Review of the future development of SISTM

SISTM (Simulation of Strategies for Traffic on Motorways) is a microscopic motorway simulation package that is owned by the Highways Agency and has been developed to evaluate methods of reducing congestion. The software has been continuously enhanced since the first release in the early 1990s, in order to model a wide range of applications, provide additional output measures and improve the graphical display of the model running. This report presents a review of past use of SISTM and considers possible future options for the package so that the Highways Agency can decide how the software fits in with their plans.

SISTM consists of a suite of programs which include both 2D and 3D representations of the motorway being modelled. It has been used in many motorway studies, mostly for the Highways Agency, including setting of parameters for the Controlled Motorways section of the M25 (J10 to J16) and improving the modelling of shockwaves. It has also been used with hypothetical networks in order to study a greater range of different scenarios including in-vehicle systems, such as Autonomous Intelligent Cruise Control.

This report describes possible enhancements that could be made to the software, in particular to the exhaust emission and noise modelling, and discusses the options for the future development of the package.

Other recent titles from this subject area

PPR193 Channel corridor community transport study: Final Report A Davies, C Burke, K Townley, S Reid, 2007
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Review of the future development of SISTM

by Ewan Hardman

PPR320
Issue 1
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PROJECT REPORT
PROJECT REPORT PPR320

REVIEW OF THE FUTURE DEVELOPMENT OF SISTM

Version: Issue 1

by Ewan Hardman (TRL)

Prepared for: Project Record: 3/326-37 Enhancement of micro-man model
Client: SSR Directorate, Highways Agency (Dr J White)

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Executive summary

SISTM (Simulation of Strategies for Traffic on Motorways) is a microscopic motorway simulation package that is owned by the Highways Agency and has been developed to evaluate methods of reducing congestion. The software has been continuously enhanced since the first release in the early 1990s, in order to model a wide range of applications, provide additional output measures and improve the graphical display of the model running. During this period many other micro-simulation packages for modelling traffic have appeared on the market. These are commercial packages which are used extensively by traffic and transport consultants to model networks of roads, both urban and inter-urban. The range of facilities that these packages offer, together with impressive 3D visualisations, has meant that use of SISTM has been very limited. This report presents a review of past use of SISTM and considers possible future options for the package so that the Highways Agency can decide how the software fits in with their plans.

SISTM consists of a suite of programs which include both 2D and 3D representations of the motorway being modelled. It has been used in many motorway studies, mostly for the Highways Agency, on both real and hypothetical networks. It has been extensively used on the Controlled Motorways section of the M25 (J10 to J16) for calibration of the model, setting of parameters for the CM system, exploring the benefits of ramp metering co-ordinated with the CM system and improving the modelling of shockwaves. Other modelling studies have included the M42 ATM Section, the M8 Kingston Bridge and the M60. It has also been used to develop hypothetical networks in order to study a greater range of different scenarios:

- In-vehicle systems, such as Autonomous Intelligent Cruise Control
- Weaving lengths
- Incident screens
- Development of the lane changing algorithm

A special version of SISTM also exists as part of the NASS-SISTM Simulator which was developed for testing the Network Advisory Sub-System (NASS). Recent activities on SISTM, carried out as part of a SISTM maintenance contract, have made corrections to the software and made improvements to the range of features that can be modelled.

In order to consider ideas for the future of SISTM, a brainstorming session was held amongst TRL traffic experts. Ideas put forward included increasing the scope of its modelling to cover the motorway-all purpose road junction and road works layouts. Usability was seen as a key feature and it was recommended that its network definition module was improved.

The review considers 3 possible options for the future:

- **OPTION A**: Hibernating the package, i.e. no further development
- **OPTION B**: Minor upgrades, i.e. continuation of past activities
- **OPTION C**: Major upgrade, i.e. to raise its modelling capabilities to those of other micro-simulation packages such as Paramics and VISSIM

Option A would involve no further HA funds being spent on the package and any user of SISTM having to accept this limitation. This would not preclude the code being given to universities who could experiment with their own algorithms.

