l|Euro_5_DPF_FAIL|
59	Car|Car|0.0-2.5t|Diesel|0.0-1.4l|Euro_6_DPF_FAIL|	83	Car|Car|0.0-2.5t|Diesel|2.0+l|Euro_6_DPF_FAIL|
60	Car|Car|0.0-2.5t|Diesel|0.0-1.4l|Euro_6_CAT_FAIL|	84	Car|Car|0.0-2.5t|Diesel|2.0+l|Euro_6_CAT_FAIL|
61	Car|Car|0.0-2.5t|Diesel|1.4-2.0l|Pre-Euro|	107	Car|Car|2.5-3.5t|Diesel|All|Pre-Euro|
62	Car|Car|0.0-2.5t|Diesel|1.4-2.0l|Euro_1|	108	Car|Car|2.5-3.5t|Diesel|All|Euro_1|
63	Car|Car|0.0-2.5t|Diesel|1.4-2.0l|Euro_2|	109	Car|Car|2.5-3.5t|Diesel|All|Euro_2|
64	Car|Car|0.0-2.5t|Diesel|1.4-2.0l|Euro_3|	110	Car|Car|2.5-3.5t|Diesel|All|Euro_3|
65	Car|Car|0.0-2.5t|Diesel|1.4-2.0l|Euro_4|	111	Car|Car|2.5-3.5t|Diesel|All|Euro_4|
66	Car|Car|0.0-2.5t|Diesel|1.4-2.0l|Euro_5|	112	Car|Car|2.5-3.5t|Diesel|All|Euro_5|
67	Car|Car|0.0-2.5t|Diesel|1.4-2.0l|Euro_6|	113	Car|Car|2.5-3.5t|Diesel|All|Euro_6|
68	Car|Car|0.0-2.5t|Diesel|1.4-2.0l|Euro_3_DPF|	114	Car|Car|2.5-3.5t|Diesel|All|Euro_3_DPF|
69	Car|Car|0.0-2.5t|Diesel|1.4-2.0l|Euro_4_DPF|	115	Car|Car|2.5-3.5t|Diesel|All|Euro_4_DPF|
70	Car|Car|0.0-2.5t|Diesel|1.4-2.0l|Euro_5_DPF_FAIL|	116	Car|Car|2.5-3.5t|Diesel|All|Euro_5_DPF_FAIL|
71	Car|Car|0.0-2.5t|Diesel|1.4-2.0l|Euro_6_DPF_FAIL|	117	Car|Car|2.5-3.5t|Diesel|All|Euro_6_DPF_FAIL|
72	Car|Car|0.0-2.5t|Diesel|1.4-2.0l|Euro_6_CAT_FAIL|	118	Car|Car|2.5-3.5t|Diesel|All|Euro_6_CAT_FAIL|

Table B.3: Liquid Petroleum Gas (LPG) Cars

85	Car|Car|0.0-2.5t|LPG|All|Euro_1|	88	Car|Car|0.0-2.5t|LPG|All|Euro_4|
86	Car|Car|0.0-2.5t|LPG|All|Euro_2|	89	Car|Car|0.0-2.5t|LPG|All|Euro_5|
87	Car|Car|0.0-2.5t|LPG|All|Euro_3|	90	Car|Car|0.0-2.5t|LPG|All|Euro_6|

Table B.4: Taxis (Black Cabs)

119	Taxi|Black_Cab|All|Diesel|All|Pre-Euro|	123	Taxi|Black_Cab|All|Diesel|All|Euro_4|
120	Taxi|Black_Cab|All|Diesel|All|Euro_1|	124	Taxi|Black_Cab|All|Diesel|All|Euro_5|
121	Taxi|Black_Cab|All|Diesel|All|Euro_2|	125	Taxi|Black_Cab|All|Diesel|All|Euro_6|
122	Taxi|Black_Cab|All|Diesel|All|Euro_3|		

B.2: Light Goods Vehicles (LGVS)

Table B.5: Light Goods Vehicles (Class N1(I))

126	LGV|VanN1(I)|All|Petrol|All|Pre-Euro|	142	LGV|VanN1(I)|All|Diesel|All|Pre-Euro|
127	LGV|VanN1(I)|All|Petrol|All|Euro_1|	143	LGV|VanN1(I)|All|Diesel|All|Euro_1|
128	LGV|VanN1(I)|All|Petrol|All|Euro_2|	144	LGV|VanN1(I)|All|Diesel|All|Euro_2|
129	LGV|VanN1(I)|All|Petrol|All|Euro_3|	145	LGV|VanN1(I)|All|Diesel|All|Euro_3|
130	LGV|VanN1(I)|All|Petrol|All|Euro_4|	146	LGV|VanN1(I)|All|Diesel|All|Euro_4|
131	LGV|VanN1(I)|All|Petrol|All|Euro_5|	147	LGV|VanN1(I)|All|Diesel|All|Euro_5|
132	LGV|VanN1(I)|All|Petrol|All|Euro_6|	148	LGV|VanN1(I)|All|Diesel|All|Euro_6|
133	LGV|VanN1(I)|All|Petrol|All|Euro_1_CAT_FAIL|	149	LGV|VanN1(I)|All|Diesel|All|Euro_1_DPFRF|
134	LGV|VanN1(I)|All|Petrol|All|Euro_2_CAT_FAIL|	150	LGV|VanN1(I)|All|Diesel|All|Euro_2_DPFRF|
135	LGV|VanN1(I)|All|Petrol|All|Euro_3_CAT_FAIL|	151	LGV|VanN1(I)|All|Diesel|All|Euro_3_DPFRF|
136	LGV|VanN1(I)|All|Petrol|All|Euro_4_CAT_FAIL|	152	LGV|VanN1(I)|All|Diesel|All|Euro_5_DPF_FAIL|
137	LGV|VanN1(I)|All|Petrol|All|Euro_5_CAT_FAIL|	153	LGV|VanN1(I)|All|Diesel|All|Euro_6_DPF_FAIL|
138	LGV|VanN1(I)|All|Petrol|All|Euro_6_CAT_FAIL|	154	LGV|VanN1(I)|All|Diesel|All|Euro_6_SCR_FAIL|
139	LGV|VanN1(I)|All|Petrol|All|Euro_4_HEV|		
140	LGV|VanN1(I)|All|Petrol|All|Euro_5_HEV|		
141	LGV|VanN1(I)|All|Petrol|All|Euro_5_PHEV|		

Table B.6: Light Goods Vehicles (Class N1(II))

155	LGV|VanN1(II)|All|Petrol|All|Pre-Euro|	171	LGV|VanN1(II)|All|Diesel|All|Pre-Euro|
156	LGV|VanN1(II)|All|Petrol|All|Euro_1|	172	LGV|VanN1(II)|All|Diesel|All|Euro_1|
157	LGV|VanN1(II)|All|Petrol|All|Euro_2|	173	LGV|VanN1(II)|All|Diesel|All|Euro_2|
158	LGV|VanN1(II)|All|Petrol|All|Euro_3|	174	LGV|VanN1(II)|All|Diesel|All|Euro_3|
159	LGV|VanN1(II)|All|Petrol|All|Euro_4|	175	LGV|VanN1(II)|All|Diesel|All|Euro_4|
160	LGV|VanN1(II)|All|Petrol|All|Euro_5|	176	LGV|VanN1(II)|All|Diesel|All|Euro_5|
161	LGV|VanN1(II)|All|Petrol|All|Euro_6|	177	LGV|VanN1(II)|All|Diesel|All|Euro_6|
162	LGV|VanN1(II)|All|Petrol|All|Euro_1_CAT_FAIL|	178	LGV|VanN1(II)|All|Diesel|All|Euro_1_DPFRF|
163	LGV|VanN1(II)|All|Petrol|All|Euro_2_CAT_FAIL|	179	LGV|VanN1(II)|All|Diesel|All|Euro_2_DPFRF|
164	LGV|VanN1(II)|All|Petrol|All|Euro_3_CAT_FAIL|	180	LGV|VanN1(II)|All|Diesel|All|Euro_3_DPFRF|
165	LGV|VanN1(II)|All|Petrol|All|Euro_4_CAT_FAIL|	181	LGV|VanN1(II)|All|Diesel|All|Euro_5_DPF_FAIL|
166	LGV|VanN1(II)|All|Petrol|All|Euro_5_CAT_FAIL|	182	LGV|VanN1(II)|All|Diesel|All|Euro_6_DPF_FAIL|
167	LGV|VanN1(II)|All|Petrol|All|Euro_6_CAT_FAIL|	183	LGV|VanN1(II)|All|Diesel|All|Euro_6_SCR_FAIL|
168	LGV|VanN1(II)|All|Petrol|All|Euro_4_HEV|		
169	LGV|VanN1(II)|All|Petrol|All|Euro_5_HEV|		
170	LGV|VanN1(II)|All|Petrol|All|Euro_5_PHEV|		

Table B.7: Light Goods Vehicles (Class N1(III))

184	LGV|VanN1(III)|All|Petrol|All|Pre-Euro|	200	LGV|VanN1(III)|All|Diesel|All|Pre-Euro|
185	LGV|VanN1(III)|All|Petrol|All|Euro_1|	201	LGV|VanN1(III)|All|Diesel|All|Euro_1|
186	LGV|VanN1(III)|All|Petrol|All|Euro_2|	202	LGV|VanN1(III)|All|Diesel|All|Euro_2|
187	LGV|VanN1(III)|All|Petrol|All|Euro_3|	203	LGV|VanN1(III)|All|Diesel|All|Euro_3|
188	LGV|VanN1(III)|All|Petrol|All|Euro_4|	204	LGV|VanN1(III)|All|Diesel|All|Euro_4|
189	LGV|VanN1(III)|All|Petrol|All|Euro_5|	205	LGV|VanN1(III)|All|Diesel|All|Euro_5|
190	LGV|VanN1(III)|All|Petrol|All|Euro_6|	206	LGV|VanN1(III)|All|Diesel|All|Euro_6|
191	LGV|VanN1(III)|All|Petrol|All|Euro_1_CAT_FAIL|	207	LGV|VanN1(III)|All|Diesel|All|Euro_1_DPFRF|
192	LGV|VanN1(III)|All|Petrol|All|Euro_2_CAT_FAIL|	208	LGV|VanN1(III)|All|Diesel|All|Euro_2_DPFRF|
193	LGV|VanN1(III)|All|Petrol|All|Euro_3_CAT_FAIL|	209	LGV|VanN1(III)|All|Diesel|All|Euro_3_DPFRF|
194	LGV|VanN1(III)|All|Petrol|All|Euro_4_CAT_FAIL|	210	LGV|VanN1(III)|All|Diesel|All|Euro_5_DPF_FAIL|
195	LGV|VanN1(III)|All|Petrol|All|Euro_5_CAT_FAIL|	211	LGV|VanN1(III)|All|Diesel|All|Euro_6_DPF_FAIL|
196	LGV|VanN1(III)|All|Petrol|All|Euro_6_CAT_FAIL|	212	LGV|VanN1(III)|All|Diesel|All|Euro_6_SCR_FAIL|
197	LGV|VanN1(III)|All|Petrol|All|Euro_4_HEV|		
198	LGV|VanN1(III)|All|Petrol|All|Euro_5_HEV|		
199	LGV|VanN1(III)|All|Petrol|All|Euro_5_PHEV|		

B.3: Heavy Goods Vehicles (HGVs)

Table B.8: Rigid Heavy Goods Vehicles

213	HGV|Rigid|3.5-7.5t|Diesel|All|Pre-Euro|	277	HGV|Rigid|20-26t|Diesel|All|Pre-Euro|
214	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_I|	278	HGV|Rigid|20-26t|Diesel|All|Euro_I|
215	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_II|	279	HGV|Rigid|20-26t|Diesel|All|Euro_II|
216	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_III|	280	HGV|Rigid|20-26t|Diesel|All|Euro_III|
217	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_IV|	281	HGV|Rigid|20-26t|Diesel|All|Euro_IV|
218	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_V_EGR|	282	HGV|Rigid|20-26t|Diesel|All|Euro_V_EGR|
219	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_V_SCR|	283	HGV|Rigid|20-26t|Diesel|All|Euro_V_SCR|
220	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_VI|	284	HGV|Rigid|20-26t|Diesel|All|Euro_VI|
221	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_I_DPFRF|	285	HGV|Rigid|20-26t|Diesel|All|Euro_I_DPFRF|
222	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_II_DPFRF|	286	HGV|Rigid|20-26t|Diesel|All|Euro_II_DPFRF|
223	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_III_DPFRF|	287	HGV|Rigid|20-26t|Diesel|All|Euro_III_DPFRF|
224	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_III_SCRRF|	288	HGV|Rigid|20-26t|Diesel|All|Euro_III_SCRRF|
225	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_III_DPFSCR_RF|	289	HGV|Rigid|20-26t|Diesel|All|Euro_III_DPFSCR_RF|
226	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_IV_DPFRF|	290	HGV|Rigid|20-26t|Diesel|All|Euro_IV_DPFRF|
227	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_IV_SCRRF|	291	HGV|Rigid|20-26t|Diesel|All|Euro_IV_SCRRF|
228	HGV|Rigid|3.5-7.5t|Diesel|All|Euro_IV_DPFSCR_RF|	292	HGV|Rigid|20-26t|Diesel|All|Euro_IV_DPFSCR_RF|
229	HGV|Rigid|7.5-12t|Diesel|All|Pre-Euro|	293	HGV|Rigid|26-28t|Diesel|All|Pre-Euro|
230	HGV|Rigid|7.5-12t|Diesel|All|Euro_I|	294	HGV|Rigid|26-28t|Diesel|All|Euro_I|
231	HGV|Rigid|7.5-12t|Diesel|All|Euro_II|	295	HGV|Rigid|26-28t|Diesel|All|Euro_II|
232	HGV|Rigid|7.5-12t|Diesel|All|Euro_III|	296	HGV|Rigid|26-28t|Diesel|All|Euro_III|
233	HGV|Rigid|7.5-12t|Diesel|All|Euro_IV|	297	HGV|Rigid|26-28t|Diesel|All|Euro_IV|
234	HGV|Rigid|7.5-12t|Diesel|All|Euro_V_EGR|	298	HGV|Rigid|26-28t|Diesel|All|Euro_V_EGR|
235	HGV|Rigid|7.5-12t|Diesel|All|Euro_V_SCR|	299	HGV|Rigid|26-28t|Diesel|All|Euro_V_SCR|
236	HGV|Rigid|7.5-12t|Diesel|All|Euro_VI|	300	HGV|Rigid|26-28t|Diesel|All|Euro_VI|
237	HGV|Rigid|7.5-12t|Diesel|All|Euro_I_DPFRF|	301	HGV|Rigid|26-28t|Diesel|All|Euro_I_DPFRF|
238	HGV|Rigid|7.5-12t|Diesel|All|Euro_II_DPFRF|	302	HGV|Rigid|26-28t|Diesel|All|Euro_II_DPFRF|
239	HGV|Rigid|7.5-12t|Diesel|All|Euro_III_DPFRF|	303	HGV|Rigid|26-28t|Diesel|All|Euro_III_DPFRF|
240	HGV|Rigid|7.5-12t|Diesel|All|Euro_III_SCRRF|	304	HGV|Rigid|26-28t|Diesel|All|Euro_III_SCRRF|
241	HGV|Rigid|7.5-12t|Diesel|All|Euro_III_DPFSCR_RF|	305	HGV|Rigid|26-28t|Diesel|All|Euro_III_DPFSCR_RF|
242	HGV|Rigid|7.5-12t|Diesel|All|Euro_IV_DPFRF|	306	HGV|Rigid|26-28t|Diesel|All|Euro_IV_DPFRF|
243	HGV|Rigid|7.5-12t|Diesel|All|Euro_IV_SCRRF|	307	HGV|Rigid|26-28t|Diesel|All|Euro_IV_SCRRF|
244	HGV|Rigid|7.5-12t|Diesel|All|Euro_IV_DPFSCR_RF|	308	HGV|Rigid|26-28t|Diesel|All|Euro_IV_DPFSCR_RF|
245	HGV|Rigid|12-14t|Diesel|All|Pre-Euro|	309	HGV|Rigid|28-32t|Diesel|All|Pre-Euro|
246	HGV|Rigid|12-14t|Diesel|All|Euro_I|	310	HGV|Rigid|28-32t|Diesel|All|Euro_I|
247	HGV|Rigid|12-14t|Diesel|All|Euro_II|	311	HGV|Rigid|28-32t|Diesel|All|Euro_II|
248	HGV|Rigid|12-14t|Diesel|All|Euro_III|	312	HGV|Rigid|28-32t|Diesel|All|Euro_III|
249	HGV|Rigid|12-14t|Diesel|All|Euro_IV|	313	HGV|Rigid|28-32t|Diesel|All|Euro_IV|
250	HGV|Rigid|12-14t|Diesel|All|Euro_V_EGR|	314	HGV|Rigid|28-32t|Diesel|All|Euro_V_EGR|
251	HGV|Rigid|12-14t|Diesel|All|Euro_V_SCR|	315	HGV|Rigid|28-32t|Diesel|All|Euro_V_SCR|
252	HGV|Rigid|12-14t|Diesel|All|Euro_VI|	316	HGV|Rigid|28-32t|Diesel|All|Euro_VI|
253	HGV|Rigid|12-14t|Diesel|All|Euro_I_DPFRF|	317	HGV|Rigid|28-32t|Diesel|All|Euro_I_DPFRF|
254	HGV|Rigid|12-14t|Diesel|All|Euro_II_DPFRF|	318	HGV|Rigid|28-32t|Diesel|All|Euro_II_DPFRF|
255	HGV|Rigid|12-14t|Diesel|All|Euro_III_DPFRF|	319	HGV|Rigid|28-32t|Diesel|All|Euro_III_DPFRF|
256	HGV|Rigid|12-14t|Diesel|All|Euro_III_SCRRF|	320	HGV|Rigid|28-32t|Diesel|All|Euro_III_SCRRF|
257	HGV|Rigid|12-14t|Diesel|All|Euro_III_DPFSCR_RF|	321	HGV|Rigid|28-32t|Diesel|All|Euro_III_DPFSCR_RF|
258	HGV|Rigid|12-14t|Diesel|All|Euro_IV_DPFRF|	322	HGV|Rigid|28-32t|Diesel|All|Euro_IV_DPFRF|
259	HGV|Rigid|12-14t|Diesel|All|Euro_IV_SCRRF|	323	HGV|Rigid|28-32t|Diesel|All|Euro_IV_SCRRF|
260	HGV|Rigid|12-14t|Diesel|All|Euro_IV_DPFSCR_RF|	324	HGV|Rigid|28-32t|Diesel|All|Euro_IV_DPFSCR_RF|
261	HGV|Rigid|14-20t|Diesel|All|Pre-Euro|	325	HGV|Rigid|32+t|Diesel|All|Pre-Euro|
262	HGV|Rigid|14-20t|Diesel|All|Euro_I|	326	HGV|Rigid|32+t|Diesel|All|Euro_I|
263	HGV|Rigid|14-20t|Diesel|All|Euro_II|	327	HGV|Rigid|32+t|Diesel|All|Euro_II|
264	HGV|Rigid|14-20t|Diesel|All|Euro_III|	328	HGV|Rigid|32+t|Diesel|All|Euro_III|
265	HGV|Rigid|14-20t|Diesel|All|Euro_IV|	329	HGV|Rigid|32+t|Diesel|All|Euro_IV|
266	HGV|Rigid|14-20t|Diesel|All|Euro_V_EGR|	330	HGV|Rigid|32+t|Diesel|All|Euro_V_EGR|
267	HGV|Rigid|14-20t|Diesel|All|Euro_V_SCR|	331	HGV|Rigid|32+t|Diesel|All|Euro_V_SCR|
268	HGV|Rigid|14-20t|Diesel|All|Euro_VI|	332	HGV|Rigid|32+t|Diesel|All|Euro_VI|
269	HGV|Rigid|14-20t|Diesel|All|Euro_I_DPFRF|	333	HGV|Rigid|32+t|Diesel|All|Euro_I_DPFRF|
270	HGV|Rigid|14-20t|Diesel|All|Euro_II_DPFRF|	334	HGV|Rigid|32+t|Diesel|All|Euro_II_DPFRF|
271	HGV|Rigid|14-20t|Diesel|All|Euro_III_DPFRF|	335	HGV|Rigid|32+t|Diesel|All|Euro_III_DPFRF|
272	HGV|Rigid|14-20t|Diesel|All|Euro_III_SCRRF|	336	HGV|Rigid|32+t|Diesel|All|Euro_III_SCRRF|
273	HGV|Rigid|14-20t|Diesel|All|Euro_III_DPFSCR_RF|	337	HGV|Rigid|32+t|Diesel|All|Euro_III_DPFSCR_RF|
274	HGV|Rigid|14-20t|Diesel|All|Euro_IV_DPFRF|	338	HGV|Rigid|32+t|Diesel|All|Euro_IV_DPFRF|
275	HGV|Rigid|14-20t|Diesel|All|Euro_IV_SCRRF|	339	HGV|Rigid|32+t|Diesel|All|Euro_IV_SCRRF|
276	HGV|Rigid|14-20t|Diesel|All|Euro_IV_DPFSCR_RF|	340	HGV|Rigid|32+t|Diesel|All|Euro_IV_DPFSCR_RF|