Option B would mean that the software would be upgraded; tasks could be carried out according to the available funds and the future HA priorities. Possible upgrades include improving the modelling of exhaust emissions, noise, driver stress and safety. The scope of SISTM’s modelling could also be extended to include the all purpose road junction with the motorway and the opposite carriageway. Improving the usability of the software would also be one of the key tasks.

Option C would involve a major development programme to build in new features including full modelling of a road network. The costs would be very high and would be difficult to justify because these features are already modelled by other micro-simulation packages.
The conclusion of this review is that option B presents the most flexible solution for the future of SISTM as the upgrades can be carried out according to the available funds and the future HA priorities.
1 Introduction

SISTM (Simulation of Strategies for Traffic on Motorways) is a microscopic motorway simulation package that is owned by the Highways Agency and has been developed to evaluate methods of reducing congestion. The first contract for writing the software was let in the late 1980s and since then it has been continuously enhanced in order to model a wider range of applications, provide additional output measures and improve the graphical display of the model running. It has been used in many motorway studies, mostly for the Highways Agency, on both real and hypothetical networks.

Over the period in which SISTM has been developed, many other micro-simulation packages for modelling traffic have appeared on the market. These are commercial packages which are used extensively by traffic and transport consultants to model networks of roads, both urban and inter-urban. The extensive facilities that these packages offer, together with impressive 3D visualisations, have meant that use of SISTM has been very limited. The Highways Agency has now asked for a review of SISTM to be carried out in order for it to consider possible options for its future development.

This report is the result of this review, carried out as TAF019 under project “Enhancement of micro-man model” for the SSR Directorate of the Highways Agency. The document presents a review of what the model can achieve and the software’s developments and uses in the past. Consideration is given to possible future use of SISTM.

Section 2 of the report summarises the development that has taken place on the software, whilst Section 3 lists some of the applications the software has been used for. The current state of the software is discussed in Section 4, including a review of current and recent activities. Section 5 lists some of the competitors for SISTM and Section 6 discusses in detail possible future upgrades of the software. A discussion of the three main options for the future is given in Section 7. Finally Section 8 presents the conclusions of the study.

2 SISTM development

2.1 History of development

The original idea behind the development of a micro-simulation package for motorway traffic in the Department of Transport occurred in the late 1980s. At this time Personal Computers were first being produced and the feasibility of modelling individual vehicles in approximate real-time, as opposed to modelling a collection of vehicles (macroscopically), became a reality. Limited success had previously been achieved with the SEV-Q software, a package developed for the Department of Transport for studying queues at the Severn Bridge toll booths, although the graphical representation of the vehicles was very primitive by today’s standards.

The first contract for developing the software was let to Wootton Jeffreys Consultants in 1988 and the contract was supervised by TRL. They developed the simulation from scratch, carrying out research on car following and lane changing algorithms. Costs were kept to a minimum by using some of their network definition software that was included in their QVIEW traffic assignment packages. As well as modelling one carriageway of motorway microscopically, they also included macroscopic modelling of the surrounding all purpose road network using their own proprietary software based on ARCADY, PICADY and OSCADY. The first release of SISTM (v1.0) was delivered in July 1990. A second contract was let to Wootton Jeffreys to improve driver behaviour in the model and this resulted in version 2.0 being produced at the end of 1992.

From 1993 onwards most of the development of SISTM has been carried out by TRL. Many new features have been added and the software was enhanced in 1997 (version 4.3) to run in the Microsoft Windows™ environment. The macroscopic modelling of the surrounding road network was removed in 1998 (version 5.0) as this had been little used and was felt to be a restriction on further development. The most recent major enhancement to SISTM has been the adding of a 3D visualisation of the main simulation program (version 6.0); this was developed by QinetiQ in 2002-4.
2.2 Control of development

The development of SISTM has been very carefully controlled, firstly by TRL and then by the Highways Agency. The source code has only been given to a limited number of parties and one-off versions have been restricted:

- A version was developed by Wootton Jeffreys in conjunction with a University of Southampton study of lane changing in 1993-4. Most of these modifications were later included in the standard version.
- A prototype was developed by TRL to incorporate Controlled Motorways and MIDAS operation; following a successful study the modifications were included in the standard version.
- A prototype was developed by TRL for studying driver behaviour at congested merges, but the project did not recommend making any permanent changes to the algorithms in the standard version.
- A special version of SISTM was developed as part of a new product (the NASS-SISTM Simulator) for testing the Network Advisory Sub-System (NASS); SISTM within this product exists as a separate off-shoot of v6.0.000 and its current version is 6.2N.

All SISTM development at TRL is carried out according to TRL’s Quality Assurance procedures which comply with TickiT requirements. This means that for each upgrade package the following is produced:

- A Requirements Specification, describing what the requirement is and how it is to be implemented
- A Detailed Design Specification, describing the changes made to the source code and the detailed testing to be carried out and recorded
- A Testing Document, describing the tests to be carried out to ensure the completed upgrade performs correctly

2.3 Versions of SISTM

A summary of versions is shown in Table 1 for the standard release and in Table 2 for the NASS-SISTM Simulator.

Table 1: SISTM versions

<table>
<thead>
<tr>
<th>Version</th>
<th>Date</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Jul 90</td>
<td>End of 1st contract with Wootton Jeffreys Consultants; first delivery of SISTM to TRL; consists of individual programs QVNET, SISQV, SIMENT, SIMDAT, SIMCNT and SIMRUN; all source code in Fortran using Prospero compiler (QVNET and parts of SISQV and SIMDAT only supplied in binary form)</td>
</tr>
<tr>
<td>2.0</td>
<td>Dec 92</td>
<td>End of 2nd contract with WJC: improvements to car following and lane changing algorithms; introduction of time dependent traffic management signs</td>
</tr>
<tr>
<td>3.0</td>
<td>Jan 93</td>
<td>Additional ramp metering strategies (ALINEA and demand/capacity) added</td>
</tr>
<tr>
<td>3.1</td>
<td>Jun 93</td>
<td>Correction to behaviour at diverges; Batch version of main simulation program SIMRUN converted to use Salford compiler; this required creation of READINTF and WRITINTF utilities to convert interim files from Prospero to Salford formats</td>
</tr>
<tr>
<td>3.2</td>
<td>Sep 93</td>
<td>New output facilities: speed, acceleration and headway distributions, lane changing stimuli, individual vehicle data</td>
</tr>
<tr>
<td>3.3</td>
<td>May 94</td>
<td>New type of diverge with split lane; driver behaviour parameters input as distributions following WJC’s contract with Southampton University for improvements to lane changing</td>
</tr>
<tr>
<td>3.4</td>
<td>Nov 94</td>
<td>Speed limits for individual lanes; speed limits on screen; flow responsive speed control systems; Salford compiler version of SIMRUN in interactive mode</td>
</tr>
</tbody>
</table>
### Table 2: NASS-SISTM Simulator versions

<table>
<thead>
<tr>
<th>Version</th>
<th>Date</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0N</td>
<td>Apr 04</td>
<td>Special one-off release of v6.0.000 produced as part of NASS-SISTM Simulator v1 for IPL for NASS testing</td>
</tr>
<tr>
<td>6.1N</td>
<td>Jul 04</td>
<td>As 6.0N but with graphical facility for displaying the NASS settings</td>
</tr>
<tr>
<td>6.2N</td>
<td>Mar 06</td>
<td>Modification of v6.1N with longer modelling period and matching with real-time clock; delivered to IPL as part of NASS-SISTM Simulator v3</td>
</tr>
</tbody>
</table>

#### 2.4 Calibration and validation

Before discussing these in relation to SISTM, it is worthwhile differentiating between them:
Calibration is the process of adjusting a model’s parameters so that the model reproduces the process it is trying to replicate as closely as possible. Real data is compared with the modelled data and the aim is to achieve a close match between the two data sets.