Table B.9: Articulated Heavy Goods Vehicles

341	HGV|Artic|14-20t|Diesel|All|Pre-Euro|	381	HGV|Artic|28-34t|Diesel|All|Euro_I_DPFRF|
342	HGV|Artic|14-20t|Diesel|All|Euro_I|	382	HGV|Artic|28-34t|Diesel|All|Euro_II_DPFRF|
343	HGV|Artic|14-20t|Diesel|All|Euro_II|	383	HGV|Artic|28-34t|Diesel|All|Euro_III_DPFRF|
344	HGV|Artic|14-20t|Diesel|All|Euro_III|	384	HGV|Artic|28-34t|Diesel|All|Euro_III_SCRRF|
345	HGV|Artic|14-20t|Diesel|All|Euro_IV|	385	HGV|Artic|28-34t|Diesel|All|Euro_III_DPFSCR_RF|
346	HGV|Artic|14-20t|Diesel|All|Euro_V_EGR|	386	HGV|Artic|28-34t|Diesel|All|Euro_IV_DPFRF|
347	HGV|Artic|14-20t|Diesel|All|Euro_V_SCR|	387	HGV|Artic|28-34t|Diesel|All|Euro_IV_SCRRF|
348	HGV|Artic|14-20t|Diesel|All|Euro_VI|	388	HGV|Artic|28-34t|Diesel|All|Euro_IV_DPFSCR_RF|
349	HGV|Artic|14-20t|Diesel|All|Euro_I_DPFRF|	389	HGV|Artic|34-40t|Diesel|All|Pre-Euro|
350	HGV|Artic|14-20t|Diesel|All|Euro_II_DPFRF|	390	HGV|Artic|34-40t|Diesel|All|Euro_I|
351	HGV|Artic|14-20t|Diesel|All|Euro_III_DPFRF|	391	HGV|Artic|34-40t|Diesel|All|Euro_II|
352	HGV|Artic|14-20t|Diesel|All|Euro_III_SCRRF|	392	HGV|Artic|34-40t|Diesel|All|Euro_III|
353	HGV|Artic|14-20t|Diesel|All|Euro_III_DPFSCR_RF|	393	HGV|Artic|34-40t|Diesel|All|Euro_IV|
354	HGV|Artic|14-20t|Diesel|All|Euro_IV_DPFRF|	394	HGV|Artic|34-40t|Diesel|All|Euro_V_EGR|
355	HGV|Artic|14-20t|Diesel|All|Euro_IV_SCRRF|	395	HGV|Artic|34-40t|Diesel|All|Euro_V_SCR|
356	HGV|Artic|14-20t|Diesel|All|Euro_IV_DPFSCR_RF|	396	HGV|Artic|34-40t|Diesel|All|Euro_VI|
357	HGV|Artic|20-28t|Diesel|All|Pre-Euro|	397	HGV|Artic|34-40t|Diesel|All|Euro_I_DPFRF|
358	HGV|Artic|20-28t|Diesel|All|Euro_I|	398	HGV|Artic|34-40t|Diesel|All|Euro_II_DPFRF|
359	HGV|Artic|20-28t|Diesel|All|Euro_II|	399	HGV|Artic|34-40t|Diesel|All|Euro_III_DPFRF|
360	HGV|Artic|20-28t|Diesel|All|Euro_III|	400	HGV|Artic|34-40t|Diesel|All|Euro_III_SCRRF|
361	HGV|Artic|20-28t|Diesel|All|Euro_IV|	401	HGV|Artic|34-40t|Diesel|All|Euro_III_DPFSCR_RF|
362	HGV|Artic|20-28t|Diesel|All|Euro_V_EGR|	402	HGV|Artic|34-40t|Diesel|All|Euro_IV_DPFRF|
363	HGV|Artic|20-28t|Diesel|All|Euro_V_SCR|	403	HGV|Artic|34-40t|Diesel|All|Euro_IV_SCRRF|
364	HGV|Artic|20-28t|Diesel|All|Euro_VI|	404	HGV|Artic|34-40t|Diesel|All|Euro_IV_DPFSCR_RF|
365	HGV|Artic|20-28t|Diesel|All|Euro_I_DPFRF|	405	HGV|Artic|40-50t|Diesel|All|Pre-Euro|
366	HGV|Artic|20-28t|Diesel|All|Euro_II_DPFRF|	406	HGV|Artic|40-50t|Diesel|All|Euro_I|
367	HGV|Artic|20-28t|Diesel|All|Euro_III_DPFRF|	407	HGV|Artic|40-50t|Diesel|All|Euro_II|
368	HGV|Artic|20-28t|Diesel|All|Euro_III_SCRRF|	408	HGV|Artic|40-50t|Diesel|All|Euro_III|
369	HGV|Artic|20-28t|Diesel|All|Euro_III_DPFSCR_RF|	409	HGV|Artic|40-50t|Diesel|All|Euro_IV|
370	HGV|Artic|20-28t|Diesel|All|Euro_IV_DPFRF|	410	HGV|Artic|40-50t|Diesel|All|Euro_V_EGR|
371	HGV|Artic|20-28t|Diesel|All|Euro_IV_SCRRF|	411	HGV|Artic|40-50t|Diesel|All|Euro_V_SCR|
372	HGV|Artic|20-28t|Diesel|All|Euro_IV_DPFSCR_RF|	412	HGV|Artic|40-50t|Diesel|All|Euro_VI|
373	HGV|Artic|28-34t|Diesel|All|Pre-Euro|	413	HGV|Artic|40-50t|Diesel|All|Euro_I_DPFRF|
374	HGV|Artic|28-34t|Diesel|All|Euro_I|	414	HGV|Artic|40-50t|Diesel|All|Euro_II_DPFRF|
375	HGV|Artic|28-34t|Diesel|All|Euro_II|	415	HGV|Artic|40-50t|Diesel|All|Euro_III_DPFRF|
376	HGV|Artic|28-34t|Diesel|All|Euro_III|	416	HGV|Artic|40-50t|Diesel|All|Euro_III_SCRRF|
377	HGV|Artic|28-34t|Diesel|All|Euro_IV|	417	HGV|Artic|40-50t|Diesel|All|Euro_III_DPFSCR_RF|
378	HGV|Artic|28-34t|Diesel|All|Euro_V_EGR|	418	HGV|Artic|40-50t|Diesel|All|Euro_IV_DPFRF|
379	HGV|Artic|28-34t|Diesel|All|Euro_V_SCR|	419	HGV|Artic|40-50t|Diesel|All|Euro_IV_SCRRF|
380	HGV|Artic|28-34t|Diesel|All|Euro_VI|	420	HGV|Artic|40-50t|Diesel|All|Euro_IV_DPFSCR_RF|

B.4 : Buses and Coaches

Table B.10: Buses and Coaches

421	Bus|Bus|0-15t|Diesel|All|Pre-Euro|	481	Bus|Bus|18t+|Diesel|All|Euro_IV|
422	Bus|Bus|0-15t|Diesel|All|Euro_I|	482	Bus|Bus|18t+|Diesel|All|Euro_V_EGR|
423	Bus|Bus|0-15t|Diesel|All|Euro_II|	483	Bus|Bus|18t+|Diesel|All|Euro_V_SCR|
424	Bus|Bus|0-15t|Diesel|All|Euro_III|	484	Bus|Bus|18t+|Diesel|All|Euro_VI|
425	Bus|Bus|0-15t|Diesel|All|Euro_IV|	485	Bus|Bus|18t+|Diesel|All|Euro_I_DPFRF|
426	Bus|Bus|0-15t|Diesel|All|Euro_V_EGR|	486	Bus|Bus|18t+|Diesel|All|Euro_II_DPFRF|
427	Bus|Bus|0-15t|Diesel|All|Euro_V_SCR|	487	Bus|Bus|18t+|Diesel|All|Euro_II_SCRRF|
428	Bus|Bus|0-15t|Diesel|All|Euro_VI|	488	Bus|Bus|18t+|Diesel|All|Euro_II_DPFSCR_RF|
429	Bus|Bus|0-15t|Diesel|All|Euro_I_DPFRF|	489	Bus|Bus|18t+|Diesel|All|Euro_III_DPFRF|
430	Bus|Bus|0-15t|Diesel|All|Euro_II_DPFRF|	490	Bus|Bus|18t+|Diesel|All|Euro_III_SCRRF|
431	Bus|Bus|0-15t|Diesel|All|Euro_II_SCRRF|	491	Bus|Bus|18t+|Diesel|All|Euro_III_DPFSCR_RF|
432	Bus|Bus|0-15t|Diesel|All|Euro_II_DPFSCR_RF|	492	Bus|Bus|18t+|Diesel|All|Euro_IV_DPFRF|
433	Bus|Bus|0-15t|Diesel|All|Euro_III_DPFRF|	493	Bus|Bus|18t+|Diesel|All|Euro_IV_SCRRF|
434	Bus|Bus|0-15t|Diesel|All|Euro_III_SCRRF|	494	Bus|Bus|18t+|Diesel|All|Euro_IV_DPFSCR_RF|
435	Bus|Bus|0-15t|Diesel|All|Euro_III_DPFSCR_RF|	495	Bus|Bus|18t+|Diesel|All|Euro_IV_HEV|
436	Bus|Bus|0-15t|Diesel|All|Euro_IV_DPFRF|	496	Bus|Bus|18t+|Diesel|All|Euro_V_EGR_HEV|
437	Bus|Bus|0-15t|Diesel|All|Euro_IV_SCRRF|	497	Bus|Bus|18t+|Diesel|All|Euro_V_SCR_HEV|
438	Bus|Bus|0-15t|Diesel|All|Euro_IV_DPFSCR_RF|	498	Bus|Bus|18t+|Diesel|All|Euro_VI_HEV|
439	Bus|Bus|0-15t|Diesel|All|Euro_IV_HEV|	499	Bus|Bus|18t+|Diesel|All|Euro_II_SCRRFNL|
440	Bus|Bus|0-15t|Diesel|All|Euro_V_EGR_HEV|	500	Bus|Bus|18t+|Diesel|All|Euro_II_DPFSCR_RFNL|
441	Bus|Bus|0-15t|Diesel|All|Euro_V_SCR_HEV|	501	Bus|Bus|18t+|Diesel|All|Euro_III_SCRRFNL|
442	Bus|Bus|0-15t|Diesel|All|Euro_VI_HEV|	502	Bus|Bus|18t+|Diesel|All|Euro_III_DPFSCR_RFNL|
443	Bus|Bus|0-15t|Diesel|All|Euro_II_SCRRFNL|	503	Bus|Bus|18t+|Diesel|All|Euro_IV_SCRRFNL|
444	Bus|Bus|0-15t|Diesel|All|Euro_II_DPFSCR_RFNL|	504	Bus|Bus|18t+|Diesel|All|Euro_IV_DPFSCR_RFNL|
445	Bus|Bus|0-15t|Diesel|All|Euro_III_SCRRFNL|	505	Bus|Coach|15-18t|Diesel|All|Pre-Euro|
446	Bus|Bus|0-15t|Diesel|All|Euro_III_DPFSCR_RFNL|	506	Bus|Coach|15-18t|Diesel|All|Euro_I|
447	Bus|Bus|0-15t|Diesel|All|Euro_IV_SCRRFNL|	507	Bus|Coach|15-18t|Diesel|All|Euro_II|
448	Bus|Bus|0-15t|Diesel|All|Euro_IV_DPFSCR_RFNL|	508	Bus|Coach|15-18t|Diesel|All|Euro_III|
449	Bus|Bus|15-18t|Diesel|All|Pre-Euro|	509	Bus|Coach|15-18t|Diesel|All|Euro_IV|
450	Bus|Bus|15-18t|Diesel|All|Euro_I|	510	Bus|Coach|15-18t|Diesel|All|Euro_V_EGR|
451	Bus|Bus|15-18t|Diesel|All|Euro_II|	511	Bus|Coach|15-18t|Diesel|All|Euro_V_SCR|
452	Bus|Bus|15-18t|Diesel|All|Euro_III|	512	Bus|Coach|15-18t|Diesel|All|Euro_VI|
453	Bus|Bus|15-18t|Diesel|All|Euro_IV|	513	Bus|Coach|15-18t|Diesel|All|Euro_I_DPFRF|
454	Bus|Bus|15-18t|Diesel|All|Euro_V_EGR|	514	Bus|Coach|15-18t|Diesel|All|Euro_II_DPFRF|
455	Bus|Bus|15-18t|Diesel|All|Euro_V_SCR|	515	Bus|Coach|15-18t|Diesel|All|Euro_II_SCRRF|
456	Bus|Bus|15-18t|Diesel|All|Euro_VI|	516	Bus|Coach|15-18t|Diesel|All|Euro_II_DPFSCR_RF|
457	Bus|Bus|15-18t|Diesel|All|Euro_I_DPFRF|	517	Bus|Coach|15-18t|Diesel|All|Euro_III_DPFRF|
458	Bus|Bus|15-18t|Diesel|All|Euro_II_DPFRF|	518	Bus|Coach|15-18t|Diesel|All|Euro_III_SCRRF|
459	Bus|Bus|15-18t|Diesel|All|Euro_II_SCRRF|	519	Bus|Coach|15-18t|Diesel|All|Euro_III_DPFSCR_RF|
460	Bus|Bus|15-18t|Diesel|All|Euro_II_DPFSCR_RF|	520	Bus|Coach|15-18t|Diesel|All|Euro_IV_DPFRF|
461	Bus|Bus|15-18t|Diesel|All|Euro_III_DPFRF|	521	Bus|Coach|15-18t|Diesel|All|Euro_IV_SCRRF|
462	Bus|Bus|15-18t|Diesel|All|Euro_III_SCRRF|	522	Bus|Coach|15-18t|Diesel|All|Euro_IV_DPFSCR_RF|
463	Bus|Bus|15-18t|Diesel|All|Euro_III_DPFSCR_RF|	523	Bus|Coach|18t+|Diesel|All|Pre-Euro|
464	Bus|Bus|15-18t|Diesel|All|Euro_IV_DPFRF|	524	Bus|Coach|18t+|Diesel|All|Euro_I|
465	Bus|Bus|15-18t|Diesel|All|Euro_IV_SCRRF|	525	Bus|Coach|18t+|Diesel|All|Euro_II|
466	Bus|Bus|15-18t|Diesel|All|Euro_IV_DPFSCR_RF|	526	Bus|Coach|18t+|Diesel|All|Euro_III|
467	Bus|Bus|15-18t|Diesel|All|Euro_IV_HEV|	527	Bus|Coach|18t+|Diesel|All|Euro_IV|
468	Bus|Bus|15-18t|Diesel|All|Euro_V_EGR_HEV|	528	Bus|Coach|18t+|Diesel|All|Euro_V_EGR|
469	Bus|Bus|15-18t|Diesel|All|Euro_V_SCR_HEV|	529	Bus|Coach|18t+|Diesel|All|Euro_V_SCR|
470	Bus|Bus|15-18t|Diesel|All|Euro_VI_HEV|	530	Bus|Coach|18t+|Diesel|All|Euro_VI|
471	Bus|Bus|15-18t|Diesel|All|Euro_II_SCRRFNL|	531	Bus|Coach|18t+|Diesel|All|Euro_I_DPFRF|
472	Bus|Bus|15-18t|Diesel|All|Euro_II_DPFSCR_RFNL|	532	Bus|Coach|18t+|Diesel|All|Euro_II_DPFRF|
473	Bus|Bus|15-18t|Diesel|All|Euro_III_SCRRFNL|	533	Bus|Coach|18t+|Diesel|All|Euro_II_SCRRF|
474	Bus|Bus|15-18t|Diesel|All|Euro_III_DPFSCR_RFNL|	534	Bus|Coach|18t+|Diesel|All|Euro_II_DPFSCR_RF|
475	Bus|Bus|15-18t|Diesel|All|Euro_IV_SCRRFNL|	535	Bus|Coach|18t+|Diesel|All|Euro_III_DPFRF|
476	Bus|Bus|15-18t|Diesel|All|Euro_IV_DPFSCR_RFNL|	536	Bus|Coach|18t+|Diesel|All|Euro_III_SCRRF|
477	Bus|Bus|18t+|Diesel|All|Pre-Euro|	537	Bus|Coach|18t+|Diesel|All|Euro_III_DPFSCR_RF|
478	Bus|Bus|18t+|Diesel|All|Euro_I|	538	Bus|Coach|18t+|Diesel|All|Euro_IV_DPFRF|
479	Bus|Bus|18t+|Diesel|All|Euro_II|	539	Bus|Coach|18t+|Diesel|All|Euro_IV_SCRRF|
480	Bus|Bus|18t+|Diesel|All|Euro_III|	540	Bus|Coach|18t+|Diesel|All|Euro_IV_DPFSCR_RF|

B.5: Powered Two-Wheelers (PTWs)

Table B.11: Powered Two-Wheelers

541	PTW|Mopeds|All|Petrol|0-50cc|Pre-Euro|
542	PTW|Mopeds|All|Petrol|0-50cc|Euro_1|
543	PTW|Mopeds|All|Petrol|0-50cc|Euro_2|
544	PTW|Mopeds|All|Petrol|0-50cc|Euro_3|
545	PTW|M/Cycles(2-stroke)|All|Petrol|0-150cc|Pre-Euro|
546	PTW|M/Cycles(2-stroke)|All|Petrol|0-150cc|Euro_1|
547	PTW|M/Cycles(2-stroke)|All|Petrol|0-150cc|Euro_2|
548	PTW|M/Cycles(2-stroke)|All|Petrol|0-150cc|Euro_3|
549	PTW|M/Cycles(2-stroke)|All|Petrol|150-250cc|Pre-Euro|
550	PTW|M/Cycles(2-stroke)|All|Petrol|150-250cc|Euro_1|
551	PTW|M/Cycles(2-stroke)|All|Petrol|150-250cc|Euro_2|
552	PTW|M/Cycles(2-stroke)|All|Petrol|150-250cc|Euro_3|
553	PTW|M/Cycles(4-stroke)|All|Petrol|0-150cc|Pre-Euro|
554	PTW|M/Cycles(4-stroke)|All|Petrol|0-150cc|Euro_1|
555	PTW|M/Cycles(4-stroke)|All|Petrol|0-150cc|Euro_2|
556	PTW|M/Cycles(4-stroke)|All|Petrol|0-150cc|Euro_3|
557	PTW|M/Cycles(4-stroke)|All|Petrol|150-250cc|Pre-Euro|
558	PTW|M/Cycles(4-stroke)|All|Petrol|150-250cc|Euro_1|
559	PTW|M/Cycles(4-stroke)|All|Petrol|150-250cc|Euro_2|
560	PTW|M/Cycles(4-stroke)|All|Petrol|150-250cc|Euro_3|
561	PTW|M/Cycles(4-stroke)|All|Petrol|250-750cc|Pre-Euro|
562	PTW|M/Cycles(4-stroke)|All|Petrol|250-750cc|Euro_1|
563	PTW|M/Cycles(4-stroke)|All|Petrol|250-750cc|Euro_2|
564	PTW|M/Cycles(4-stroke)|All|Petrol|250-750cc|Euro_3|
565	PTW|M/Cycles(4-stroke)|All|Petrol|750+cc|Pre-Euro|
566	PTW|M/Cycles(4-stroke)|All|Petrol|750+cc|Euro_1|
567	PTW|M/Cycles(4-stroke)|All|Petrol|750+cc|Euro_2|
568	PTW|M/Cycles(4-stroke)|All|Petrol|750+cc|Euro_3|

Appendix C: Environmental Models

This section briefly describes the environmental models considered and selected for application within the transport elements of the M4ShaleGas and ReFINE projects, resulting in UHTIM. The individual model components, utilised in UHTIM, cover:

- Local Air Quality (LAQ) emissions;
- Greenhouse Gas Emissions;
- Noise;
- Road Surface Wear;

Additional environmental appraisal elements considered, but ultimately not used, during the course of UHTIM development include:

- Vibration;
- Water Environment;
- Landscape, Townscape and Heritage aspects;
- Biodiversity;
- Journey stress and ambiance to other road users;

The individual modelling sections are intended to provide a brief context as to their inclusion in the study, the form of the model as implemented for ReFINE, discussion of the strengths and limitations of the approach, the form of outputs (and any relevant discussion as to how outputs should be interpreted) and recommendation on potential further improvements to each element.

Broadly, all of the models examined are intended to provide a 'broad-brush' examination of impacts, equivalent to a 'screening study' approach (see: DMRB Vol 11, HA, 2011). Models have been based on existing implementations found within Newcastle University's PITHEM (Platform for Integrated, Traffic, Health and Emissions Modelling) tool (Namdeo and Goodman, 2012; O'Brien *et al.*, 2014). The estimation of additional road surface wear is a bespoke addition for UHTIM.

NB: THE MAJORITY OF MATERIAL IN THIS APPENDIX WAS WRITTEN FOR THE FIRST VERSION OF UHTIM, BASED ON MODEL IMPLIMENTATION IN NEWCASTLE UNIVERSITIES' PITHEM TOOL. SOME ELEMENTS MAY THEREFORE BE OUT-OF-DATE – NOTABLY EXAMPLES IN FIGURES USE URBAN ROAD CONDITIONS WITH BASE YEARS AROUND 2010-2014. HOWEVER, BASIC MODELLING PRINCIPLES REMAIN THE SAME. A SEPARATE REFERENCE SECTION IS ALSO PROVIDED AT THE END OF THE APPENDIX.

C.1: The UK Emission Factor Toolkit

The Emissions Factor Toolkit covers both 'Regulated' Local Air Quality (LAQ) emissions, and emissions of the Greenhouse Gas (GHG) CO_2.

C.1.1: Local Air-Quality Emissions:

Since late 1997 local authorities in the UK have had a responsibility to review and assess air quality in their areas, to ensure compliance with the current National Air Quality Strategy (NAQS) objectives (e.g. legislation in the Air Quality Standards Regulations (2010) for England), which implement the EU Ambient Air Quality Directives (2008/50/EC; 2004/107/EC). If locations within a local authorities' area are identified where the objectives are unlikely to be met then an Air Quality Management Area (AQMA) must be declared. This is then followed by a comprehensive strategy being put in place to ameliorate identified issues. Declared AQMAs throughout the UK are primarily due to road traffic, and associated with two key families of LAQ pollutants: Nitrogen Dioxide (NO_2)/Oxides of Nitrogen (NO_x) and Particulate Matter (PM).

- Oxides of Nitrogen (NO_x) and NO_2 (Nitrogen Dioxide). NO_2 causes respiratory and allergenic problems. High levels can cause damage to vegetation and contribute to acidification of the environment. NO_x contributes to particulate formation. Comes mainly from road transport, followed by electricity supply industry. NO_x/NO_2 concentrations depend on reactions with sunlight and Ozone (O_3);
- Particulate Matter (PM_{10} or $PM_{2.5}$) – causes respiratory and cardiovascular illness. Particles come from a wide variety of sources, including natural sources (i.e. soil, dust), as well as man-made ones (chimney stacks, heating systems, combustion sources, re-suspended tyre dust and debris etc.). Particles may be classified as 'primary' – emitted or blown directly into the air, or 'secondary' – formed when chemicals in vapour form react in the atmosphere. The '10' and '2.5' in the descriptions of particulate matter refer to the aerodynamic size of the particle (e.g. PM_{10} refers to all particles of aerodynamic size of 10 microns or less).

In addition to legislation on Local Air Quality, national targets for total emissions, The National Emission Ceilings Regulations (NECR) (2002), have been set in compliance with EU directive (2001/81/EC). These regulations affect Total Oxides of Nitrogen (NOx), Sulphur Dioxide (SO2), Volatile Compounds (VOCs) and Ammonia (NH_3). Other air pollutants of concern include: Ozone (O3), Polycyclic Aromatic Hydrocarbons (PAHs) – especially Benzo(a)pyrene ($C_{20}H_{12}$) , Methane (CH_4), Benzene (C_6H_6), 1,3-Butadiene (C_4H_6), Carbon Monoxide (CO), Lead (Pb) and various other metals – though these are considered outside of the scope of this study. For NO_x, the ceiling defined in the NECR is 1167kT per year (including contribution from Gibraltar). Legislation such as the NECR drive the need for compilation of emissions inventories, such as the National Atmospheric Emissions Inventory (NAEI) (NAEI, 2011; BEIS, 2014), which in-turn, provide a wealth of data for studies such as ReFINE.