Validation is the process of checking whether a calibrated model is a good representation of the situation it is trying to replicate. The comparison in this case is with real data representing different circumstances from those used in the calibration process (e.g. a different day, a different location).

Both processes involve a mathematical calculation of the comparisons and both are subject to interpretation with regard to the type and amount of real data used. For example a traffic model may be calibrated for 3-lane motorways, but not calibrated for 4-lane motorways because driver behaviour is different.

SISTM has been calibrated for:

- 3- and 4-lane motorways by adjusting car following parameters in order to achieve as close a match as possible with 1-minute speeds and flows obtained through MIDAS data recorded at real sites
- Lane changing rates by adjusting lane changing parameters so as to achieve a close match with real lane changing rates from several motorway locations

Calibration at a microscopic level has not been carried out, mostly due to the lack of available data and the costs involved of obtaining a statistically valid amount of such data.

Validation has been carried out for specific motorway sections modelled.

2.5 Documentation

Documentation on SISTM’s internal workings consists of a Technical Engineering reference document produced at the end of the first contract with Wootton Jeffreys and documents produced for specific upgrades, in particular:

- the modelling of Controlled Motorways, exhaust emissions, driver stress and noise (Abbott *et al.*, 2000)
- the review of the lane changing algorithm (Baguley *et al.*, 2003)

The main user documentation consists of various User Guides which show how to use SISTM in interactive mode (i.e. supplying the parameters using data entry software and running the simulation with graphics) and in batch mode (i.e. supplying the parameters in text files and running the simulation at the DOS command prompt).

3 SISTM applications

3.1 Applications on hypothetical sections of motorways

SISTM has been used on hypothetical motorway sections to evaluate the general applicability of control measures. Some examples are:

(i) A study of weaving sections (HA customer: John Smart of TSE Division) used simple networks with a merge followed by a diverge where the distance between the two varied and where different types of merge and diverge (e.g. lane gain/lane drop, ghost island, auxiliary lane) were assessed (Summersgill, Hardman and Smith, 1998). The capacity of each configuration was reported. The SISTM runs showed that the effect on throughput of weaving section length, weaving proportion, design of the merge and diverge, and the types of layout are relatively small. As a result the study recommended a simpler calculation be used in TD 22/92 for deciding how many lanes are provided in weaving sections. The document has recently been revised (TD 22/06) but the weaving calculations have not been modified.
(ii) A similar network was used to explore the effect of fitting Autonomous Intelligent Cruise Control to cars. These devices aim to maintain a preset headway with the vehicle in front by applying acceleration or a small amount of braking. The study (for Jaguar Cars Ltd) considered different headway settings, different proportions of vehicles fitted and different system parameter settings and their effect on journey times and motorway capacity.

(iii) A specially developed version of SISTM was used in a study (HA customer: Robert Stewart of TSS Division) to improve the modelling of merges under congested conditions (Summersgill et al, 2002). Using the enhanced algorithms, the study found that improvements in the operation of merges with a nearside slip road lane gain could be achieved if drivers in the offside slip road lane were encouraged to move into the nearside slip road lane upstream of the merge, and both main carriageway and slip road drivers were encouraged to stay in lane downstream of the merge. For merges with an offside lane gain, journey times were reduced to the greatest extent when drivers in the offside slip road lane were encouraged to remain in that lane throughout the merge area.

(iv) A TRL funded study was carried out in 2002 to investigate the feasibility of determining SISTM’s driver behaviour parameters using the TRL driving simulator (Flint and Hardman, 2002). A simple motorway driving scenario was devised and 2 test subjects participated. From their reaction to an event (a vehicle ahead braking) it was possible to derive a value for a SISTM parameter and reproduce the event in the simulation. The theory was shown to be feasible but a larger number of subjects would be required to obtain a useful data set.

(v) A study in 2003 (HA customer: Peter Whitfield of SSR Directorate) used SISTM to investigate the benefits of installing screens on the central reservation in the event of an incident so as to prevent “rubber necking” and the reduction of speeds on the opposite carriageway (Gorell, 2006). The SISTM modelling suggested that rubber necking behaviour only impacts significantly on vehicle speed if the initial flow levels are high, but in these situations it is very important to erect the screens as soon as possible in order to minimise delay.

(vi) The development work on the lane changing algorithm (HA customer: Nanu Rayman of SSR Directorate) used 2 networks (one with a 3-lane main carriageway, the other 4-lane) which consisted of a merge followed by a diverge and then a second merge in order to count lane changing rates at different geometric locations (Baguley et al, 2005). These were compared with real lane changing rates obtained from several motorways. The networks were run both before and after changes were made to the lane changing algorithm and the study was successful in that SISTM’s predicted lane changing rates were closer to reality after the changes were made.

(vii) SISTM was used in a 1994 study to evaluate the benefits of restricting lane changing on the approach to a merge at road works (Burrow and Freeman, 1994). The results suggested that the proposed restrictions were likely to reduce capacity, impose greater delay and increase the accident risk.

The advantages of using hypothetical motorways are that a greater range of sensitivity testing can be employed, i.e. simulation runs with different motorway geometries, numbers of main carriageway lanes, percentage of HGVs or overall traffic demand levels. The results will then have wider applicability than simulation runs carried out on specific motorways, where special conditions (e.g. a gradient at a critical location) may apply.

3.2 Applications on specific motorways

SISTM has been used in studies on several sections of the UK motorway network. Some examples are:

(i) M25 J10-J16 (both carriageways). This has been modelled mainly because it was a very congested section (before the recent widening to 5/6 lanes) and has Controlled Motorways. SISTM has been used for:
   - Calibration of the model (using J11-J15 data);
   - Assisting in the setting of parameters for the CM system;
• Evaluating different options for a bus lane;
• Exploring the benefits of ramp metering co-ordinated with the CM system;
• Improving the modelling of shockwaves.

(ii) M42 J3A-J7A (both carriageways). This has been modelled as a result of the HA’s Active Traffic Management (ATM) being used on this section. The NASS-SISTM Simulator has been used to test NASS in its development for use on this section of motorway. This work was carried out for SSR Directorate (initial customer Nanu Rayman, subsequently John Lewis). This version of SISTM can model the operational regimes (variable speed limits, hard shoulder running and ramp metering), but has so far only been used for testing NASS.

(iii) M60 J12-J18 westbound, J12-J14 eastbound. SISTM models of a morning peak on the westbound carriageway and an evening peak on the eastbound carriageway were created for Faber Maunsell in their assessment of different options for widening this section of motorway for the HA’s North West Office. Calibration and validation of SISTM was carried out as a pre-requisite to evaluating the individual schemes.

(iv) M8 J19-J22 westbound (Kingston Bridge). SISTM models of an afternoon/evening peak were run with different lane configuration options. This work, for Glasgow City Council, produced recommendations on the best layout to adopt when road works, which would remove one of the five lanes across the bridge, were taking place.

(v) M6 J20 northbound. This study (HA customer: Nanu Rayman of SSR Directorate) took place when ramp metering was being considered at a number of sites on the M6, M60 and M62. A SISTM model of this junction was created with time profiles for two morning and two evening peaks. Runs with and without ramp metering were carried out. The benefits of ramp metering were very small, but when the traffic demand was increased by 10% to represent future traffic levels, traffic speeds were 2.6 km/h higher with ramp metering. In the roll out programme, ramp metering was not implemented at this location, this decision largely being taken for geometric reasons.

3.3 Outside use of SISTM

SISTM has mostly been used by TRL, but occasional use has been made by other consultants and universities. The Highways Agency encourages use of the software by providing researchers with a free copy of the current version, subject to some conditions, e.g. output from the study will be made available to the HA.