Operation of large numbers of heavy vehicles in an area have historically been associated with elevated emissions of both PM and NO_x, suggesting potential issues with routing of traffic associated with hydraulic fracturing activities through areas affected by AQMAs.

It is generally recognised that the most effective way to reduce pollution is abatement at the source. Implementation of European legislation to reduce emissions through the type approval process for new vehicles (the so-called 'EURO-Standards') have led to better technologies for cleaner engines (e.g. improved ignition systems, lean-burn engines and exhaust gas recirculation (EGR) systems), improved exhaust/after exhaust systems (e.g. Diesel Oxidation Catalysts (DOCs), Particulate Filter Traps (DPFs), 'de-NO_x' equipment such as Selective Catalytic Reduction (SCR)). These standards have helped 'close the gap' of heavy vehicle PM and NO_x emissions compared to cars and vans. The latest standards (EURO 6/VI) also include improved maintenance and emissions testing cycles during the life of heavy vehicles, to further help NO_x reductions. EURO 6 itself has become further subdivided, with phased entry of real-world emissions testing and particle number count considerations – both should act to better inform how modelled emissions vary from actuality, and improve control of air quality.

However, issues remain in many locations (primarily urban locations, or areas adjacent to strategic routes) due to the sheer volume of traffic, and technical problems with EURO standard implementations (e.g. late-EURO car and vans have lower overall NO_x emissions, but higher 'primary' NO_2 emissions from the tailpipe when compared to their older cousins). There are also questions as to whether some technologies are appropriate for all road types (e.g. SCR catalysts require a high, constant engine operating temperature to work effectively, which may be achieved on a motorway, but may not be achieved on a short duration run on a congested urban road). NO_x and PM reductions may also be achieved through the retrofit of de-NO_x technologies (primarily SCR catalysts) and particulate traps to early model Euro vehicles.

Modelling of concentrations of pollutants adjacent to roads requires two elements, an emissions model to calculate total mass of emissions from the traffic, and a dispersion model, to propagate those emissions away from the road source under the influence of topographical and meteorological conditions. Emissions themselves may be categories as hot emissions (from the vehicle tailpipe, under normal operation), cold emissions (excess emissions from the tailpipe during the first few kilometres of travel (~200seconds of operation), before the vehicle has reached operating temperature) and evaporative emissions (mainly of hydrocarbons from the vehicle fuel tank). The latter two types of emission have been considered outside of the scope of this study.

For the UK, the standard methodology for hot emissions, taking into account the vehicle fleet technology mix, is provided by the DEFRA '*Emissions Factors Toolkit*' (EFT). At the time of writing the latest version of the EFT is version 8.0.1 (DEFRA, 2017). Due to time constraints the version of the EFT used in the default files for UHTIM is based on Version 5.1.3 (DEFRA, 2013). The main difference between the versions is the increased importance of NOx emissions from diesel vehicles in later EFT versions, in the wake of various 'EmissionsGate' scandals in recent years.

The EFT provides 'average speed-emissions' curves for over 500 vehicle types (see Appendix B), for the key pollutants NOx, PM_{10}, $PM_{2.5}$, Total Hydrocarbons and Carbon Dioxide (CO_2). Figure C.1 shows the fleet hierarchy used by the EFT, based on data from the UK National Atmospheric Emissions Inventory (Boulter *et al.*, 2009; NAEI, 2011; BEIS, 2014).

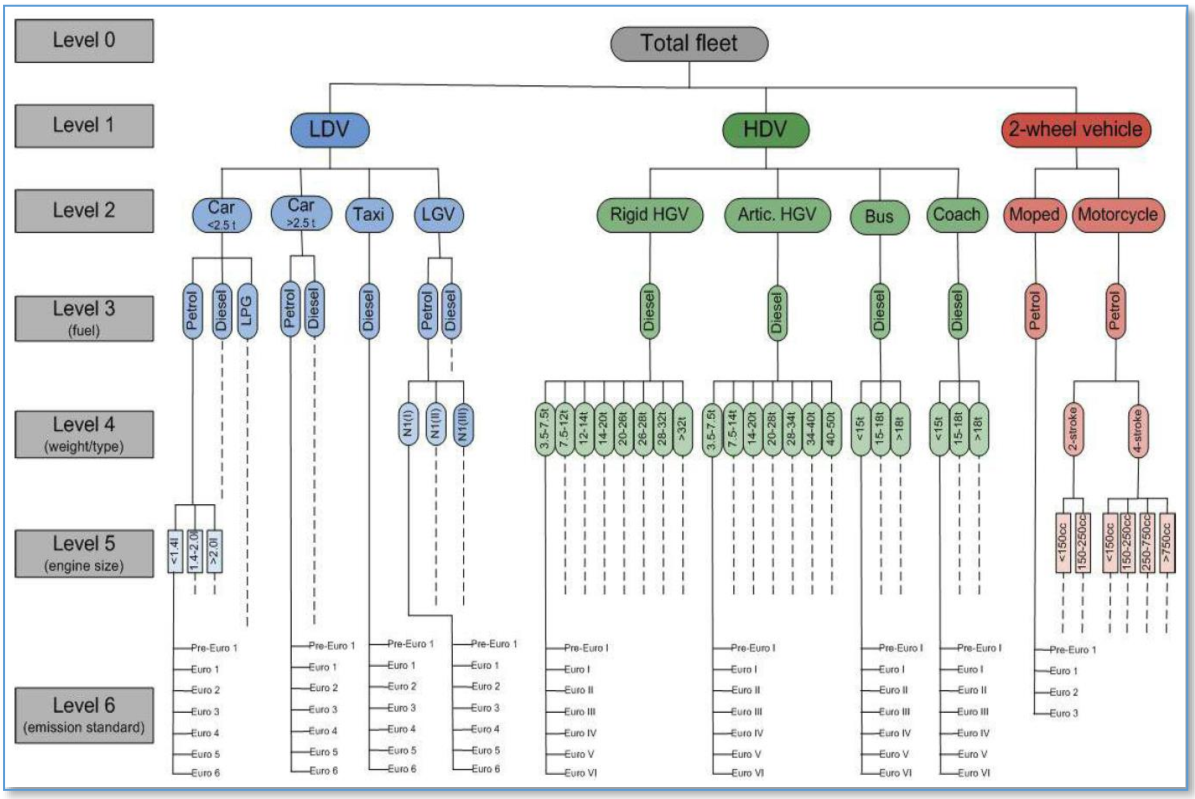
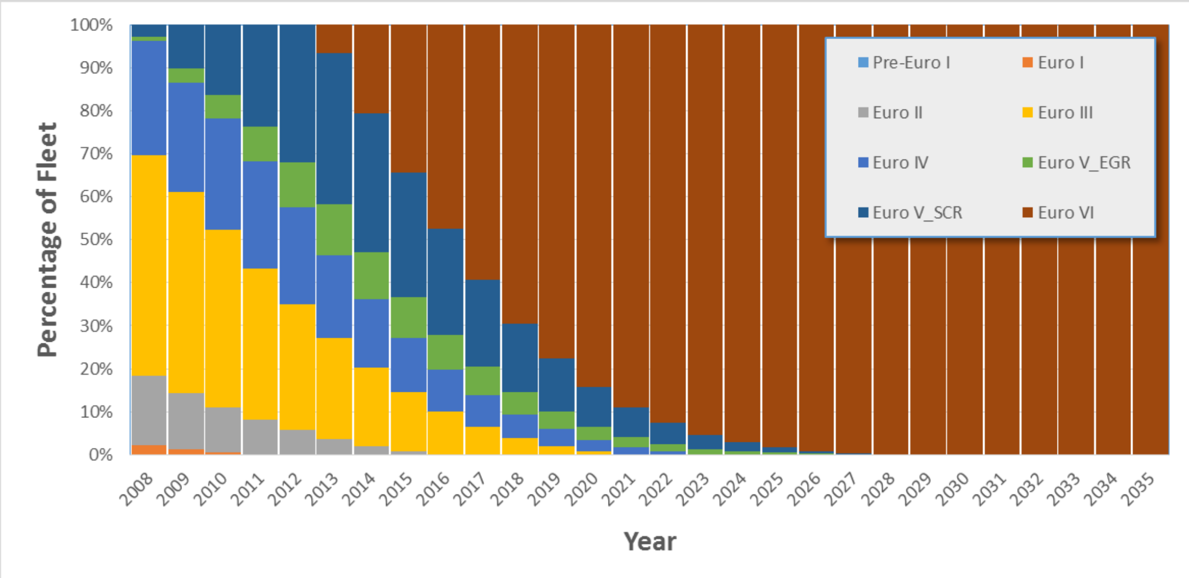


***Figure C.1: NAEI Fleet Hierarchy for Emissions Modelling** (Source: Boulter et. al., 2009).*

Figure C.2a and C.2b present the assumed evolution of Euro Technologies across the rigid and articulated heavy vehicle fleets out to 2035. Whilst both chassis types are expected to show a similar evolution of technologies, the update schedule for rigid vehicles lags slightly behind that for articulated vehicles, though after 2026 the entirety of both fleets are essentially completely Euro VI compliant.



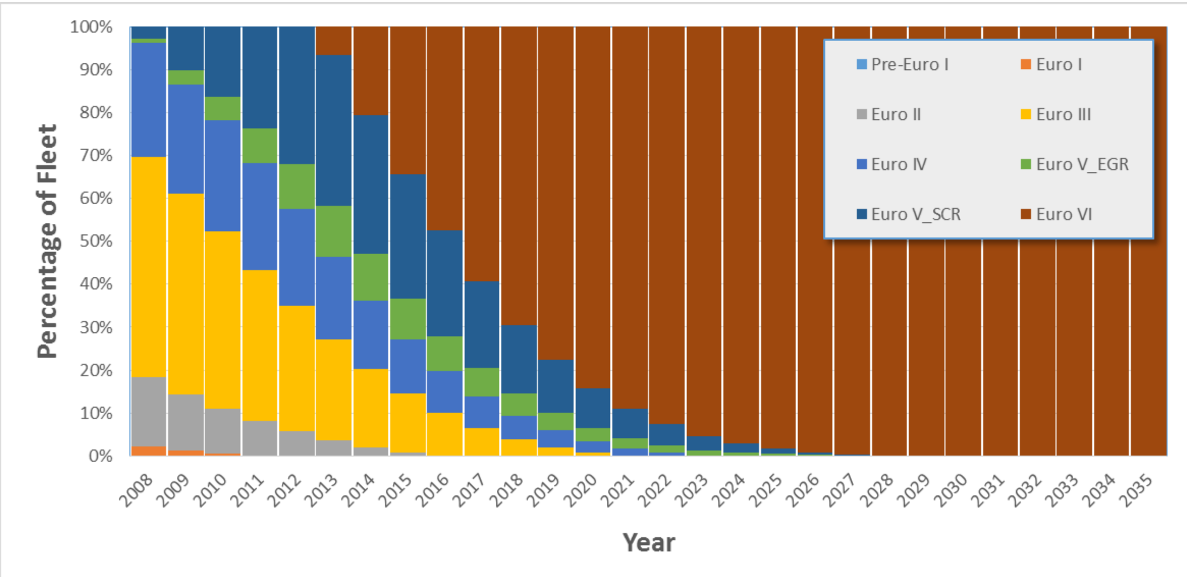


Figure C.2a and C.2b: Vehicle fleet technology changes from 2008 to 2035 for rigid body goods vehicles (top) and articulated goods vehicles (bottom)

(Source: EFT v5.1.3, DEFRA, 2013, as implemented in PITHEM)

Figure C.3 provides a sample average speed-emissions curve for NO_x emissions from the EFT heavy-vehicle fleets for the years 2010 and 2020. The effect of the introduction of the EURO V and EURO VI emissions standards on assumed NO_x emissions may clearly be seen. Note that, in Figure C.3 the rate of emissions per km becomes higher at lower speeds, becoming effectively infinite at 0 km/h. High emissions are prevented in the low speed domain by clamping speeds to a minimum value (typically 5km/h), prior to emission calculation. Likewise, it is assumed that the maximum achievable speed for a HGV is in the order of 90km/h (56mph – the value for new HGV speed limiters). For heavy goods vehicles the EFT emissions factors assume that trips are made at an average of 56% laden (Boulter *et al.*, 2009).

Whilst emissions rates for the various pollutants may vary by order of magnitude with vehicle type, generally the speed-emissions curves are of ‘L’ or ‘U’ shaped form. The ‘U’-shaped curves exhibit a local minima at around 30-60km/h, so changes in mean flow speed in either direction (i.e. adding vehicles, causing increasing congestion, or removing vehicles resulting in more freely-flowing traffic) will increase emissions.

The equations used in the speed-emissions curves are derived both from work by the Transport Research Laboratory (Boulter *et al.*, 2009) and from the European Environment Agency's COPERT program (EMISIA, 2014), which implements the methodology outlined in EMEP/EEA air pollution emission inventory handbook (EEA, 2013). NB: All of these curves have subsequently been superseded in later revisions of the EEA handbook, or COPERT software, but the general principle of NO_x reduction over time still holds, albeit not necessarily as dramatically as presented in Figure C.3.

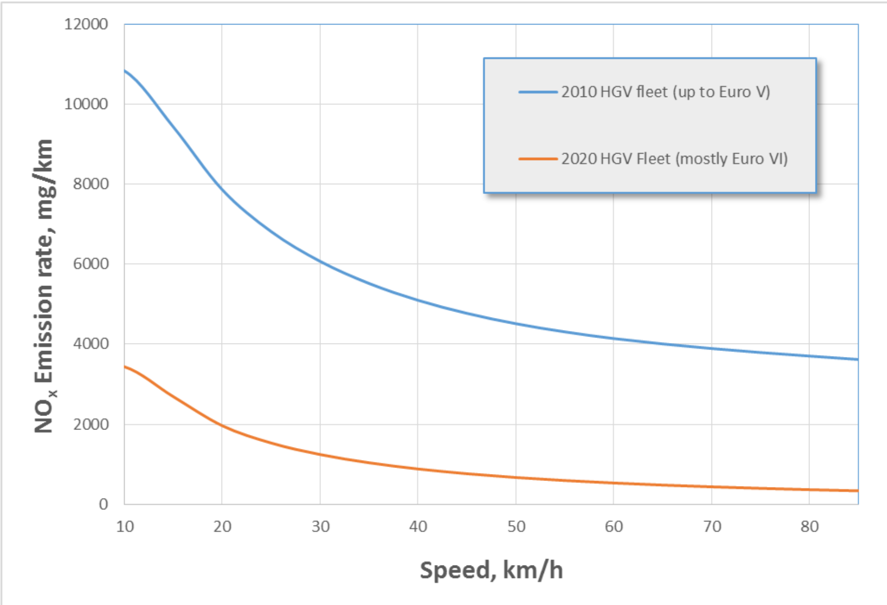


Figure C.3: Speed-emissions curves for NO_x from HGVs for 2010 and 2020.

Source: EFT Version 5.1.3, DEFRA 2013, as implemented in PITHEM)

Figure C.4 demonstrates the variability in technologies used to control emissions for a single chassis and weight class of truck (Rigid trucks, 7-12 tonnes weight). Note that at low speeds Euro V HGVs equipped with SCR catalysts are modelled as having emissions comparable to earlier model vehicles, due to issues with the technology at low speeds.

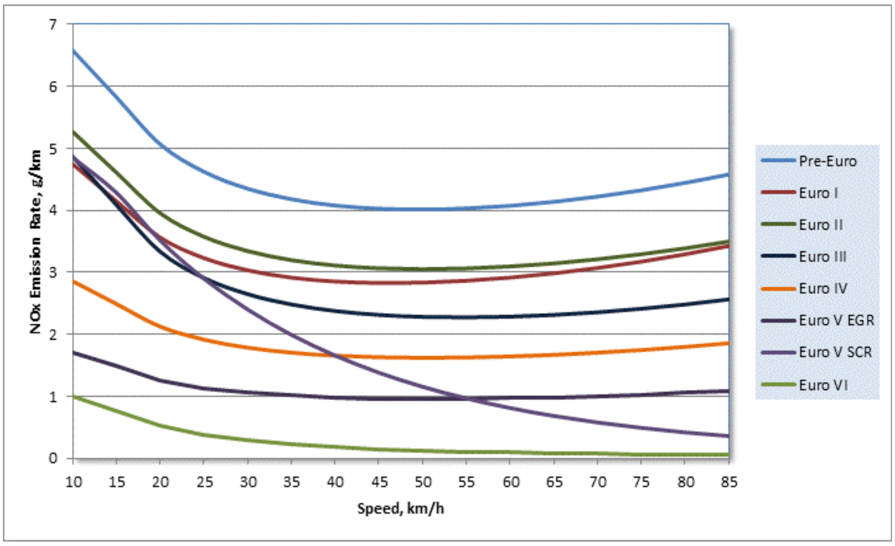


***Figure C.4: Speed-emissions curves for NO_x from Rigid-HGVs (7-12t), based on EFT Version 5.1.3, showing technology variations** (Source: Goodman et. al., 2014/ EFT Version 5.1.3, DEFRA 2013, as implemented in PITHEM).*

Figure C.5 provides the relative emissions contribution for NO_x from individual vehicle classes in the NAEI fleet, for a typical urban road in 2013, with a mean speed of 50km/h. The solid bars represent the emissions rates from a single vehicle. The green line provides the percentage contribution of that type to overall NO_x emissions. It is notable that diesel cars (35% of fleet, but >50% of NO_x total) and LGVs (13% of fleet, but > 20% of NO_x total) provide the greatest overall contribution to total emissions. This has occurred due to the trend towards increased diesel as a fuel for light vehicles over the past two decades, primarily based on economic savings (and promotion of these vehicles as 'green' due to lower average CO_2 emissions that petrol vehicles). Euro VI improvements and de-NO_x technologies applied to heavy vehicles in the coming decade are expected to further compound the dominance of the light vehicle contribution to NO_x emissions.

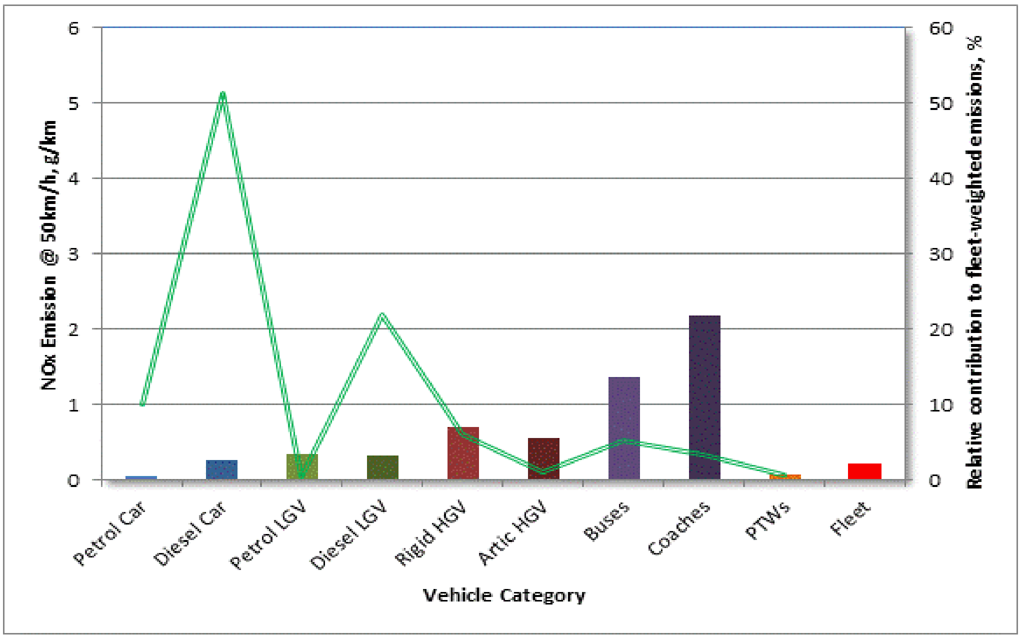


***Figure C.5: NO_x emission rates (bars) and vehicle class contributions to total NO_x emissions (line) for a typical urban road in 2013** (Source: Goodman et. al., 2014/ EFT Version 5.1.3, DEFRA 2013, as implemented in PITHEM).*

Final calculation of total, mass-based emissions is simply performed by taking the total number of vehicle kilometres travelled (VKT) by a certain class of vehicle, and multiplying by the speed-dependent emissions rate. This methodology has two primary flaws:

1. The average-speed emissions factors are based on 'drive-cycle' data. Standardised drive cycles provide a way of repeating measurements across the vehicle fleet, but may also provide erroneous data if the drive cycle used to develop emissions doesn't adequately reflect 'real world' driving. Many research studies point to 'real-world' emissions being higher than emissions factors indicate.
2. Related to the above, an average speed over a particular distance may be achieved by an almost infinite combination of smaller speeds and distances, hence an average speed emissions factor cannot possibly represent all driving conditions. It is recognised that average speed emissions factors may under-represent emissions in heavily congested situations (e.g. for a specific example regarding the use of the PITHEM-based emissions, as found in UHTIM, compared to more-realistic 'congested' emissions modelling, see O'Brien *et al.*, 2014).

Point 1 may be mitigated somewhat by introduction of 'uplift' factors to reflect real world conditions, whilst similarly point 2 may be mitigated by introduction of additional route elements, subject to high emissions, to represent queueing traffic at junctions. However in the absence of specific information on either point (e.g. inclusion of junction delay and congestion into the studied networks) these effects have been ignored at present.

As noted previously further limitation of the methodology used in UHTIM is the use of EFT v5.1.3 compared to EFT v8.0.1. It is believed that EFT v8.0.1 further increase NO_x emissions from light vehicle categories, to better represent real-world conditions, and changes the methodology used for other pollutant (PM and HC) calculations. Hence, it may be considered that outputs from UHTIM modelling, whilst potentially under-representing overall (absolute) values for NO_x emissions, could also over-represent the relative differences between vehicle categories. A final limitation is that all of the NAEI fleet information is valid for the UK only.

The primary advantages of the approach are:

- Provides a good representation of average emissions over large areas, based on detailed fleet and speed information;
- Computationally straightforward, allowing many scenarios to be considered in a short space of time;
- It is based on a nationally recognised approach, as set out by DEFRA on the LAQM web guidance and support pages - http://laqm.defra.gov.uk/, which, in turn has taken emission factors from the EU state-of-art model, COPERT.
- The methodology could be adapted to the context of other EU countries, given adequate fleet composition information.