The most recent external use has been by a PhD student at the University of Southampton who carried out a study of motorway diverge areas and used SISTM to evaluate different geometric configurations (Wall, 2004). The reasons for choosing SISTM over other microsimulation models were given as:

• It has been used within TRG (Transportation Research Group of the University of Southampton) on a number of projects including a recent project entitled “Access Control” commissioned by the Highways Agency. It has also been used by TRL on a number of related motorway projects for the Highways Agency.
• It has the ability to model diverges with or without lane drops. It can also be adapted to model Ghost Island diverges with two exit points.
• It can cater for motorways of up to six lanes. Diverging behaviour can therefore be assessed for motorways with various numbers of mainline lanes.
• It has been carefully validated and calibrated using data from various English motorways and provides the user with default parameter values.
• It produces a wide variety of output data including flow, speed, journey time and lane changing information at specific points/areas before, on and after the diverge by the use of pseudo-detectors.
• It has an awareness and aggression factor for drivers that may be useful when assessing drivers’ reactions to different diverge layouts.
• Various road management strategies can be implemented such as the introduction of VMS signing (or other signing) and the imposition of variable speed limits.
• It is a non-commercial product and is therefore free for academic use subject to agreement.
• It is well documented in English.

The author made extensive use of SISTM in his study and a number of recommendations were made concerning improvements to diverge layouts. He also identified some weaknesses in the software and suggested enhancements to SISTM’s modelling capabilities.

3.4 Reports
A list of reports on SISTM produced by TRL is given in Appendix A.

4 Current state of SISTM

4.1 Features
SISTM models up to 999 km of one carriageway of a motorway. Current limits within the software are:
• 9 entry slip roads and 9 exit slip roads
• 9600 vehicles on the motorway at any instant
• 8 vehicle types
• 6 main carriageway lanes, 3 slip road lanes at any point
• 6 hours 10 minutes of simulation time, but cannot span midnight

Since SISTM only models a motorway, no route choice is required; the user specifies the origin/destination flows with the origins being the upstream end of the motorway or entry slip roads and the destinations being the downstream end of the motorway or the exit slip roads.

4.2 Current constituent modules

4.2.1 Main version
SISTM currently consists of the following individual main programs:
• DataInput This program, written in C++, is the first program the user runs to create a SISTM network. It is a data entry program for all the input that the main simulation program needs. The user enters data for vehicle definition, driver characteristics, motorway geometry, traffic demand (O/D flows), traffic management strategies and amount of output to be produced. An example screenshot is shown in Figure 1.
SIMDAT

This program is written in Salford Fortran and checks the files created by DataInput. Errors are reported to the user. It converts the main data entry file from text to binary format.

SimRunG

This program is written in Compaq Fortran and C++ and takes input files produced by DataInput and SIMDAT and runs the main simulation software, producing a 2D representation of the motorway being modelled and the output. It can also be run in batch mode without any on screen drawing. A separate version written exclusively in Salford Fortran (called SIMRUN) also exists; this is used for debugging the core algorithms.

The program also produces many output files which are user configurable. Data on speeds, flows and occupancies are available from detectors that can be placed at any point on the motorway. Individual vehicle data (journey times, exhaust emissions, fuel consumption) are produced and can be imported into Excel for analysis. Overall results for the simulation run (e.g. average speed, noise) can also be produced.

An example screenshot is shown in Figure 2.

Figure 1: Example of DataInput screenshot showing how a new network is created
• **SIMRUN-3D** This program is written in Compaq C++ and uses OpenGL (a graphics library). It runs in conjunction with SimRunG and provides a 3D visualisation of the carriageway being modelled. An example screenshot is shown in Figure 3.
The following are ancillary programs that are sometimes used depending on the application requirements:

- **SISTMTV**  
  This program is written in Salford Fortran and converts the output files produced by SIMRUN/SimRunG into a format that can be input into MTV.

- **MSC**  
  This program (MSC = MIDAS SISTM Converter) is written in Visual Basic and converts the Controlled Motorways database files into a format suitable for input into SIMDAT.