Output values should generally be given in kilogrammes (kg), tonnes (T) or kilo-tonnes (KT).

C.1.2: Emissions versus Concentrations:

The National Air Quality Strategy defines limits and target values for pollutant concentrations in the atmosphere, not only in terms of annual average mean concentrations, but also in terms of hourly or short-term rolling average mean values that mist not be exceeded over a number of periods in a given year. For example, the NO_2 standard is defined (Air Quality Standards Regulations, 2010) as:

- 40 $\mu g/m^3$ annual average mean, and;
- 200 $\mu g/m^3$ hourly mean not to be exceeded more than 18 times per calendar year.

For particulate matter in England, Wales and Northern Ireland, limit values for PM_{10} are:

- 40 $\mu g/m^3$ annual average mean, and;
- 50 $\mu g/m^3$ not to be exceeded more than 35 times per calendar year;

Scotland has more stringent values than the rest of the UK, set at 18 $\mu g/m^3$ annual average mean and 50$\mu g/m^3$ not to be exceeded more than 7 times per calendar year (Ricardo EE, 2014).

For $PM_{2.5}$ the annual mean limit value in England is 25 $\mu g/m^3$ and Scotland 12$\mu g/m^3$, but as no safe limit for these fine particles exists in the atmosphere, a process of continual reduction to 2020 is also specified.

As hydraulic fracturing operations may be expected to produce a high-intensity, but short-duration peak in heavy vehicle traffic. Therefore, whilst it may be possible for hydraulic fracturing operations to not adversely alter the mean concentrations over a year, but actually cause a breach of the standards through non-compliance of the short-term exceedence element of the standard.

Whilst simple 'screening' tool are available to calculate concentrations based on estimated traffic patterns, such as the DMRB 'Air Quality Spreadsheet' (HA, 2007) this is now based on quite dated emissions factors, and is unable to handle effects of transient emissions associated with sudden onsets of high volume traffic flows.

Therefore, the translation of changes in short-term traffic patterns, into roadside concentrations that are suitable to assess both annual mean values and exceedence periods requires adequate temporal resolution (e.g. hourly), plus the use of a suitable dispersion methodology, taking into account meteorological and topographical conditions, as well as background concentrations from other pollutant sources. Furthermore, the chemical relationships between NO_x, NO, NO_2 and O_3 in the atmosphere, plus assumptions about primary tailpipe NO_2, need to be handled robustly, in order for accurate determination of road-side NO_2 concentrations to be achieved.

C.1.3: Greenhouse Gas Emissions:

Greenhouse gases (GHGs) absorb and emit heat in the atmosphere contributing to the global problem of climate change. For transport, the primary emission of greenhouse gas is in the form of CO_2. The Stern Review (Stern, 2006) examined the evidence on the global economic impact of climate change. This review was instrumental in informing the UK policy in response to global warming, as set out in the Climate Change Act (2008). As reported in Mitchell *et al.* (2011) "The act creates a framework for building the UK's ability to adapt to climate change, and makes the UK the first country in the world to have a legally binding long-term framework to cut carbon emissions (by 80% in 2050 from a 1990 base)".

Emissions of CO_2 are calculated using the same methodology as local air quality emissions, through consideration of VKM totals, fleet composition and the use of speed-emission curves. For this study the CO_2 curves in the EFT have been used. Figure C.6 presents sample speed-emissions curves for CO_2 based on the 2012 UK urban fleet. Note, that as with LAQ emissions, the curve is 'U'-shaped with speed with each vehicle class having a minimum point at a certain speed.

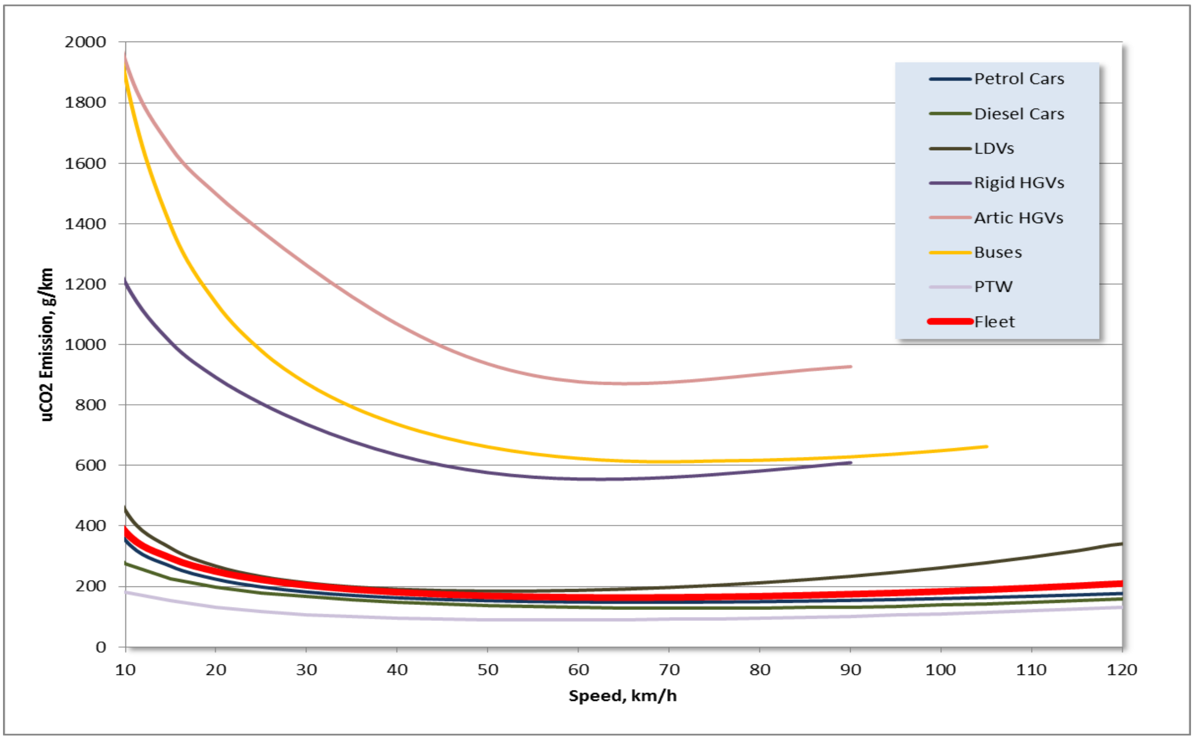


***Figure C.6: Sample fleet-weighted speed-emission curves for CO2, based on the English Urban fleet for 2012** (Source: EFT v5.1.3 DEFRA (2013a), as implemented in PITHEM)*

The CO_2 speed-emissions curves produced by the EFT vary from the emissions values used by the Department for Transport (DfT) in the UK National Traffic Model (NTM) (DfT, 2012), and the GHG conversion factors, published annually by the Department for Business, Energy and Industrial Strategy for company reporting of emissions from their fleets (e.g. BEIS, 2018). The EFT emissions factors differ from the DfT and DEFRA values, as they do not include any assumptions about the continual development of the fuel economy of the fleet, as is the case with the DfT values, or are not corrected by sales data for new vehicles in a given year, as are the company reporting factors (Murrells, 2014). The NTM, for example assumes a 5% improvement in HGV fuel efficiency 5 years after 2010, plus the introduction of low rolling resistance tyres, for a total reduction of 11% over the period to 2035. On the other hand EFT provides a static, technology based estimate of fuel consumption/CO_2 emissions. Indeed for late Euro class vehicles (e.g. Euro V and VI) or retrofitted older vehicles, the EFT actually assumes a 1% *decrease* in fuel efficiency, due to the presence of exhaust abatement technologies. The DEFRA GHG conversion factors provide typical values from vehicle activities across all road types.

Three parameters are potentially used for the calculation of greenhouse gas emissions from vehicles:

- Tailpipe CO_2 – CO_2 emissions directly from the vehicle exhaust;
- Ultimate CO_2 – Tailpipe emissions of CO_2 calculated by assuming all other pollutants (i.e. CO and HCs) present eventually have their carbon content oxidised to CO_2. The uCO_2 value is of the order of 101% of the tailpipe CO_2 value.
- CO_2e –Carbon Dioxide Equivalency, which includes the global warming potential (GWP) of a gas over a defined time period (typically 100 years) expressed to an equivalent mass of CO_2. The DEFRA GHG Conversion factors include contributions from the other GHGs primarily present in vehicle exhausts: nitrous oxide (N_2O) and methane (CH_4). From the DEFRA GHG conversion factors, CO_2e is for heavy vehicles is approximately 101% the tailpipe CO_2 value.

Table C.1 provides a comparison between EFT derived emissions factors for CO_2 (assume 56% laden) and current DEFRA GHG conversion (GHG Conv.) values for typical journeys for 0%, 50% and 100% laden HGVs. The EFT only provides uCO_2 values (but over a range of speeds and road types) whilst the GHG conversion factors provide both CO_2 and CO_2e, but only a single value for all roads and speeds.

Table C.1: Per kilometre CO_2 and CO_2e values for heavy goods vehicles in the UK for 2014.
(Sources: EFT v5.1.3 DEFRA (2013a) and DEFRA (2014b))

	EFT @ 35km/h	**EFT @ 50km/h**	**EFT @ 90 km/h**	**GHG Conv. @ 0% laden**	**GHG Conv. @ 50% laden**	**GHG Conv. @ 100% laden**	**GHG Conv. average load**
CO_2							
Rigid HGV	677.1	573.4	605.9	668.4	815.1	961.8	822.0
Artic HGV	1154.7	932.6	923.4	746.9	933.7	1120.5	984.2
CO_2e							
Rigid HGV	N/A	N/A	N/A	677.0	823.8	970.4	830.6
Artic HGV	N/A	N/A	N/A	757.3	944.1	1130.8	994.6

From Table C.1, it appears that there is a large discrepancy (up to 60%) between the EFT v5.1.3 rigid HGV emissions factors and those from the GHG Conversion tables, than for those for articulated HGVs. This is in partially due to EFT's weighting towards light HGVs (values assume over 50% of the fleet kilometres travelled are by vehicles under 20 tonnes gross laden weight). It is also noted that the EFT and the GHG Conversion tables use different gross vehicle weight categories, which makes direct comparisons somewhat problematic.

For calculating carbon emissions associated with shale gas operations, Broderick *et al.* (2011) assumed a HGV emission factor of 983 gCO_2/km and a 60km 'round trip' for transportation of water to site, and removal of wastewater from site. Estimates of Truck movements over the lifetime of a 6 well pad were taken from the New York (NYCDEP, 2009). The total number of truck visits was assumed to be 4300 to 6600 over the lifetime of the pad, 90% of which are associated with water for the hydraulic fracturing process itself.

Based on this emissions rate, Broderick *et al.* (2011) give total CO_2 emission values of 26.2 – 40.8t for water transportation and 11.8 – 17.9t wastewater removals. This implies an emissions rate assumed by Broderick *et al.* of approximately 993.9 gCO_2/km. Assuming a 2014 fleet of 40t articulated HGVs at 50km/h and 56% average loading, a comparable value of 1006.7 gCO_2/km is given when using EFT Version 5.2c (DEFRA, 2013).

Including both GHG and LAQ emissions from EFTv5.1.3, a 60km round trip, with NYCDEP (2009) trucks replaced with 40t articulated UK trucks, as per the EFT, the same 6 well pad would produce the following truck transport-related emissions over its lifetime:

- 42.9 – 69.1t CO_2 /well
- 1.6 – 2.5kg Total Hydrocarbons /well
- 134.7 – 217.0kg Total Oxides of Nitrogen/well
- 15.2 – 24.5kg Primary NO_2/well
- 5.7 – 9.2kg PM_{10} /well
- 3.7 – 6.0kg $PM_{2.5}$/well

Regarding limitations and benefits of the approach, the uCO_2 calculation in UHTIM shares exactly the same issues as discussed for LAQ pollutants in the previous section. Additional correction of UHTIM

uCO_2 values, to better reflect either a) expected fleet improvements as per DfT (2012), or b) the GHG conversion tables (BEIS, 2018) are identified as potential improvements.

Output of uCO_2 from UHTIM is total mass emissions from a road link, in a given time period, based on the summation of contributions from individual vehicle types. Output values should generally be given in kilogrammes (kg), tonnes (T) or kilo-tonnes (KT).

C.2: The CNOSSOS-EU Noise Model

Noise from vehicles is associated with a number of health concerns (including sleep disturbance, cardiovascular and psychophysiological effects), as well as broadly causing annoyance and interference with daily activities. It has also been linked to reduced capacity for learning and cognitive impairment in children, and changes in social behaviour in both humans and animals (WHO, 2011; WHO, 2014). Noise at night causing sleep disturbance is a specific, current concern (WHO, 2009). Noise is measured in decibels (dB), with 0dB considered the 'threshold of hearing' and 140dB the 'threshold of pain'. Frequency content of noise measurements or calculations are 'weighted' to better correlate with human response to noise – for environmental noise the 'A-weighting' scale is used.

For the EU, the CNOSSOS-EU 1/1 Octave emissions curves (JRC, 2012) are suggested for use to model the effects of surface transport, over the default UK road noise assessment procedure, codified in the Design Manual for Roads and Bridges (DMRB) (HA, 2011) and Calculation of Road Traffic Noise (CoRTN) (DTP, 1988). There are several reasons for this, though most notably CNOSSOS-EU is a recently developed noise calculation methodology, intended to be the standard methodology for calculating 'noise maps' as required by the European Noise Directive (END) (2002/49/EC). CNOSSOS-EU is also capable of providing the 'L_{Aeq}' parameter (A-weighted, equivalent energy average noise level) required by EU legislation. The original CoRTN methodology (and data used to derive the methodology) is now almost 40 years old, though has been updated periodically throughout that time. CoRTN only provides an L_{A10} parameter (A-weighted noise level exceeded for 10% of a measurement period) which must subsequently be converted to L_{Aeq}. For sleep disturbance other noise measures (e.g. maximum peak noise and number of occurrences of peaks) may be more appropriate than 'average' L_{A10} or L_{Aeq} measures – unfortunately neither CoRTN nor CNOSSOS-EU adequately cover such parameters.

CNOSSOS-EU provides:

- parameters for more types of vehicle (5-classes) over CoRTN (only 2-classes);
- separate sub-models for the separate treatment of rolling noise and power-train noise, allowing individual tailoring of these elements to the scenario (e.g. modelling of alternate fuelled vehicles, or vehicles with non-standard axle configurations);
- production of sound-power levels, as opposed to a sound pressure level metric, which enables separation of source elements from propagation elements;
- Octave-band resolution, rather than broadband only noise using CoRTN.

The downsides of using CNOSSOS-EU for modelling are associated with:

- treatment of octave-bands which inherently involves more data processing than simple broadband measurements;
- conversion of 'abstract' sound power levels to more readily understandable sound pressure levels, which requires use of a propagation model;
- The model is considered valid for speeds above 20km/h, making modelling of congested roads problematic.

Both of these issues are overcome in UHTIM in relatively straightforward fashion.

The example 'SPwLA_base_table.csv', provided with the UHTIM installation, gives vehicle-specific, pre-calculated, overall broadband sound power levels. These are derived from summating the levels from both the rolling and power-train noise sub-models, across all frequency bands, for each vehicle type. Each of the 500+ vehicle types defined in Appendix B were assigned a CNOSSOS-EU class, modified by the number of axles >2, for additional noise where required. 'M4FleetPollProc.exe' uses these values in its calculation of user class-specific, per vehicle emissions. 'M4RegPollProc.exe' then uses these values, scaled by the user class flow to produce an overall sound power level for a link.

Link-based calculations within 'M4RegPollProc.exe', apply a simple broadband propagation model. This is based on straightforward mathematical assumptions (i.e. '1/d' propagation over a set distance, above acoustically hard ground, from an infinitely long, straight road source), to give an approximate 'at roadside', broadband, A-weighted decibel value. These are adequate for scenario assessment and comparison purposes (see Watts *et. al.*, 2004), though the values should be treated as relative, rather than absolute, given the inherent simplifications and lack of site-or-context-specific corrections.

Figure C.7 shows the CNOSSOS-EU broad-band sound power level curves for a large (5-axle) HGV, compared to those calculated for a more general, urban, vehicle fleet.

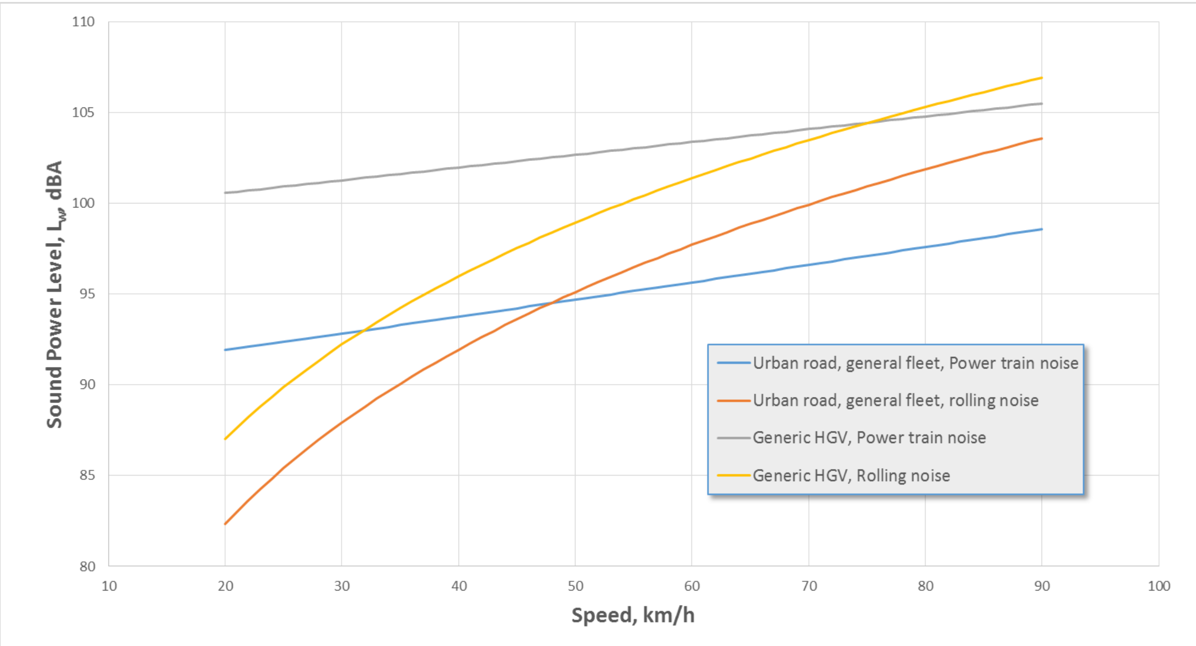


Figure C.7: CNOSSOS-EU broadband, A-weighted sound power levels with speed, for rolling and power train sub models, for a general urban fleet (NAEI 2014) and large HGVs.

A major modifying 'site-specific' factor to either the CoRTN or CNOSSOS-EU approaches is the type of pavement, which greatly influences the generation of road/tyre noise (potentially by up to +/-6dBA). Without further information, the results provided by CNOSSOS-EU, and hence from the output of the ReFINE traffic model, are valid for either stone mastic asphalt or dense asphalt concrete roads, with chipping size of 0/11mm, in good maintenance condition, in dry weather (see JRC, 2012, p34). It is not known how many roads in the UK comply with this 'reference condition'.

To put noise in an overall context:

- Traffic noise generally falls in the range 50-85dBA, depending on road and time of day;

- The UK Noise Insulation Regulations for compensation arising from new developments trigger at a threshold level of 68dBA ($L_{A10,\ 18\text{-}h}$ – or approximately 65 $L_{Aeq,\ 18\text{-}h}$);
- A previous green paper (COM(96) 540) from the EU considered 'excessive' noise to be above 65dBA during the day and 55dBA during the night (CEC, 1996);
- The WHO consider 40dBA a long-term target for night-time noise to protect the public, with an interim target of 55dBA (WHO, 2009);
- Doubling of traffic on a road will increase noise by 3dBA, whilst doubling of speed and number of HGVs may have far larger effects (6-9dBA);
- Noise at source is being mitigated both through EU legislation on the type-approval process of vehicles, the type-approval of tires and the road-worthiness of vehicles;
- Annoyance generated by noise is highly subjective, depending not only on the absolute level of noise, but also the frequency content of the noise, its duration, the perceiver's current activity (e.g. noise during a quiet activity such as reading is more distracting and annoying than at other times), and how accustomed the perceiver is to the noise.

For short-term impacts of noise from new road development, DMRB Vol 11, Sec 3, Part 7 (HA, 2011) provides Table C.2 (based on the L_{A10} parameter, but the values are also applicable to L_{Aeq}). The table may be considered applicable to describing the effects of unconventional gas operations on a particular road, or in a particular area.

Noise Change, $L_{A10,\ 18\text{-}h}$	Magnitude of Impact
0	No change
0.1 – 0.9	Negligible
1.0 – 2.9	Minor
3.0 – 4.9	Moderate
5.0+	Major

***Table C.2: Classification of the magnitude of short-term impacts on noise** (Source: HA, 2011).*

For impacts over a longer term (i.e. months to years), where people may be expected to adapt to conditions, the DMRB suggests the descriptions in Table C.3 are used.

Noise Change, $L_{A10,\ 18\text{-}h}$	Magnitude of Impact
0	No change
0.1 – 2.9	Negligible
3.0 – 4.9	Minor
5.0 – 9.9	Moderate
10.0+	Major

***Table C.3: Classification of the magnitude of long-term impacts on noise** (Source: HA, 2011).*

Specifically regarding unconventional gas operations, the NYSDEC (2011) documentation references the REMEL (Reference Energy Mean Emissions Level) curves provided by the FHWA Traffic Noise Model (1999) for calculation of transportation noise from trucks. Whilst these have been used with some success in calculating noise levels from European Vehicles (Goodman, 2001), their use is not recommended, given access to the CNOSSOS-EU methodology.

Excess transient noise peaks, generated by load shifting on HGVs travelling on uneven road surfaces, or panel vibration occurring with empty vehicles, have been recognised as major sources of irritation with heavy vehicle traffic. Unfortunately such effects are very difficult to model using existing noise methodologies, even given knowledge of local conditions. It may be considered that damage to pavement surfaces, caused by heavy water transportation to well pad sites may exacerbate noise issues. Operations outside of normal daytime hours may also have an excessively detrimental effect on annoyance and sleep disturbance.

Output from UHTIM is initially in the form of Sound Power Levels, in units of dB/m, disaggregated by vehicle type and Octave band, scaled by flow values for vehicle types on a given road link. The contributions from individual vehicle types are then A-weighted, summed logarithmically and the L_{Aeq} value calculated assuming a distance of 10m from the road, and propagation over hard ground. The L_{Aeq} value is a sound pressure level in dB considered representative of the road-side noise level in a given period.

C.3: Equivalent Standard Axle Loadings

As with vibration, modelling the amount of wear to surface courses, or outright structural damage suffered by a road under additional loading is somewhat problematic, given the variability of ground conditions and types of pavement construction, e.g. use of rigid (i.e. concrete) or flexible (i.e. bituminous) pavements versus gravel or dirt roads, presence or absence of road bases and sub-bases, porosity, drainage conditions existing maintenance and presence of imperfections etc. The transient and dynamic nature of the loading also presents modelling challenges, with models based on static loading potentially underestimating detrimental effects.

A basic methodology for providing an estimate of the amount of design traffic a new road is expected to take over its lifetime, or the amount of maintenance an existing road is expected to require, is provided in DMRB (Volume 7 Section 2 Part 1) (HA, 2006). This methodology is based on the work of AASHTO (1986) and assumes that wear is assumed to be proportional to the 4th power of axle load (i.e. Wear/axle $\propto$ axle load^4) and primarily considers heavy-duty (i.e. trucks and buses or coaches) traffic. The axle load is assumed to be calculated with reference to a 'standard axle' applying a force of 80kN.

Example 'maintenance wear' factors for 'typically loaded' heavy vehicles are:

- 2-axle rigid = 0.4 standard axles
- 3-axle rigid = 2.3 standard axles
- 4-axle rigid = 3.0 standard axles
- 3 or 4-axle articulated = 1.7 standard axles
- 5-axle articulated = 2.9 standard axles
- 6-axle articulated = 3.7 standard axles

For comparison a passenger car (1.2 tonnes, or 6kN/axle) of represents approximately $6x10^{-5}$ equivalent standard axles. Factors for new roads are modified to be slightly higher, to account for 'uncertainty in the calculation of future traffic patterns, when considering the design life of the road'.

More precise calculation of axle loading values requires information on the number and position of axles on the vehicle's wheelbase plus estimates for the cab mass and load mass distributions relative to the wheelbase (Atkinson *et. al.*, 2006). At present UHTIM uses values based on assumed length, number of axles and loaded/unloaded weight of vehicle, based on the NAEI Gross Vehicle Weight (GVW) data. Loads are generally distributed equally to the rear of the vehicle, though it is recognised that this may not be the case in reality (e.g. more loading towards the drive axles at the rear of a truck cab might be expected, or the use of separate bulkhead compartments in a tanker might create unequal loading).

A further concern is that the equations apply broadly to constructed pavements with good drainage, not necessarily to very minor roads, construction road, or dirt tracks, which may see disproportionality high damage in adverse weather conditions.

Output from loading calculations in UHTIM is in terms of ESAL (Equivalent Standard Axles), which represents the summation of standard axle loading for the vehicle type, multiplied by the flow for that vehicle type, across all types for a given period on a road link.

C.4: Un-modelled Environmental Effects:

The following aspects were initially considered for inclusion within the scope of the traffic appraisal in the ReFINE project, but were ultimately not included, due to lack of data to perform an effective assessment, or requiring excessive additional development time to be implemented within the UHTIM framework correctly.

Aside from vibration, the aspects below, were implemented in a forerunner to both UHTIM and PITHEM, called SMARTNET (Mitchell and Namdeo, 2009), which followed the multi-modal, multi-criteria approach to new transport scheme appraisal laid down in NATA (New Approach to Appraisal) by the former Labour Government. Whilst NATA has subsequently been updated in the DfT's current appraisal methodology (WebTAG: DfT, 2013; TAG Unit A3: Environmental Impact Appraisal; DfT, 2015) elements of SMARTNET could potentially be updated and re-implemented in PITHEM to extend appraisal into further environmental and non-environmental areas.

C.4.1: Vibration*:*

The effects and implications of truck movements on airborne and ground-borne vibration are problematic to assess in broad terms, both due to the lack of a generic model for vibration and being heavily dependent on localised pavement (and pavement imperfection), underlying ground and structural (i.e. receptor point) foundation conditions. As with noise, vibration may be transient, intermittent or continuous (BSI, 2009).

The *Design Manual for Roads and Bridges (Vol. 11, Sec. 3, Part 7)* (HA, 2011) states that airborne vibration may be produced "by the exhausts of road vehicles with dominant frequencies in the 50-100Hz range", with ground-borne vibration in the 8-20Hz range. Whilst CNOSSOS-EU does provide low frequency information for both rolling and power-train noise for the 63Hz Octave-band, no information is available for lower frequencies. Indeed, as DMRB notes, ground-born vibration is usually expressed in Peak Particle Velocity (PPV) in mm/s, rather than as a noise function in decibels.

Watts (1990) suggests that, based on "case studies of heritage buildings adjacent to heavily trafficked roads" it may be "concluded that although traffic vibration can cause severe nuisance to occupants there is no evidence to support the assertion that traffic vibration can also cause significant damage to buildings."

An empirically-derived evaluation methodology for calculating vibration from various construction activities is given in Annex E of BS 5228 (BSI, 2009). A rise of above 0.3mm/s at a receptor location calculated using BS 5228 may be considered excessive (HA, 2011). Unfortunately, no description for site-traffic activities is present.

In the absence of a simple, reliable and accurate method of assessment, vibration was not considered further in this study, though is recognised as a potential major source of irritation and concern to residents and businesses on routes used by unconventional gas operations.

C.4.2: Water Environment:

SMARTNET (Mitchell and Namdeo, 2009) provided quantitative measures of the number of road links requiring some 'form of abatement treatment of water run-off from highway discharge' in terms of both 'dissolved' pollutant abatement and 'aesthetic' pollution abatement. The SMARTNET methodology was based on the 'CIRIA 142' methodology (Luker and Montague, 1994), which was subsequently adopted into DMRB Vol 11, Sec 3 Part 10 (HA, 2009), rather than the more qualitative, current WebTAG Unit 3A approach (DfT, 2013). The water environment has not been considered further in the development of the UHTIM applications.

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Appendix D: Cost functions for Road Links

The default forms of the link cost (speed-flow) relationships that are defined in the default 'Speed_flow_curves.csv' are presented below, alongside some brief discussion on their appropriateness and use in UHTIM.

D.1: COBA-type functions:

The UK DfT approach to appraisal of new road schemes has historically been based on COst Benefit Analysis (COBA) (DfT, 2004). One of the key elements of the COBA methodology is the calculation of speed on road links, in order to estimate benefits accrued through savings in journey times. The methodology for this calculation forms part of the (now withdrawn) DMRB Volume 13 Section 1 Part 5 (HA, 2002).

At is heart, the COBA methodology encapsulates the 'fundamental principle' of traffic flow: up to a certain limit (capacity) increases in flow cause little or no decrease in vehicle speed (free-flow conditions). At or near capacity speed starts to drop rapidly as inter-vehicle interaction increases. Beyond capacity flow and speed drop rapidly, till at jam conditions there is no flow, or speed, but very high vehicle density. For the calculation of economic costs from delay in COBA (and hence emissions from UHTIM), the congested case is represented by very high flow/very low speed conditions, resulting in highest cost/highest emissions, over any other road state. The capacity of the road is determined by many factors, primarily the quality of construction and the number of lanes. By default COBA provides capacity information, and speed/flow relationships for 11 road types: rural single carriageways, rural dual 2 or 3 lane carriageways, motorways of 2, 3 or 4 lanes, urban central and non-central roads, small town roads, suburban single and dual carriageway roads.

Proper application of COBA requires knowledge of many parameters (e.g. visibility and sight lines, hilliness, curvature of roads, number of side roads, developed area densities etc.), so it is usual in traffic modelling to pre-calculate speed-flow relationships for representative roads in a traffic network. For ReFINE, information to calculate COBA speed flow curves has been taken from the Greater Bristol Area Transport Model Study, Local Model Validation Report (Atkins, 2009).

Note that, for rural roads, DMRB 13.1.5 only covers estimation of speed on links, not the additional reduction in speed through either geometric (turning) delay or queuing delay at road junctions. Whilst these elements are covered by COBA, and formed an integral part of traffic appraisal model, they rely on detailed geometric information, which is considered outside the scope of UHTIM.

Likewise for urban roads, the COBA speed-flow relationships give average speed information that, whilst adequate to determine journey times in a network as a whole, will not accurately represent delay or speeds at specific locations. The lack of these additional delay elements, and their potential impact on congested emissions, represents a major simplification of the analysis procedure. At present the UHTIM model may be expected to significantly under-estimate the effects of congestion on emissions, and this should be a focus for more detailed enhancement of the model in the future. Of course, application of the UHTIM approach to an actual network, with delays included via use of a suitable transport model, would partially mitigate this concern (though as noted in Appendix C, limitations of the emissions calculations procedures would remain without explicit treatment of queuing).

The functional form of the COBA curves is (derived and modified from Atkins, 2009):

$$S = S_0 + (S_1 - S_0)\left(\frac{V}{F}\right) for\ V \leq F \qquad [D.1]$$

$$S = S_1 + \frac{(S_2 - S_1)(V - F)}{C - F} for\ F < V \leq C \qquad [D.2]$$

$$S = \frac{S_2}{1 + \frac{S_2(V - C)}{8dC}}\ \ for\ V > C \qquad [D.3]$$

Where:

‘S’ is the link speed under the demand flow/hour in PCUs;
‘S_0’ is the link speed at zero flow, in km/h;
‘S1’ is the link speed at maximum ‘free-flow’ conditions, km/h
‘S_2’ is the link speed at capacity, in km/h;
‘V’ is the link demand flow in PCU/hour/lane;
‘F’ is the maximum flow/hour at which ‘free-flow’ conditions could be said to hold;
‘C’ is the capacity flow/hour;
‘d’ is the average distance between intersections on this type of road, in km.

Table D.1 presents the default road types in UHTIM and their associated COBA and physical parameters, as defined in the ‘Speed_flow_curves.csv’ file. The roads types themselves are subdivided into Rural (‘R’), Sub-Urban (‘S’), Urban (‘U’) and town/village (‘V’) categories (first character of the ‘name’ field). The next two characters of the name filed give the number of bi-directional lanes, and whether the road is duelled or not, whilst the final character gives a ‘road quality/road hierarchy’ level, from (‘M’)otorway, down through (‘T’)runk, (‘A’), (‘B’) and (‘C’) roads, to a final category of (‘D’) for very minor roads.

In the description field, the following two-letter descriptors are used:
‘AP’ – A-Road in perfect condition, used mainly for very high quality rural A-roads/dual carriageways;
‘GA’ – A good-quality A-road;
‘AA’ – Average-quality A-road;
‘PA’ – Poor-quality A-road;
‘GB’ – Good-quality B-road;
‘AB’ – Average-quality B-road;
‘PB’ – Poor-quality B-road;
‘GC’ – Good-quality C-road;
‘AC’ – Average-quality C-road;
‘PC’ – Poor-quality C-road.
‘LD’ – Low density urban development at the side of the road;
‘MD’ – Medium density urban development at the side of the road;
‘HD’ – High-density urban development at the side of the road.

Obviously, the application of these road descriptions within a model is somewhat subjective to ‘engineering judgement’ – the descriptions are intended merely as a guide to choosing and appropriate road type within a scenario. Likewise, there is some overlap between road categories – e.g. a ‘good’ B-road, might be an ‘average’ or ‘poor’ A-road. Nominal speed limits of roads (in mph) are also included in their description where appropriate. If not listed, the road is subject to the National Speed Limit (NSL), or is under a 20mph speed limit, at the extremes.

Table D.1: 'COBA-Type' parameters for default UK road types defined in 'Speed_flow_curves.csv'

ID1	ID2	Name	Description	S0	S1	S2	F	C	N	d	Width /lane	# of Lanes	Dual?
1	1	R4DM	Rural_D4M	116	109.5	45	1200	2520	3.81	16	3.75	8	TRUE
2	1	R3DM	Rural_D3M	116	109.5	45	1200	2520	3.81	16	3.65	6	TRUE
3	1	R2DM	Rural_D2M	112	105.5	45	1200	2430	3.85	16	3.65	4	TRUE
4	1	R3DT	Rural_D3/AP_(A_Trunk)	108.5	102.5	45	1080	2260	3.66	8	3.65	6	TRUE
5	1	R3DA	Rural_D3/AP	108.5	88	45	1080	2260	3.63	8	3.65	6	TRUE
6	1	R2DT	Rural_D2/AP_(A_Trunk)	104.5	98.5	45	1080	2180	3.66	8	3.65	4	TRUE
7	1	R2DA	Rural_D2/AP	108.5	88	45	1080	2180	3.63	8	3.65	4	TRUE
8	1	R3ST	Rural_S3_(GA)_10m	91	71.5	45	1100	1860	2.24	8	5	2	FALSE
9	1	R3SA	Rural_S3_(AA)_10m	84	64.5	45	1100	1660	2.13	8	5	2	FALSE
10	1	R2SA	Rural_S2_(GA)/S3(PA)	87	71.5	45	880	1640	2.16	8	3.65	2	FALSE
11	1	R2SB	Rural_S2_(AA/GB/GC)_-_50mph	78	63.5	45	850	1380	2.07	8	3.65	2	FALSE
12	1	R2SC	Rural_S2_(PA/AB/GC)_-_40mph	67	53.5	45	770	1010	1.79	8	3.65	2	FALSE
13	2	SD4T	Suburban_D2_(GA)(LD)_-_50mph	78	66	35	1050	1730	3.29	2.5	3.65	4	TRUE
14	2	SD4A	Suburban_D2_(AA/GB/GC)(TD)_-_40mph	71	45	35	1050	1270	3.29	1.3	3.65	4	TRUE
15	2	SD4B	Suburban_D2_(PA/AB/GC)(HD)_-_40mph	68	46.5	35	950	1030	1.94	0.8	3.65	4	TRUE
16	2	SD4C	Suburban_D2_(PB/AC)(HD)_-_40mph	58	46.5	35	250	500	1.4	0.4	3.65	4	TRUE
17	2	SS2T	Suburban_S2_(GA)(LD)_-_50mph	66	56	25	1050	1540	3.75	2.5	3.65	2	FALSE
18	2	SS2A	Suburban_S2_(AA/GB/GC)(TD)_-_40mph	61	35	25	1000	1270	3.76	1.3	3.65	2	FALSE
19	2	SS2B	Suburban_S2_(PA/AB/GC)(HD)_-_40mph	58	36.5	25	950	1030	2.32	0.8	3.65	2	FALSE
20	2	SS2C	Suburban_S2_(PB/PC)(HD)_-_40mph	48	36.5	25	250	500	1.55	0.4	3.65	2	FALSE
21	3	US2T	Urban_Non-Central_S2_(GA)(LD)_-_30mph	54	39.5	25	490	980	1.67	1	3.65	2	FALSE
22	3	US2A	Urban_Non-Central_S2_(GA)(TD)_-_30mph	48.5	36.8	25	390	780	1.56	0.5	3.65	2	FALSE
23	3	US2B	Urban_Non-Central_S2_(AA/GB)(HD)_-_30mph	44.5	34.8	25	325	650	1.48	0.3	3.65	2	FALSE
24	3	US2C	Urban_Central_S2_(AA/GB)(LD)_-30mph	37	26	15	370	740	1.83	1	3.65	2	FALSE
25	3	US2D	Urban_Central_S2_(PA/AB/GC)(TD)_-_30mph	34	24.5	15	315	630	1.56	0.5	3.65	2	FALSE
26	3	US2E	Urban_Central_S2_(PA/PA/PC)(HD)_-_30mph	28.5	21.8	15	225	450	1.55	0.3	3.3	2	FALSE
27	4	VS2A	Town/Village_S2_(LD)_-_40mph	65.5	57	30	700	1300	3	0.8	3.65	2	FALSE
28	4	VS2B	Town/Village_S2_(MD)_-_40mph	56.5	48	30	700	1300	3.39	0.5	3.65	2	FALSE
29	4	VS2C	Town/Village_S2_(HD)_-_30mph	46.5	38	30	700	880	2.45	0.3	3.65	2	FALSE
30	4	VS2D	Town/Rat-Run_Road	34	26	10	200	350	2.36	0.1	3.3	2	FALSE

Figures D.1 to D.4 plot the speed-flow relationships for the various road types, based on the data in Table D.1. Note that values in the figures have been curtailed at a volume-to-capacity (V/C) ratio of approximately 1.4. Model scenarios resulting in higher V-to-C ratios on links (and their pollutant outputs) should be viewed with some caution, given the excessive level of congestion this would represent in actuality.

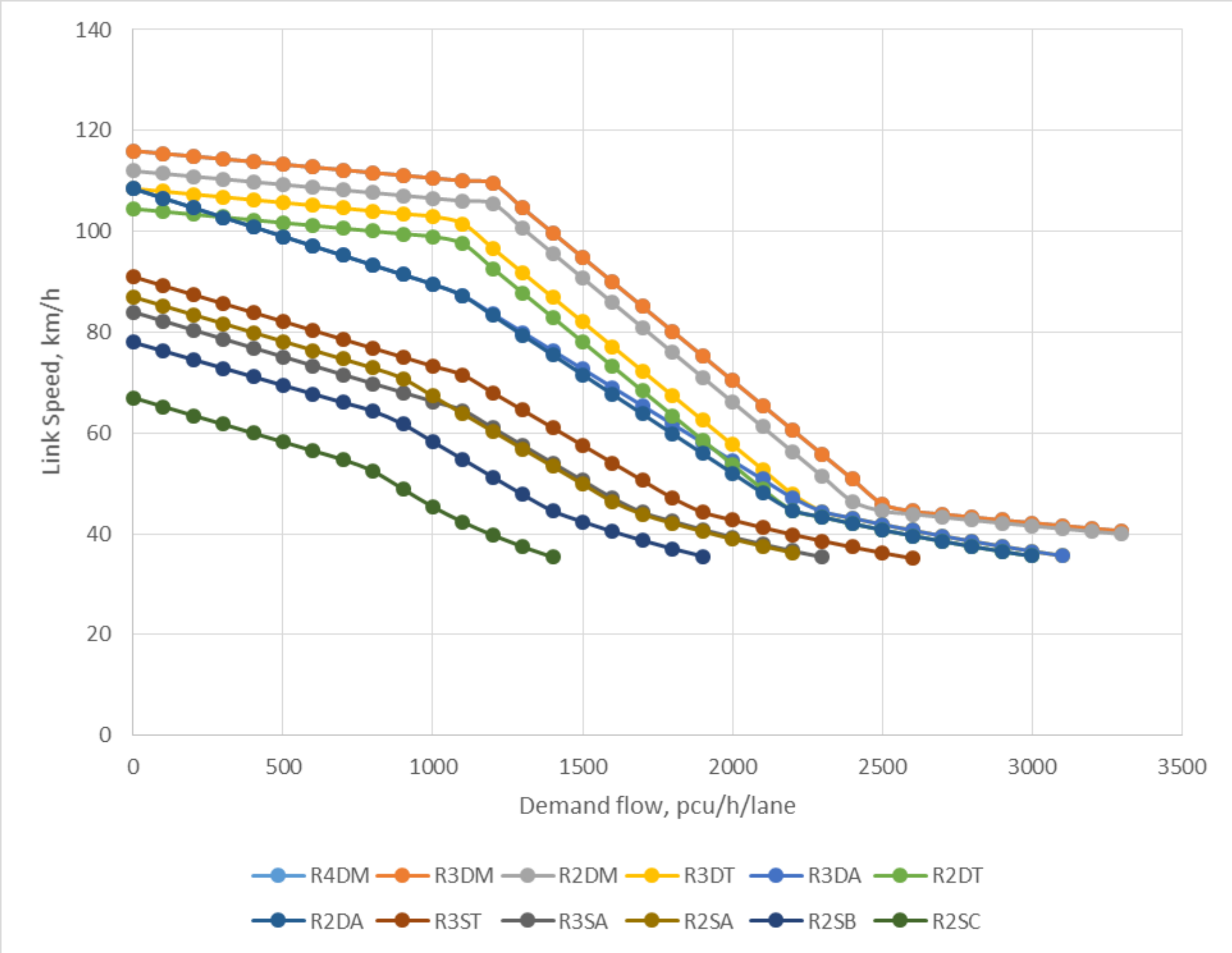

Figure D.1: COBA-type speed-flow functions for rural roads

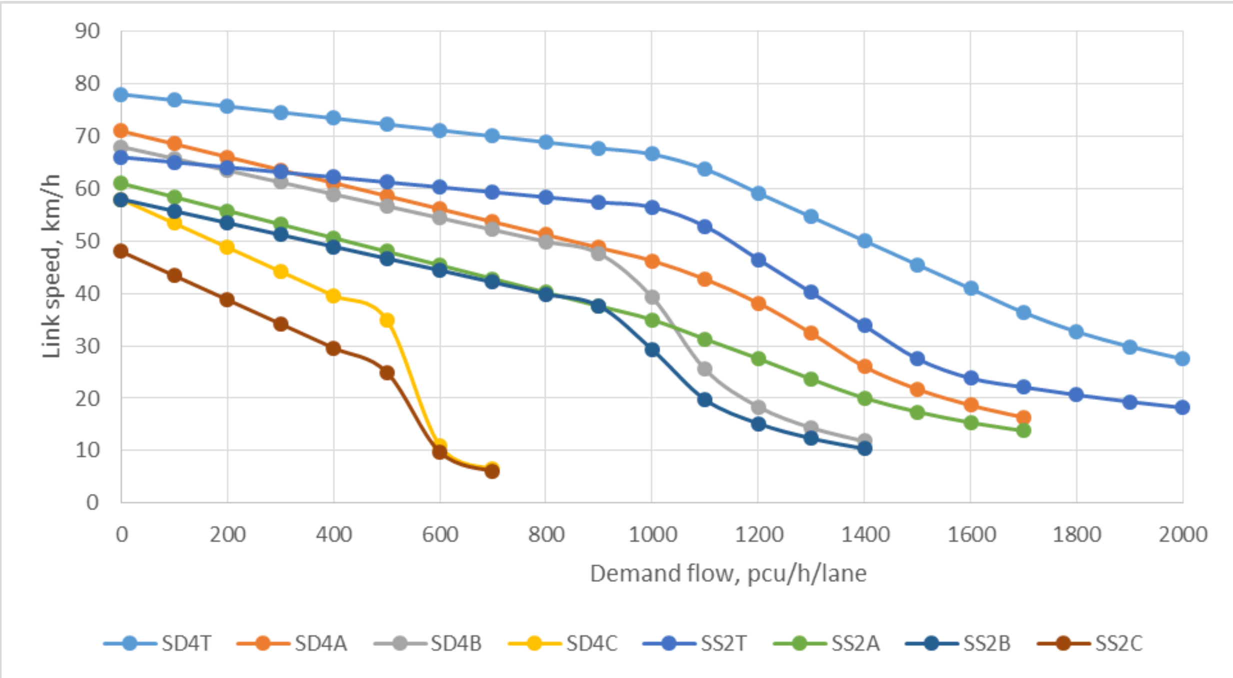

Figure D.2: COBA-type speed-flow functions for sub-urban roads

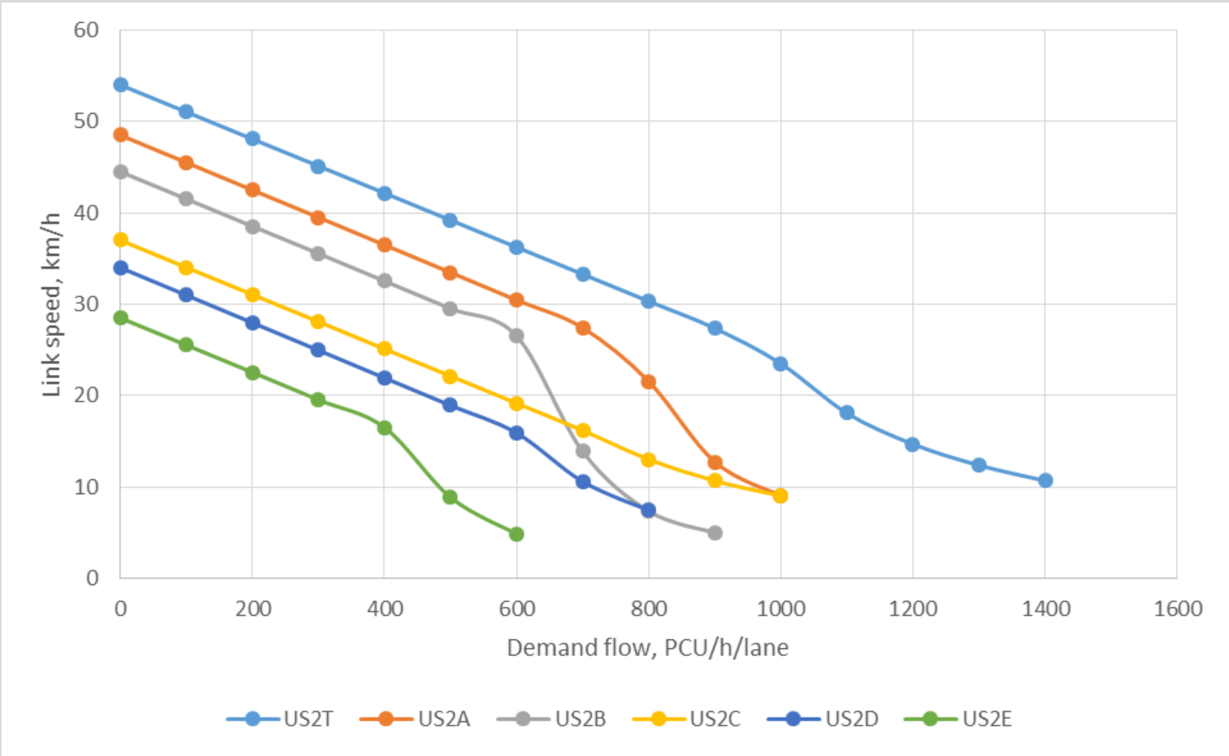

Figure D.3: COBA-type speed-flow functions for urban roads

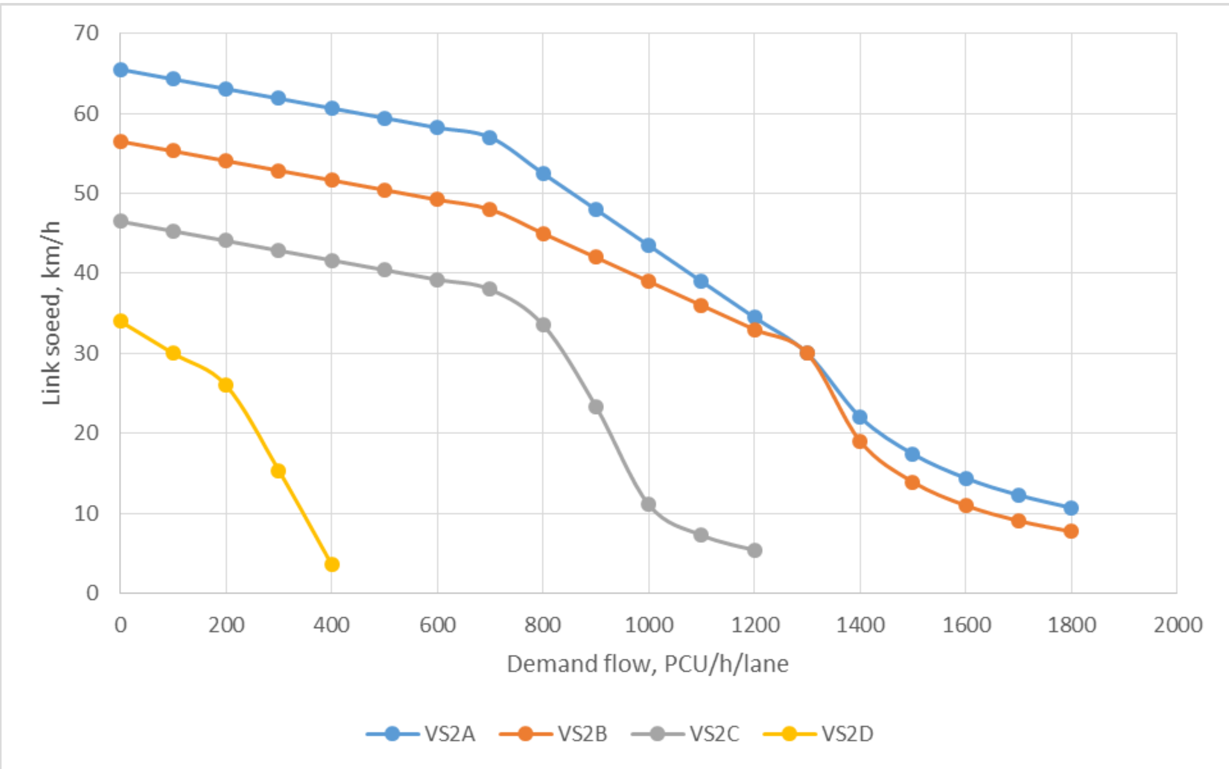

Figure D.4: COBA-type speed-flow functions for town and village roads

D.2: BPR-type functions:

The BPR (Bureau of Public Roads) function (BPR, 1964) equates average travel time, to the defined capacity and current flow level on a given link using the following formula:

$$S_a = t_a\left(1 + 0.15\left(\frac{v_a}{c_a}\right)^4\right) \quad [D.4]$$

Where:

'S_a' is the average travel time on link 'a', given the demand flow 'v_a' per unit time;
't_a' is the free-flow travel time on link 'a' (i.e. the travel time when 'v_a' tends to 0;
'c_a' is the capacity of link 'a' in unit time.

Figure D.5 gives an example of the BPR function, assuming a 1km stretch of road, with capacity of 1200veh (pcu)/lane/hour, and a free-flow speed of 70mph (112.65km/h), giving a 't_a' value of 31.95 seconds.

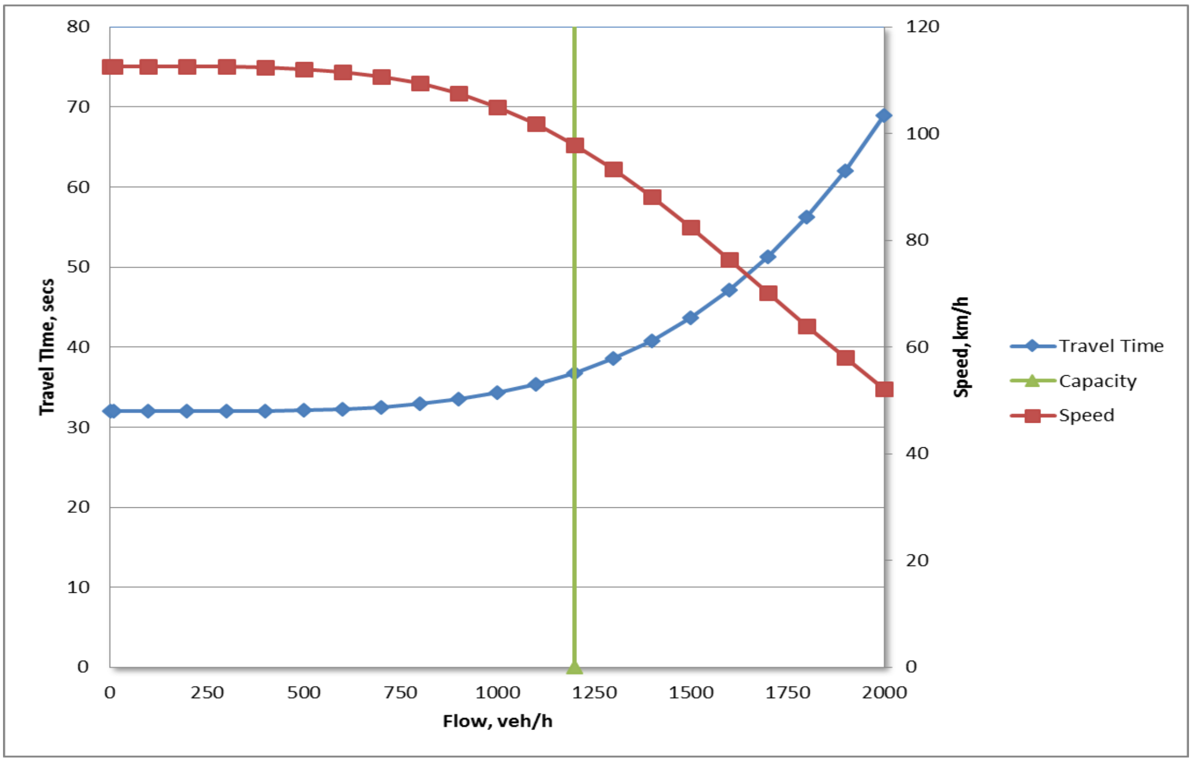

Figure D.5: Example of link travel-time and speed calculated using the BPR function.

D.3: CENTROID functions:

The centroid cost/speed-flow function simply assumes that a (virtual) link has infinite capacity and zero travel time.

D.4: References

Atkins (2009). *G-BATS3 v2.3 Highway Local Model Validation Report – Appendix B. Speed Flow Curves*. Online resource: http://www.westofengland.org/media/105087/appendix%20b%20-%20speed%20flow%20curves%20_final%20v5.3_.pdf [Accessed: 13/08/2014].

BPR (1964). *Traffic Assignment Manual*. U.S. Department of Commerce, Urban Planning Division, Washington D.C., U.S.

HA (2002). *Speeds on Links.* Design Manual for Roads and Bridges (DMRB): Volume 13 (Economic Assessment of Road Schemes), Section 1 (The COBA Manual), Part 5. Highways Agency. DMRB 13.1.5 (Withdrawn).

Appendix E: Traffic Assignment Methodologies

This appendix provides implementation details on three of the traffic assignment algorithms implemented within UHTIM applications (specifically 'M4BaseTraffGen.exe' and 'M4RecTraffGen.exe').

The internal representation of the road network, and the 'All-Or-Nothing' assignment algorithm are derived from the Boost Graph Library (Siek *et al.*, 2002) implementations. Many options available to, and used by, the UHTIM applications aren't (yet) made available to the user, but could be in future versions, to allow better control of assignments.

E.1: All-Or-Nothing Assignment

The 'All-Or-Nothing' Assignment methodology uses a fixed set of costs for all vehicle classes wanting to access the network in a given time period. All vehicles in that given period, for a particular OD pair, are allocated to the network using the shortest path through the network based on these invariant costs, even if that means links go 'over-capacity' during assignments.

The calculation of shortest paths between OD pairs is based on Dijkstra's Algorithm (Dijkstra, 1956).

E.2: Frank-Wolfe Assignment

The general Frank-Wolfe algorithm is "an iterative first-order optimization algorithm for constrained convex optimization". In a particular iteration "the Frank–Wolfe algorithm considers a linear approximation of the objective function, and moves towards a minimizer of this linear function (taken over the same domain)" (Wikipedia, 2018).

The heuristic for the algorithm is:

1. Initialise by:
   a. Generating free-flow travel costs, 't_f' for the network using Dijkstra's Algorithm;
   b. Calculating all-or-nothing flows, 'f_{ij}', based on these costs;
   c. Set increment counter 'n' to 1, and set maximum number of iterations 'n_{max}'

2. For each iteration:

   1. Re-compute travel times, $t_{ij}(f_{ij}^n)$ on each link;
   2. Use Dijkstra's Algorithm to recalculate shortest paths, using the updated times, $t_{ij}(f_{ij}^n)$;
   3. Calculate new flows 'g_{ij}^n' on links using $t_{ij}(f_{ij}^n)$;
   4. Use an appropriate search method to find a value for the step size parameter 'λ' such that
   $$\sum(g_{ij}^n - f_{ij}^n) . t_{ij}\left(f_{ij}^n + \lambda(g_{ij}^n - f_{ij}^n)\right) = 0 \qquad \text{[E.1]}$$
   5. Set $f_{ij}^{n+1} = f_{ij}^n + \lambda(g_{ij}^n - f_{ij}^n)$ for each link
   6. If $\frac{\sqrt{(f_{ij}^{n+1} - f_{ij}^n)^2}}{\sum f_{ij}^n} < \epsilon$, or n = n_{max} terminate calculation, else n = n+1, and start a new iteration.

In UHTIM, the search algorithm for 'λ' is based on a recursive, 'Golden Section' search (Kiefer, 1953), terminating when a minimum change threshold, or a maximum number of recursion iterations, is reached.

Setting an upper bound on the number of iterations ('n_{max}') is done to try to curtail issues with slow convergence, in some networks, at the expense of not all traffic actually being allocated to the network. Obviously, the value chosen should allow enough iterations for the bulk of traffic to have been assigned.

E.3: Incremental Assignment

Incremental assignment loads vehicle demand for a given time period onto the network in small 'chunks'. After each 'chunk' of traffic has been allocated, using 'all-or-nothing' assignment, network costs are recalculated, before the next chunk is loaded.

Note, any number of 'chunks' could be used, and travel costs may be based on weightings of previous assignment costs. The current 'Incremental' procedure in UHTIM is based on the heuristic presented in Wikipedia, supposedly reflecting that used in historic FHWA software packages (see: https://en.wikipedia.org/wiki/Route_assignment).

The heuristic for this procedure is:

1. Load all demand to the network via 'all-or-nothing' assignment;
2. Re-compute travel times, then reload traffic using the 'all-or-nothing' costs;
3. Split demand into four equal chunks;
4. Assign each chunk to the network using weighted costs from the previous two iterations – the most recent getting a weighting of 0.25, the most previous a weighting of 0.75.

E.4: Assignment Order

In the presence of multiple user classes on the network, vehicles are usually assigned in 'reverse PCU order'. The logic behind this is to allow priority access to the network for heavier vehicles, which would want to prefer access to main routes. Lighter vehicles then 'reroute' around the heavier vehicles where necessary.

Obviously, there are instances where this may be undesirable – i.e. where a planning application has been approved with traffic to site taking a designated route. In which case heavier vehicles will still be assigned to the route (modelled as a fixed, partial traffic state) first.

E.5: References:

Dijkstra, E. W. (1959). A note on two problems in connexion with graphs*. Numerische Mathematik. **1**: 269–271.*

Frank, M., Wolfe, P. (1956). An algorithm for quadratic programming. *Naval Research Logistics Quarterly. **3**: 95.*

Kiefer, J. (1953), Sequential minimax search for a maximum, *Proceedings of the American Mathematical Society*, **4** (3)

Siek, J., Lee, L.Q. and Lumsdaine, A. (2002). *The Boost Graph Library: User Guide and Reference Manual*. Addison-Wesley, New York, NY US. Online resource: https://www.boost.org/doc/libs/1_67_0/libs/graph/doc/index.html [Accessed: 07/08/18].

Wikipedia (2018). The Frank-Wolfe Algorithm. Online resource: https://en.wikipedia.org/wiki/Frank%E2%80%93Wolfe_algorithm [Accessed: 07/08/18].

Appendix F: Reference flow volumes for Fracking Traffic

This appendix provides a summary of the literature reviewed during the development of the first TIM model, under the ReFINE project. As this review was substantively completed prior to 2014 some of the references may be out-of-date, and not reflect current, best practice, or the current legislative states in the respective countries examined. It is also noted (and has been critiqued upon) that much of the data on fracking operations has been gleaned from US and Canadian experience, which again, may not have direct relevance to the social, economic, legislative, physical infrastructure and geology of Europe. Likewise many sources in this section are not peer-reviewed, and therefore may be treated with some scepticism. Finally, it is noted that the current UHTIM model is more flexible in its potential application, than to just fracking operations alone.

The appendix begins with a brief overview of the 'known unknowns' regarding traffic associated with fracking, before proceeding through discussion of the stages of operation and their demands. It concludes with a few estimates for the volume of traffic required for operations.

F.1: Transport and Hydraulic Fracturing: The known unknowns:

Known unknowns regarding the transportation element of fracking arise from the movement of both light and heavy duty vehicles during all stages of operation, from transportation of materials to site during well construction, through operation to final closedown and decommissioning. The greatest numbers of vehicle movements are associated with tanker transportation of water to the well site during the operational phase.

Such truck movements may be on inappropriate rural roads for part of their journey to the site, leading to inconvenience to local residents, formation of congestion in certain periods and excessive damage to the surface and structure of roads. However, the key concerns relate to vehicle emissions, in terms of both gaseous emissions and noise. Gaseous emissions may be further broken down into those gases associated with global warming effects, such as Carbon Dioxide (CO_2), and those associated with local air quality issues, such as Nitrogen Dioxide (NO_2) and particulate matter (PM). At present heavy duty vehicles are recognised as key contributors to the latter.

Other transport issues associated with large-scale heavy duty vehicle movements include: noise, vibration, direct damage to road pavements and sub-surface layers, additional congestion, community severance and disruption and potential safety issues (including collisions involving increased traffic, as well as the potential for contaminated water or chemical spillage from tankers).

Whilst the issues surrounding the above are well understood, have been extensively researched and form part of standard Environmental Impact Assessments (EIAs), carried out as part of the planning process for construction and industrial activities, the potential scale and spatial distribution of traffic associated with unconventional gas activities, may lead to deterioration of environmental quality not readily covered by existing environmental standards. For example, given the transient nature of operations, potentially short-term exceedance air-quality criteria may be breached, whilst annual average air quality standards and limits remain un-breached. The health impacts of such events are less readily understood and quantified.

F.2: Stages in Shale Gas Extraction:

AEA (2012) assumed six stages in their assessment of potential risks arising from unconventional gas operations in Europe. These stages were defined as:

1. Well pad site identification and preparation;
2. Well design, drilling, casing and cementing;
3. Technical hydraulic fracturing;

4. Well completion and water flow-back;
5. Well production;
6. Well abandonment.

At each stage risks and impacts were assessed under broad headings, including ‘traffic’, for ‘individual installations’ and for the ‘cumulative effects of multiple installations’.

AMEC (2013) presents a similar, but slightly more detailed list of stages to AEA, as part of the Strategic Environmental Assessment (SEA) examining issues surrounding the licensing of onshore oil and gas exploration in the UK. Stages, and sub-stages considered include:

1. Non-Intrusive Exploration:
    a. Site identification, selection, characterisation;
    b. Seismic surveys;
    c. Securing operational permits.
2. Exploration Drilling:
    a. Pad preparation, road connections, baseline monitoring;
    b. Well design and construction;
    c. Trial hydraulic fracturing;
    d. Well testing and flaring.
3. Production development:
    a. Pad preparation, baseline monitoring;
    b. Facility design and construction;
    c. Well design and construction;
    d. Hydraulic fracturing;
    e. Well testing and flaring;
    f. Pipeline connections (water in/out, gas out);
    g. Possible re-fracturing.
4. Production/operation/maintenance:
    a. Gas production;
    b. Disposal of wastes;
    c. Power generation, chemical use, reservoir monitoring.
5. Decommissioning:
    a. Well plugging;
    b. Site equipment removal;
    c. Environmental and well integrity monitoring.
6. Site Restoration and relinquishment:
    a. Survey and inspection;
    b. Site restoration and reclamation.

AMEC (2013) notes that exploratory wells (Stage 2) may move through the subsequent stages as part of either long-term production testing, or site redevelopment to full production capabilities, both subject to new consents and planning permission).

As noted in the previous section, examination of the literature suggests that the vast majority of road traffic associated with hydraulic fracturing (70%+) is associated with the movement of water and sand proppant to the site for injection to wells as part of the fracturing process, followed by movement of 'flow-back' or 'recovered' fluids away from the site, prior to full gas production (i.e. Stages 3 and 4 from the AEA document, or 2c and 3d from AMEC).

F.3: Vertical versus Horizontal or Directional Drilling:

Traditionally, wells for hydrocarbon resource extraction have been drilled vertically into resource bearing strata. Modern methods and technologies now enable drilling rigs capable of directional drilling, allowing wells to travel along resource bearing strata – vastly increasing their potential for resource extraction. Directional wells may be bored either horizontally, or at a slant (US EPA, 2010). As noted previously, multi-well pads are becoming more common throughout the US, and the same trend is expected in Europe. As noted previously, the term HVHF (High-Volume Hydraulic Fracturing) is assumed to mean the hydraulic fracturing of horizontal wells on a pad, requiring large amounts of water resource.

There may be considerable variation in the depth of a vertical well. A well tapping resource close to the surface may be only 300 m deep, but deeper wells may descent to 2.5 km depth (US EPA, 2010).

A horizontal well initially starts vertically, but, upon reaching the resource bearing strata, turns through 90° to travel along the strata – possibly for considerable distance. Horizontal sections may extend many hundreds of metres, if not kilometres away from the surface pad depending on geology. Broderick *et al.* (2011) suggested an example depth of 2 km and a lateral distance of 1.2km for UK modelling, whilst values of up to 3.2km have been suggested based on US operational data (Carroll and Klump, 2013). The Preese Hall test well was drilled to a depth of 2804 m (Cuadrilla, 2014a).

In plan, the wells may look like 'fingers of a hand', extending in parallel away from the wellheads (COGA, 2011) – see Figure F.1. Alternately, wells may radiate out like spokes on a wheel (Foreman, 2011).

Directional wells are similar to horizontal wells, but with boreholes extending initially vertically, but then at oblique angles to a) avoid local geologic structures such as aquifers or faults, and b) to make better use of resource-bearing strata. Actual penetration of gas bearing zones may be vertical again, making the overall well bore 'S' shaped (vertical-slant-vertical) (Foreman, 2011).

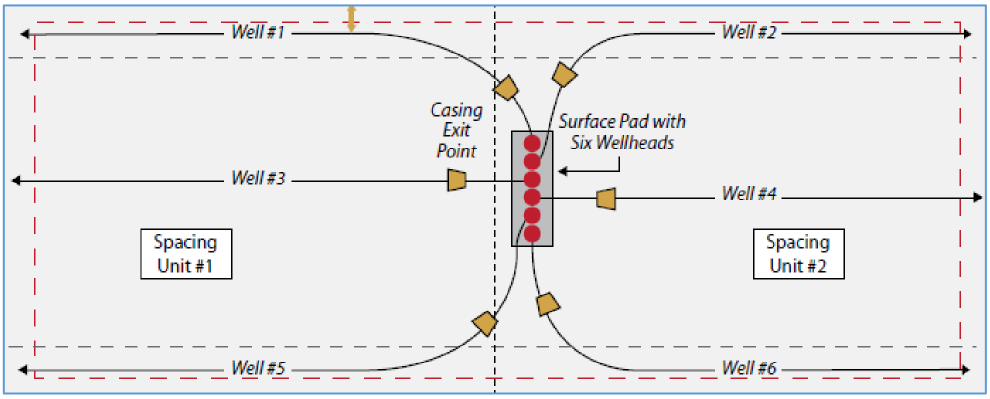

Figure F.1. Multi-well pad coverage diagram. (Source: COGA, 2011)

Given the greater overall length of bore in the horizontal or directional well situation, water demands may be far higher than for vertical wells, and there is an increase in the amount of materials needed for construction, on-site water storage and operation. Hence horizontal and directional wells are associated with higher surface transport demands for fracturing operations.

F.4: Single versus Multi- Well Pads:

The suitability of an area for hydraulic fracturing operations, and the number of wells sited on a pad is a complex problem to determine accurately. Site suitability and scale of operation depend on geological characteristics, including 'mineralogical, petro-physical and geo-mechanical properties that underpin the quality of a source rock for gas' (Gény, 2010). Unfortunately, gas flow rates from wells on the same pad, or in the same area, may be highly variable, leading to the need to drill many exploratory wells in an area before 'reliable well flow rates' can be ascertained (Rogers, 2013). This, in-turn would increase traffic and environmental impacts in the exploratory phases of pad development in an area.

The number of wells per pad may be variable. Traditional, conventional drilling over the past 100 years has been focused on the concept of a drilling pad containing a single well. Modern techniques allow for multiple wells on a single pad. Such multi-well pads are becoming the norm due to new drilling technologies (i.e precise horizontal or directional drilling – see next section) allowing economies of operation. A horizontal shaft, running laterally through gas bearing strata provides more equivalent 'payzone' for gas extraction than a vertical one. Hence, a modern, single centralised pad bearing horizontal wells, sharing common facilities, may be far more efficient than the older concept of drilling a large number of vertical well in an area, spaced every 300m or so – each requiring its own facilities. NYSDEC (2011) reports that 90% of Marcellus Shale development in the state is expected to be by 'horizontal wells on multi-well pads'. Examination of the literature suggests 6-, 8-, 10- or 12-well pads are now expected as standard, though only a single-well test pads have been operated to date in the UK, e.g. Preese Hall, Lancashire operated by Cuadrilla Resources (Cuadrilla, 2014a). Broderick *et al.* (2011) used 6- and 10- well configurations in their estimates of impacts on greenhouse gas emissions, whilst Rogers (2013) used 12-well pads in modelling estimates of UK production.

Less commonly, 20+ well pads have been suggested (SEAB, 2011; DrillingInfo, 2014), with literature from one US operator (DEC, 2008) citing operation of 21-well and a 36-well pads in north Texas. The size of a pad (and the amount of materials required for its construction) will be dependent on the number of wells to be cited on it – though the actual land take and amount of materials does not necessarily scale linearly with the number of wells. Pad and site size may also be determined by regulations on the proximity of equipment – e.g. the proximity of storage of potentially combustible materials away from ignition sources, or the storage of waste water away from natural surface water sources or residences.

Well pads themselves may be 'spaced out as an array' over a target geological formation at a density of 3-4 pads/km^2 (Broderick *et al.*, 2011). Sumi (2008) notes that as time and technology has progressed, and more experience of fracturing operations at a particular gas reservoir are gained, there is a trend for well pads to be 'downspaced' (i.e. operated more densely in a particular area).

Whilst efficient multiple well pads may produce economies of scale through utilisation of shared resources, and reduce surface transport demands, benefits be completely offset by the multiplication of well pads for a particular gas reservoir, all requiring the same system of access roads to transport materials to and from the local area (NYSDEC, 2011).

F.5: Pad and Access Road Construction:

Pad construction involves the initial construction of suitable access roads, followed by the clearing of vegetation or other obstacles from a small area of land. Foundations are then dug and laid in anticipation of the arrival of heavy plant and drilling rigging to the site. Foundations will ideally use gravel and concrete from local sources (e.g. quarries, local cement etc.) to reduce transportation demands.

Given the large number of number possible wells associated with a pad, overall site and pad sizes are also variable, with ICF (2009) reporting site dimensions (pad + lined pits for water storage, but excluding access roads) for horizontal well pads in the range 300' by 250' (91 m x 76 m / 0.69 ha) to 500' by 500' (152m x 152 m / 2.3 Ha). A 'rule-of-thumb' was suggested, based on discussion with operators of assuming an initial, single-well pad size of 350' by 400' (106 m x 122 m / 1.3 ha), which increased the largest dimension of the pad by 50' (15 m) for each well present (i.e. an increase of 400' x 50' (122 m x 15m / 0.18 ha) per well) – to give a total of 2.1 hectares for a 6-well pad. Broderick *et al.* (2011) suggested a range for a 6 well pad of between 1.5 – 2.0 hectares, but land take for a single well pad being 0.7 hectares. Regeneris (2011) states that a single test well pad of 0.7 hectares could eventually support commercial operation of 10 wells spaced out across the total site area. King (2012) states that a single 2.4 hectare pad supporting multiple wells could collect gas from an area 1000x larger (2400 ha). After well completion, and during production, land reclamation would be expected to shrink overall pad dimensions, with one operator suggesting dimensions of 200' by 250' (61m x 76 m / 0.46 ha) (ICF, 2009).

Regarding the duration of pad construction, AEA (2012) cites both NYSDEC (2011) and Broderick et al. (2011) as concurring 'that the well pad construction phase may be expected to last up to 4 weeks per well pad'. Both NYSDEC (2011) and AEA (2012) note that the impact of pad construction traffic (estimated as 135 one-way, loaded trips over the period), spread over a 4-week period would 'not be environmentally significant in itself, although would be noticeable in a rural or residential area'.

F.6: Well Construction:

ICF (2009) gives the following values for the duration of preparation, drilling and completion activities for individual wells, based on planning application data from Wyoming, for the Hornbuckle Drilling programme:

- Rig transport and assembly: 7 days/well
- Drilling operation to target depth, and then lateral section: 35 days/well

For operations in New York Marcellus Shale data from Chesapeake Energy drilling applications in Delaware gave the following data:

- Rig transport and assembly: 5 - 30 days/well
- Drilling operation to target depth, and then lateral section: 20 - 30 days/well

Less conservative estimates from the US place well construction and drilling at 25 days or under (Rogers, 2013). A representative for Chesapeake Energy Corporation, quoted by Carroll and Klump, 2013, suggested that, with operational experience well construction times had been brought down from 25 days to 18 days over the 2011-12 period, and that the company was ultimately aiming for under 13 days per well in developments of Eagle Ford shale. This decrease in construction times suggests a potential increase in the *intensity* of surface construction traffic, over a shorted demand period as operations progress into the future.

Regarding the amount of waste material produced by drilling, Broderick *et al.* (2011) assumed a typical horizontal well (drilled to a depth of 2 km, then 1.2 km laterally) would produce a cuttings volume of approximately 830 m^3 from a 6 well pad (i.e. ≈140 m^3 cuttings/well). A conventional 2km deep vertical well was quoted as producing 85 m^3 of cuttings.

F.7: Hydraulic Fracturing and Well Completion:

Broderick *et al.* (2011) state that the actual fracturing procedure is carried out sequentially, with one well fractured after the other. Each fracturing involves a number of 'stages'. Each stage involves isolating a segment of the well bore (starting at the far end), perforating the well casing, pumping fluid into the segment at high pressure, maintaining pressure for a period, then allowing flow-back. Broderick *et al.* (2011) suggest that an initial fracturing operation may consist of 8–13 stages, involving 30-60 days per well (though multiple wells can be prepared simultaneously), followed by 2-5 days per well for fluid pumping. Delivery of water, and other materials, to the site prior to fracturing would occur within this 30-60 day period. Mooney (2011) suggested that horizontal wells could eventually incorporate 30 stages or more.

The data from Wyoming and Delaware, reported in ICF (2009) is as follows.

Wyoming, Hornbuckle Drilling Program:

- Fracturing and Completion: 30 days/well
- Total time to completion (including construction): 72 days/well

For operations in New York Marcellus Shale ICF (2009) notes that both drilling depths, and lengths of lateral sections were increased, with more stages (see below) required for fracturing. Data from Chesapeake Energy, Delaware gave times as:

- Fracturing and Completion: 35 - 65 days/well
- Total time to completion (including construction): 60 - 125 days/well

ICF (2009) also reported that, given an estimate of 72 days/well, sequential operation on a six-well pad would require over a year to complete, excluding pad construction and site assembly times. The report also noted that some operators, drilling in Marcellus Shale would drill one or two initial wells on a pad to determine productivity, then if found viable, a further 4 to 6 wells would be drilled up to 2 years later.

NYCDEP (2009) also states that the majority of environmental impacts (transport and other) from fracturing occur in 'an approximately two to four month period as the well is developed (to completion). Once the well is completed the risk of serious impacts is reduced'.

Broderick *et al.* (2011), based on NYCDEP, 2009, suggest that all construction and preparation activities for a 6-well pad, prior to production of gas could stretch over a period of 500 – 1500 days, assuming 'no overlap of activities' – though both reports recognise some 'limited' overlap potential in practice. Drilling of wells on a multi-well pad was assumed to be conducted one or two wells at a time for subsequent modelling.

Rogers (2013) noted that the physical scale of operations on a 12 well pad meant that the overall drilling and construction of wells on the pad could last a period of 12 to 16 months. This was based on the author's own estimate of 1 to 1.5 months of construction per well, a shorter estimate

Regeneris (2011) suggest that a test well pad with a single well may be prepared to completion in 30-60 days, with the key variable being the weather during the period.

F.8: Drilling and Fracturing Water Demand:

Initial drilling of wells, prior to any fracturing procedure, has an associated demand for coolant water. Goodwin *et al*. (2012) report initial drilling as requiring on average 77,000 gallons (US) (290m^3) for a vertical well and 130,000 gallons (US) (492m^3) for a horizontal well, based on data from 445 wells in Wattenberg Field, Colorado. Jiang *et al.* (2013) cite values of 300 – 380m^3 of drilling water required, with a median of 320m^2 for Marcellus shale wells.

The need for large volumes of water for the fracturing process drives the major demand for surface transport to hydraulic fracturing sites. The amount of water required is highly dependent on the type of well (vertical or horizontal, as noted above) and the underlying geology of the drill site – though depth is a key determining factor (Gény, 2010).

The US EPA (2010) suggests that ’50,000 to 350,000 gallons (US)’ (190 – 1,325m^3) of water are required for one well in a coal-bed formation, but for shale gas that value increases to ‘2 million to 5 million gallons (US)’ (7,570 – 18,930m^3) per well. Abdalla and Drohan (2010) cite values of ‘4 million to 8 million gallons (US)’ (15,140 – 34,000m^3) for Marcellus shale wells, required in the period of a single week, whilst Jiang *et al.* (2013) cite a range from 6,700 to 33,000 m^3, with a mean of 20,000 m^3 for Marcellus shale wells. Jiang *et al.* (2013) also report using a normal distribution with mean 15,000 m^3 and overall range from 3,500 to 26,000 m^3 to model freshwater (i.e. non-recycled water) demand for each well.

King (2012) provides the following table (Table F.1) of average water demand, for both drilling and fracturing (NB: Values have been converted from US Gallons, rounded to nearest 10 m^3):

Table F.1: Average water demands per Shale Well for Drilling and Fracturing (Source: King, 2012)

Unconventional development	Average freshwater volume for drilling, m^3	Average freshwater volume for Fracturing, m^3	Saltwater volume for Fracturing, m^3
Barnett	950	17,410	-
Eagle Ford	470	18,930	-
Haynesville	2,270	18,930	-
Marcellus	320	21,200	Increasing use
Niobrara	1,140	11,360	-
Horn River (EnCana and Apache)	950	-	Up to 45,420

Unfortunately for European operations, shale depths, especially in Eastern Europe may be up to 1.5x deeper than those found in the US and may require additional demands for water (Gény, 2010), though Gény also notes that the cost of water is typically ‘10x higher’ in Europe than in the US, driving a greater need to reduce use, and re-cycle wherever possible. More encouragingly data from the Preese Hall site suggested lower requirement of 8,400 m^3 for a single test well, implying a total of 84,000 m^3 for a 10-well pad (Broderick *et al.,* 2011).

The UK Department for Energy and Climate Change (DECC) suggest values for a fracturing operation of 10,000 to 30,000 m^3 per well, and comment that operating a well for a decade has the same water demand as ‘a golf course for a month, or a 1,000MW coal-fired power station for 12 hours (DECC, 2014).

For their modelling activities Broderick *et al.* (2011) suggest that each stage of a fracking operation for a single well will require between 1,100 and 2,200 m^3 of water, leading to a total demand of 9,000 to 29,000 m^3 per well, or 54,000 to 174,000 m^3 for a six-well pad. These values were then used to provide carbon emissions estimates for a typical UK well.

The European Parliament report ‘*Impacts of shale gas and shale oil extraction on the environment and on human health’* (EP DGIP, 2011) also summarises water-demand data from the states, based on site and region, as per King (2012). See Table F.2:

Table F.2: Water Demand of Various Wells for Shale Gas Production [Source: EP DGIP, 2011]

Site/Region	Total Water per Well, (inc. drilling)	Fracturing water per well	Data source and year
Barnett Shale	17,000 m^3		Chesapeake Energy 2011

Barnett Shale	14,000 m^3		Chesapeake Energy 2011
Barnett Shale	No data	4,500 m^3 – 13,250 m^3	Duncan 2010
Barnett Shale	22,500 m^3		Burnett 2009
Horn River Basin (Canada)	40,000 m^3		
Marcellus Shale	15,000 m^3		Arthur *et al.* 2010
Marcellus Shale	1500 m^3 – 45,000 m^3	1,135 m^3 – 34,000 m^3	NYCDEP 2009
Utica Shale, Québec	13,000 m^3	12,000 m^3	Questerre Energy 2010

As literature on hydraulic fracturing typically quotes 'per well' values, and there may be a number of wells in operation on a particular pad, care must be taken to scale demand for (and waste produced by) fracturing fluids appropriately. The profile of on-site water demand, and hence the intensity of water deliveries by truck, may be buffered somewhat by the presence of on-site water storage facilities.

Need for the transportation of water to the site may be reduced, or mitigated completely either by the construction of dedicated pipelines, or by tapping local surface, ground or aquifer water supplies (though possibly at the expense of local potable water reserves). However, given the spatial distribution of well pads (3-4/km^2) and the short duration of the fracturing process per well (2-5 days), Broderick *et al.* consider a scenario utilising pipelines to transport water to sites as unlikely in the UK context. They also note that water abstraction is tightly regulated in the UK, and again, may not be viable for fracturing on a large scale. DECC (2014) also notes that abstraction is an option 'if permitted by the relevant environment regulator', though to date 'the only company to have hydraulically fractured in the UK used water from the local water supply utility company'.

F.9: Fracturing: Other Material, Fluid and Chemical Demands:

For a variety of reasons various substances are added to the water in a fracturing operation. Primarily 'proppants' are added to aid keeping fractures open once they are formed. Generally proppants are formed from various sands or man-made ceramics. Other additives may include: friction reducers and surfactants, clay stabilisers, corrosion inhibitors, scale inhibitors, crosslinking agents (to increase viscosity and improve proppant transport), breakers (to reduce viscosity), acids and bactericides (Broderick *et al.*, 2011). Generally fracturing fluid may consist of greater than 90% water, 9.5% proppant and 0.5% other chemical additives by volume. Data from previous, current and proposed sites in the UK operated by Cuadrilla (Cuadrilla, 2014a; Cuadrilla, 2014b) suggest fracking fluids with greater than 99.95% water and proppant, and 0.05% chemical additives by volume. Generally fracturing additive requirements in exploratory wells in the UK have been lower than typically used in the US (Broderick *et al.*, 2011).

If a base requirement of 20,000m^3 of water and 5% by volume proppant is assumed, this equates to a transportation need for delivery of 1,000m^3 of sand, or 1,700 tonnes of sand (assuming dry sand with density 1700kg/m^3).

Unfortunately, many of the additive chemicals are hazardous or toxic – requiring separate, carefully controlled delivery to site. NY DEC (2009) states that most transportation and on-site storage of chemicals is done in 1 – 1.5m^3 high density polyethylene (HDPE) steel caged containers.

F.10: Flow-back Material:

The US Environmental Protection Agency (US EPA, 2010) suggests that the rate recovery of injected fluids from hydraulic fracturing is variable – ranging between 15 and 80%. NYCDEP (2009) suggests use of a 'worst case' option of 100% in the calculation of tanker demand, whilst NYSDEC (2011) reports 9 to 35% for Marcellus shale wells in Pennsylvania. Cuadrilla report values of 20 to 40% for returned waters (Cuadrilla, 2014b). The variability in reported flow-back water percentages makes modelling transport demands problematic, potentially almost doubling overall traffic in the 'worst case' scenario.

Using the US EPA (2010) values above, Broderick *et al.* (2011) give flow-back per well as being between 1,300 and 23,000m^3 of fluid (or 7,900 to 138,000m^3 for a six-well pad). For further calculations a rate of 50% was assumed.

As with initial water demand, the actual intensity and duration of surface transport profiles associated with flow-back material will therefore depend heavily not only on the amount of waste produced, but also on the available storage of that waste (if any) on site. Broderick *et al.* cite one operator as suggesting that a typical waste-water pit for flow-back fluid form a single well as having a volume of 2,900 m^3 (with dimensions approximately 10m x 10m x 3m deep), hence for a multi-well pad, with larger water demands, further on-site storage would be necessary. Alternately, rather than being stored in on-site lined pits, on-site tanks may be used.

The availability of on-site storage would also influence the operational profile of wells at the site, given that ability to operate wells simultaneously may be curtailed by available waste storage capacity.

The overall demand profile is also potentially non-linear, given the bulk of flow back occurs immediately following the fracturing operation, implying that more tankers may be needed to transport water away from site in the days directly after fracturing. Broderick *et al.* state that approximately 60% of flow-back waste is produced within the first four days after fracturing, with reducing amounts of flow-back continuing for each day, over an approximate two-week period. NYSDEC (2011) also gives the '60% over the first four days' value and suggests a total recovery period of 2 to 8 weeks.

Hydraulic fracturing fluids are typically mixed and blended on-site during operations to achieve better overall control, flexibility and suitability of the fluids to the operation on-hand. The nature of the additive chemicals used, plus the increased salinity of the flow-back waste with contact to minerals, mean that storage and disposal of wastes is problematic. The same tankers used in the delivery of water to site are not the same vehicles removing waste from site, NYCDEP (2009) notes that a 3 million gallon (11,360 m^3) fracking operation, using 9,000 gallon (34 m^3) tankers, and assuming 100% flow-back, produces over 600 tanker trips.

Additionally, waste flow-back fluid may be re-cycled on- or off-site. Re-cycling involves the separation and removal dissolved solid materials from the fluid, before re-mixing and further use in fracturing operations. Eventually, the accumulating fraction of solid material and salinity renders the water as non-viable for recycling. However, the presence or absence of re-cycling facilities may mitigate or alter the demand profiles for water transportation.

The waste problem is further compounded if waste has come into contact with naturally occurring radioactive materials (NORMs), as it may not be feasible to use conventional wastewater treatment plants to process or recycle waste, necessitating further specialist vehicles, and transportation to possibly more distant and remote treatment sites.

F.11: Additional Produced Water:

In addition to the immediate disposal of flow-back fracking fluids, there is also the need to handle longer-term 'produced water' from wells, both before full gas production can occur, and possibly constantly throughout the production life of the well. Produced water is water that occurs naturally in the gas-bearing strata. Sumi (2008) reports that the volumes of produced water can be considerable (sample data from two US operators suggested initial median rates of 6.2m^3 and 8.4m^3 of produced water for every 28m^3 of gas extracted – though these values may also include flow-back fluids), and that the periods over which produced water removal is required can be lengthy: from 6-18 months till peak gas production, then periodically through the operational life of the site.

The volume of traffic associated with produced water removal will depend both on the amount of water produced on the site's capacity to store the water in tanks or evaporate from/store the water in lined ponds. As with the initial flow-back fluids, produced water will likely be highly saline and contaminated. Somewhat contrary to the figures suggested by Sumi, NYSDEC (2011) (requited in EP DGIP, 2011) give a suggested requirement of 2 to 3 tanker trips per year to handle produced water removal – which would produce almost negligible environmental impact.

F.12: Re-fracturing:

During the 5-20 year operational lifespan of a drilling site, it may be viable to 're-fracture' the well a number of times in order to release further gas resources (Abdalla and Drohan, 2010) and increase the economic productivity of a particular site. However, Roussel and Sharma (2011) report that re-fracturing may be viable for only 15% of pads, based on analysis of data from Colorado, whilst NYCDEC (2011) states that Barnett shale wells 'generally would benefit from re-fracturing within 5 years of completion, but the time between fracture stimulations can be less than one year or greater than 10 years', whilst 'Marcellus shale operators … have stated their expectation that re-fracturing is a rare event'. Broderick *et al.* (2011) assumed a single re-fracturing of 50% of wells in a UK-wide shale gas scenario.

If feasible, each re-fracturing operation will incur the need for similar, if not greater levels of water demand (and hence transportation demand) as the initial fracturing operation. Sumi (2008) quotes Halliburton as reportedly requiring '25% more job volume' in a re-fracturing, when compared to the previous fracturing. The precise number of times re-fracturing may occur is also reportedly variable. For example, Ineson (2010) reported that, as of 2006, some Barnett Shale wells had been re-fractured over 10 times, with the majority re-fractured at least twice.

Aside from the uncertainty regarding the feasibility of re-fracturing and the number of re-fracturing events, it may be assumed that there would be a surface transport demand at least as great as the initial fracturing demand, for each re-fracturing operation, assuming that no additional pipeline infrastructure had been constructed in the intervening time.

F.14: Well plugging and Decommissioning:

At the end of operational life (or in the event of an unsuccessful operation) wells are plugged and abandoned. Well casings and ancillary equipment are removed, and sites may be further re-landscaped to 'make good'.

NYCDEP (2009) (re-quoted in Broderick *et al.*) suggests that at least 15m^3 of cement must be placed in the top of wellbores 'to prevent any release or escape of hydrocarbons or waste water'.

F.15: Total Truck Demand:

Many reports investigated in the literature (e.g. Broderick et al., 2009; EP DGIP, 2011) cite elements of NYCDEP (2009) when calculating the resource demands, and commensurate overall truck movements associated with fracturing operations.

Broderick *et al.* (2011) provide the following summary table (Table F.3), based on NYCDEP (2009) data, as used in their calculation of greenhouse gas emissions from a six-well pad:

Table F.3: Truck Visits over the lifetime of a six-well pad

[Source: Broderick et al. (2011), based on NYCDEP (2009)]

Purpose	**Per well**		**Per pad**	
	Low	**High**	**Low**	**High**
Drill pad and road construction			10	45
Drilling rig			30	30
Drill fluid and materials	25	50	150	300
Drilling equipment (casing, drill pipe etc.)	25	50	150	300
Rig completion			15	15
Completion fluid and materials	10	20	60	120
Completion equipment (pipes, wellheads)	5	5	30	30
Hydraulic fracture equipment (pumps and tanks)			150	200
Hydraulic fracture water	400	600	2,400	3,600
Hydraulic fracture sand proppant	20	25	120	150
Flow-back water removal	200	300	1,200	1,800
Total (Bracketed number for 'per well' includes values associated with pad construction)	685 (890)	1050 (1340)	4,315	6,590
…of which associated directly with fracturing process			*3,870*	*5,750*
			90%	*87%*

A separate table in Broderick *et al.* provides resource requirements per well based on a combination of Cuadrilla data (Regeneris, 2011) and NYCDEP data (2009). This information is presented in Table F.4.

Table F.4: Resource requirements per well under Cuadrilla Development Scenarios

[Sources: Broderick et al. (2011) quoting Regeneris Consulting (2011) and NYCDEP (2009)].

Parameter	**Resource use per Well**	
Well pad area	0.7 ha	
Water required for fracturing	8,399 m^3	
Fracking chemicals volume	3.7 m^3	
Well cuttings volume	138 m^3	
	Low estimate	High estimate
Flow-back fluid volume	1,232 m^3	6,627 m^3
Total duration of activities in pre-production phase	83 days	250 days
Total truck visits	719	1,098

EP DGIP (2011) also cites NYCDEC (2009) as a primary data source, and provides a slightly different, but comparable table (Table 5) to Broderick *et al.* (Table 3). Table F.5 assumes:

> "A single well pad. Total well length 1500m to 4000m, consisting of 900m to 2100m depth and 600m to 1800m of lateral length with a 6 inch diameter production casing and 8 inch diameter production borehole. Lateral is cased but not grouted" (EP DGIP, 2011)

Table F.5: Estimated quantities of materials and truck movements for a single well

[Sources: EP DGIP (2011); summarised from NYCDEP (2009) with conversion of US Imperial values to SI units)[1].

Activity	Materials	Volume	Associated Truck movements	Implied truck capacity/rate
Site access and pad construction	Cleared earth and vegetation	0.8 to 2.0 ha site, plus access roads	20 to 40	0.04-0.05 ha/truck
Drill rig set up/initial Drilling Chemicals	Drill equipment Various chemicals	-	40	N/A
Drilling water (in)	Water	40 m^3 to 400 m^3	5 to 50	8m^3/truck
Casing	Pipe	2100 – 4600m of casing (60 – 130 t). Each truck will carry 15 x 6 m of casing.	25 to 50	84 – 92 m of casing/truck (2.4 – 2.6 tonnes/truck)
	Cement (grout)	14 to 28 m^3	5 to 10	2.8m^3 /truck
Drill cuttings	Rock/Earth/Formati on Material	71 to 156 m^3	Depends on the fate of the cuttings	
Drilling water (waste)	Water waste	40 m^3 to 400 m^3	5 to 50	8m^3/truck
Casing perforation	Explosives	Single 25g charge, number of charges used per length of lateral	1	
Fracturing fluid water (in)	Water	11,355 m^3 to 34,065 m^3	350 to 1000	32 - 34m^3/truck
Fracturing fluid chemicals	Various	Assume 1 to 2% of fracture fluids are chemicals: 114 m^3 to 681 m^3	5 to 20	22.8 – 34m^3/truck
Fracturing fluid water (out)	Waste fracturing fluids	Assume 100% of initial water: 11,355 m^3 to 34,065 m^3	350 to 1000	32 - 34m^3/truck
Well pad completion	Equipment	N/A	10	N/A
Gas collection	Produced water	57m^3 per year/ per well	2 to 3	19 – 29 m^3/truck
TOTAL			800 to over 2000	

[1]All truck trips in the original NYCDEP (2009) document were assumed to be by '18-wheeler semi- trucks or 9,000 gallon (34 m^3) tankers.

A separate column has been added to Table 4, to provide estimate the capacities of the trucks used in the transportation of materials. These values assume that each truck movement is associated with a two-way trip, rather than a movement being associated with a single on-way trip, to or from site.

The NYSERDA (2010) and NYSDEC (2011) documents go somewhat further than the other literature presented in this document that four scenarios are discussed [NB: the same scenarios are repeated in both documents, with information from NYSERDA (2010) forming parts of NYSDEC (2011)]:

1. An 'early development vertical well' scenario – with a single well, on a single pad with all water demands met by truck;
2. As above, but with a horizontal well;
3. As one, but a 'peak well' scenario, with water delivery transport demands significantly reduced through the use of pipelines to bring water to, and remove water from the site;
4. As three, but with a horizontal well.

NYSERDA (2010) / NYSDEC (2011) also breaks the component traffic down into 'light' trucks and 'heavy' trucks. Data for all scenarios is presented in Table F.6 (Vertical well data) and Table F.7 (Horizontal well data). Columns have been added to the original tables to show the percentage reductions between early- and peak- development.

Table F.6: Estimated One-way, Loaded trips per Vertical Well, in Early- and Peak- Development Scenarios *[Source: NYSDEC, 2011].*

Activity	**Early Well Pad Development**		**Peak Well Pad Development**		**Percentage reduction (Early well to Peak well)**	
	Light Trucks	Heavy Trucks	Light Trucks	Heavy Trucks	Light Trucks	Heavy Trucks
Drill Pad Construction	90	32	90	25	-	-22%
Rig Mobilisation	140	50	140	50	-	-
Drilling Rig Fluids		15		15		-
Non-Rig Equipment		10		10		-
Drilling (Rig crew etc.)	70	30	70	30	-	-
Completion chemicals	72	10	72	10	-	-
Completion Equipment		5		5		-
Hydraulic Fracturing Equipment (on-site tanks)		75		75		-
Hydraulic Fracturing Water Haulage		90		25		-72%
Hydraulic Fracturing Sand		5		5		-
Waste and produced water disposal		42		26		-38%
Final pad preparations	50	34	50	34	-	-
Miscellaneous	85	0	85	0	-	-
TOTAL One-Way, Loaded Trips Per Well	**507**	**398**	**507**	**310**	**-**	-22%

Table F.7: Estimated One-way, Loaded trips per Horizontal Well, in Early- and Peak- Development Scenarios *[Source: NYSDEC, 2011].*

Activity	**Early Well Pad Development**		**Peak Well Pad Development**		**Percentage reduction (Early well to Peak well)**	
	Light Trucks	Heavy Trucks	Light Trucks	Heavy Trucks	Light Trucks	Heavy Trucks
Drill Pad Construction[1]	90	45	90	45	-	-
Rig Mobilisation	140	95	140	95	-	-
Drilling Rig Fluids		45		45		-
Non-Rig Equipment		45		45		-
Drilling (Rig crew etc.)[2]	140	50	140	50	-	-
Completion chemicals	326	20	326	20	-	-
Completion Equipment		5		5		-
Hydraulic Fracturing Equipment (on-site tanks)		175		175		-
Hydraulic Fracturing Water Haulage[3]		500		60		-88%
Hydraulic Fracturing Sand		23		23		-
Waste and produced water disposal		100		17		-83%
Final pad preparations	50	45	50	45	-	-
Miscellaneous	85	0	85	0	-	-
TOTAL One-Way, Loaded Trips Per Well	**831**	**1,148**	**831**	**625**	**-**	-46%
Percentage difference compared to Vertical Well scenarios	**+63%**	**+188%**	**+63%**	**+102%**	**-**	-

[1]Assumes construction of a new well pad for each well, which could be considered an overestimate if the site is initially planned as a multi-well pad. [2]Assumes that separate vertical and directional drilling rigs are required. [3]Assumes 5 million gallons (US) (18,927m^3) of water per well is required, which implies that individual tankers are assumed to carry approximately 38m^3 of liquid.

NYSDEC (2011) also provides some information regarding the temporal distribution of vehicles at a single well-pad, during the phases of construction to completion (Figure F.2). The figure contrasts the demand pattern for a vertical well pad, against a horizontal well over a '50-day period of early pad development'.

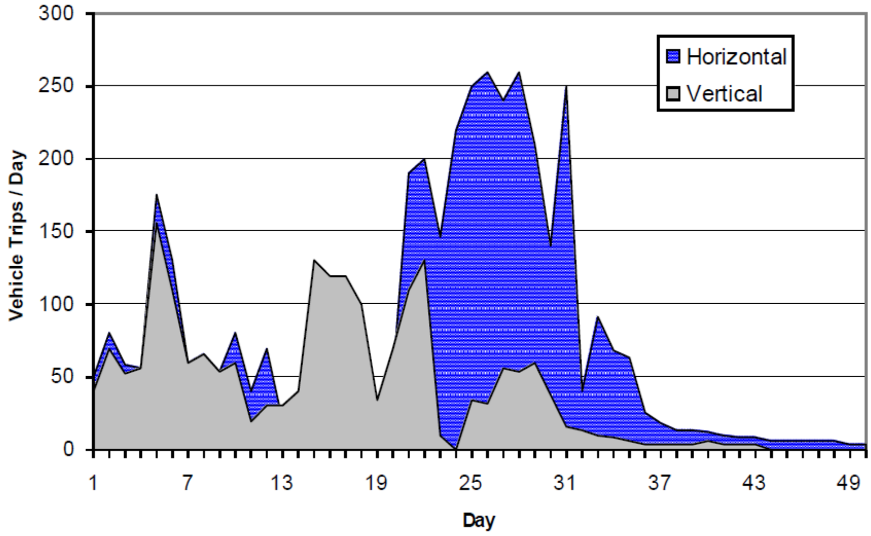

Figure F.2: Estimated Round-Trip Daily Traffic by Well Type

(Source: NYSDEC, 2011)

It is noted from the figure that initial mobilisation and drilling for both well types is comparable, though 'from Day 20 to Day 35, the Horizontal well requires significantly more truck transport than the vertical well' (NYSDEC, 2011). Unfortunately, it is not clear from the document and supporting text as to which phases in construction can be associated with individual features (peaks) in the diagram.

Figure 4 presents truck traffic data from a further scenario. The scenario assumes that three drilling rigs are initially operated over a 120-day period. Each rig drills four wells in succession, then is moved to allow well completion and fracturing. All water for the wells is brought in by truck. Fracturing at each well occurs sequentially, with all four wells sharing the same on-site tanks.

NYSDEC (2011) notes that, for horizontal wells the highest volume of truck traffic occurs 'in the last five weeks of well development, when fluid is utilised in high volumes'. Features in the profile associated with heavy transportation of water are clearly visible from approximately day 70 onwards. Also notable are recurrent features with peaks at approximately days 4, 22 and 40 - presumably associated with well construction and drilling, though again, as with Figure F.3, further breakdown of the timetable of events is unfortunately not possible.

Both diagrams presented in NYSDEC are based on previous modelling, referenced in the text as 'Dutton and Blankenship (2010)'. Unfortunately, at the time of writing it has not proved possible to track this document down to see if further details on the modelling assumptions could be ascertained.

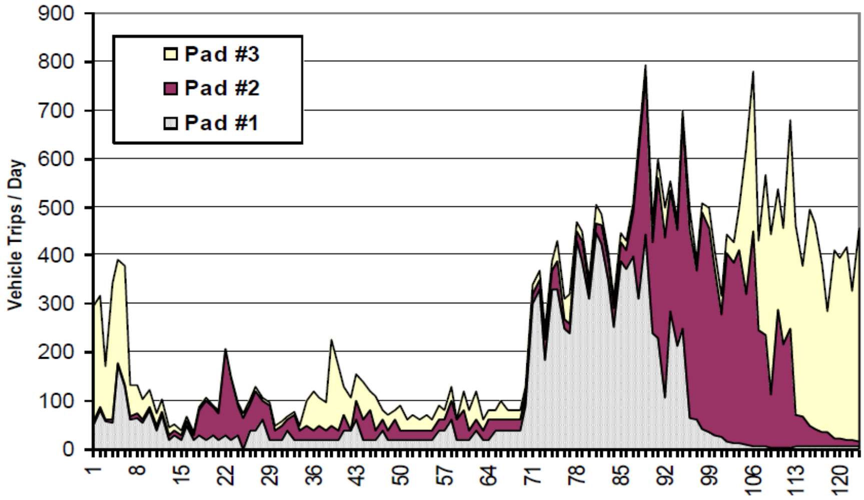

Figure F.3: Estimated Truck Traffic associated with Three Rigs Drilling 12 Horizontal Wells
(Source: NYSDEC, 2011)

ICF (2009) represents a further document that supplied information to the NYSDEC (2011). In the section on 'Onsite Truck Usage' the following values are given per horizontal well, based on personal communication with a particular operator:

- Haulage of construction equipment: 25 truck loads
- Location buildings and equipment: 4 truck loads
- Construction materials and sand: 143 truck loads
- Hydraulic fracturing 158 truck loads
- Total prior to well completion 330 truck loads

The total truck loads given in ICF (2009) appear lower than the total values given in other literature, plus there is no indication as to the volumes of materials and water transported to and from the site.

F.16: Kirby Misperton KM8, UK Traffic Management Plan:

Aside from the figures derived from US data in the previous section, this section presents a summary of the information provided regarding traffic and traffic management, supporting the planning application, for the fracking of the Third Energy KM8 site, near the village of Kirby Misperton in North Yorkshire, UK (Third Energy, 2017). This site is somewhat atypical from those that could be expected during commercial production in the UK, as it is the experimental/exploratory fracking of an existing wellsite. Therefore, figures are presented for information only.

The phases of activity at the site are given (in summary) as:

- **(Pre-stimulation noise barrier construction)** – 36 HGVs in total with a peak of 4veh/h entering and leaving the site between 07:00 and 19:00 on a single day;
- **Pre-stimulation workover** – 18 HGV vehicle movements for mobilisation, 12 HGV movements for demobilisation, 6 LGV/car movements per day. Operations carried out over a 2 week period, 24/7 access required;
- **Hydraulic fracture stimulation** – 193 HGV movements for mobilisation, 195 HGV movements for de-mobilisation. "During peak times of mobilisation and demobilisation, the estimated HGV movements per hour will be four, which is based on two vehicles per hour entering and then leaving the KMA wellsite over a four day period between the hours of 07:00 to 19:00".

In-between mobilisation and demobilisation there will be periodic traffic movements of approximately 8 HGVs and 10 LGV/Cars per day, with access required 24/7;

- **(Post- stimulation noise barrier removal)** – 36 HGVs in total with a peak of 4veh/h entering and leaving the site between 07:00 and 19:00 on a single day.
- **Production Test** – 4 LGV/Car movements per day, and 1 HGV movement per 2-3 days. Operation will take 'up to 90 days' with access to site will be between 07:00 and 19:00, seven days per week.
- **Production** – 4 single HGV movements, followed by 4 LGV/Car per day, over a production period of 9 years.
- **Well abandonment and Site restoration –** 6 LGV/Car movements and 36 HGV movements per day, over a six week period. Peak HGV movements will be 4 per hour, between 07:00 and 19:00, Mondays to Saturdays.

In addition to the above the Management Plan notes:

> "Peak vehicle movements during the six (6) week hydraulic fracturing phase will be during the mobilisation and demobilisation of the hydraulic fracturing equipment and materials. Equipment may not necessarily be brought onto site immediately prior to each distinct phase. Operational demands may dictate that equipment be brought onto site during the earlier development phases for use in the later phases. For example during the workover phase the well test equipment may well be brought onto site. This spreads the number of vehicle movements over a longer time period, which in turn reduces the number of peak traffic movements." (Third Energy, 2017)

And:

> "During the production life of the well(s) it may be necessary to undertake maintenance within the borehole(s), referred to as a workover. Historically, major workovers or tubing replacement, has been permitted as part of the development, subject to approval of information reserved by planning condition. The number and extent of workovers required is not predicable at the planning application stage, however, workover operations are generally short duration activities and require minimal number of HGV movements." (Third Energy, 2017)

F.17: Truck and Tanker Size, Weight and Loading Assumptions:

All truck trips in the original NYCDEP (2009) document were assumed to be by '18-wheeler semi- trucks or 9,000 gallon (34 m^3) capacity tankers. AEA (2012) notes from NYCDEP (2009) that the maximum laden weight of tanker used in the state is 36 tonnes, as compared to the maximum laden weight of an EU/UK tanker of 40 tonnes (44 tonnes for vehicles moving materials from railheads). Therefore, AEA (2012) posits that there may be fewer overall vehicle movements than the US figures indicate, given the heavier possible loading, with the suggestion that values for heavy truck movements and trips be reduced to 83% (or equivalent to '20 to 30 movements a day') of the values suggested in Tables 6 and 7.

A fully-laden 44 tonne tanker may contain 37,000 litres of fluid, whilst AMEC (2013) assumed a tanker capacity of 30m^3 (30,000 litres). A rigid-body 'dumper truck' was assumed to be used to move materials on site. Such a vehicle with a capacity of 10m^3 has a laden weight of 17 – 25 tonnes.

F.18: Scale of total operations in the UK:

Broderick *et al.* (2011) examined data from Cuadrilla's 'Commercial Development Scenarios' for Lancashire to give three scenarios: low, medium and high for resource requirements in Lancashire, over a 2014 to 2040 time horizon. These are presented in Table F.8. In addition to the Lancashire scenario analysis, Broderick *et al.* (2011) also offered a series of 'whole UK' scenarios, with the target of providing approximately 10% of the UK's demand for gas, over a 20-year time horizon. The results of this analysis are presented in Table F.9.

Table F.8: Estimated Resource Requirements under Cuadrilla Development Scenarios

[Source: Broderick et al., 2011]

Parameter	Scenario					
	Low		Medium		High	
Wells	190		400		810	
Pads	19		40		81	
Well cuttings volume	27,567m^3		55,133m^3		110,267m^3	
Water volume	1,679,800m^3		3,359,600m^3		6,719,200m^3	
Fracturing chemicals	740m^3		1,480m^3		2,960m^3	
	Low	High	Low	High	Low	High
Flow-back fluids	246,371m^3	1,325,304m^3	492,741m^3	2,650,609m^3	985,483m^3	5,301,217m^3
Total truck visits	143,833	219,667	287,667	439,333	575,333	878,667

Analysis of the data in Table 8 suggests that, on average each truck visit transports approximately 13.6 to 13.8m^3 of materiel (liquid or solid, water, waste or chemicals).

Table 9: Estimated Resource Requirements under Cuadrilla Development Scenarios

[Source: Broderick et al., 2011]

	Assuming no re-fracturing		**Assuming single re-fracturing on 50% of wells, delivering a 25% increase in productivity from those wells)**	
Wells	2,970		2,592	
Well pads	297		259	
Well cuttings volume	409,365m^3		357,264m^3	
Water volume	24,945,030m^3		32,655,312m^3	
Fracturing chemicals volume	10,989m^3		14,386m^3	
	Low	High	Low	High
Flow-back fluid volume	3,658,604m^3	19,680,768m^3	4,789,446m^3	25,783,915m^3
Total truck visits	2,135,925	3,262,050	2,732,400	4,132,080

Rogers (2013) used data from Texas Barnett shale gas plays to assess the total number of new pads required in the UK each year to achieve a gas production level of 10% of UK gas consumption requirements (same target as Broderick *et al.*). Twelve-well pads were assumed to reduce 'visibility, impact and associated traffic on testing public acceptance'. The results of Rogers show that, after 10 years of operations (excluding an estimate of an additional 2-years of exploratory drilling), the target was met by drilling 300 new wells (25 new pads) per year, consistent with Broderick *et al.*'s estimate of 130 to 150 wells per year over a 20 year period. Whilst the scale of operations to meet even a fraction of demand was considerable, Rogers noted that the *intensity* of operations at any given time, driven by declining outputs from individual wells may be an overlooked factor in both current research, and current media reporting.

F.19: Traffic Mitigation Measures:

NYSDEC (2011) suggest potential mitigation measured for the high volume of truck traffic associated with hydraulic fracturing as potentially including:

- Efficient route selection to maximise 'efficient driving and public safety';
- Avoidance of operations:
    - in peak traffic hours;

    - where movements could disrupt school bus traffic;
    - where community events could be disrupted;
    - in overnight quiet periods;
- Coordination with local authorities, especially highway departments and emergency services;
- Upgrades or improvements to roads that will be frequently used to transport water to sites with many well and pads, or roads that will bear the brunt of traffic from multiple sites;
- Advance notice to the public of detours and road closures if necessary;
- Adequate off-road parking and site delivery areas, and ultimately:
- Use of rail or temporary pipeline, wherever feasible to move water to and from sites.

In the UK context, Broderick *et al.* suggest that:

> "The UK is densely populated and consequently wells associated with commercial scale shale gas extraction will be relatively close to population centres. The proximity of such extraction will give rise to a range of local concerns for instance, high levels of truck movements on already busy roads … that require meaningful engagement, assessment, regulation and enforcement" (Broderick *et al.* 2011).

F.20: References:

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