The following software development packages are required for compiling SISTM source code:

- **Visual Studio 6**  
  This contains Visual C++ and Visual Basic

- **Compaq Fortran**  
  This is a Fortran-77 add-on to the Visual Studio package

- **Salford Fortran**  
  Fortran-77

- **FarPoint Spread**  
  This is required for the data entry fields in DataInput

- **RoboHelp**  
  This processes the help scripts for DataInput

### 4.2.2 NASS-SISTM Simulator

The NASS-SISTM consists of the following programs:

- **SIMDAT 6N**  
  This is a special version of SIMDAT which converts the main data entry file from text to binary format. Additional user input is required to represent the devices. Note that DataInput has not been modified to run with the NASS-SISTM Simulator – the data entry files can only be created by a text editor.

- **FileConvert**  
  This is a utility program which converts the binary file produced by SIMDAT 6N into a format readable by SimRunG 6N.

- **SimRunG 6N**  
  This is a special version of SimRunG which models the ATM scheme, produces MIDAS data and displays the signal settings on screen. The 3D visualisation module does not function in the NASS-SISTM Simulator.

- **SSCIP**  
  This program acts as the interface between SimRunG 6N and NASS (or a test version of it). It receives instructions (e.g. proposed signal settings) from NASS and sends these through to SimRunG. Communication with SimRunG 6N is via an Access database. SSCIP also sends data to NASS, including MIDAS traffic data and confirmation of signal settings actually implemented.

### 4.3 Recent activities

TRL has a contract with the HA under framework agreement 326 (task 37: “Enhancement of micro-man model”) which has run since August 2004. Under this contract activities are authorised by Task Authorisation Forms (TAFs), the ones relating to SISTM development are shown in Table 3.
Most of the modifications carried out under this project have been correcting known faults and implementing new features that have been deemed desirable. A list of faults and enhancements is maintained by TRL. A summary of the known faults is shown in Table 4.

**Table 4: Status of faults in SISTM’s faults and enhancements list**

<table>
<thead>
<tr>
<th>Status</th>
<th>Priority</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Completed</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>No longer relevant</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Unable to verify error</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Not started</td>
<td>4</td>
<td>35</td>
</tr>
<tr>
<td>Temporary solution implemented</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total outstanding</td>
<td>4</td>
<td>36</td>
</tr>
</tbody>
</table>

Of the 63 faults outstanding (i.e. those not started or where a temporary solution has been implemented):

- 16 relate to errors in the driver behaviour core algorithms (car following, lane changing)
- 16 relate to the 3D visualisation (software failing to implement specific features)
- 13 relate to data entry (software not accepting valid entries or failing to report invalid entries)
- 11 relate to the operation of the 2D simulation (features not working correctly, but simulation results unaffected)
- 3 relate to traffic management strategies (features not working correctly)
- 2 relate to processing of O/D data and vehicle generation
- 1 relates to incorrect output data
- 1 relates to MSC

The total number of man days’ effort for these 63 modifications is estimated as 288, with most requiring between 3 and 5 days’ work. These estimates assume that the modifications are carried out sequentially. However if several related modifications are worked on simultaneously reductions in the total number of man days can be significant.

A summary of the enhancements is shown in Table 5.
Table 5: Status of enhancements in SISTM’s faults and enhancements list

<table>
<thead>
<tr>
<th>Status</th>
<th>Priority</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Completed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not started</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Temporary solution implemented</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total outstanding</td>
<td>18</td>
<td>19</td>
</tr>
</tbody>
</table>

Of the 43 items outstanding:

- 13 relate to new features (e.g. toll booths, ANPR cameras, abnormal loads, additional output)
- 11 relate to the 3D visualisation
- 7 relate to improving the software’s ease of use
- 4 relate to increasing the current input data limits of the software
- 3 relate to improvements in data entry
- 3 relate to improving the software development process
- 2 relate to improvements in the core algorithms

The total number of man days’ effort for 31 of these enhancements is estimated as 192. The remaining 12 enhancements are more complex requiring a full specification to be written before an estimate can be made; writing the specifications is estimated to take 38 days in total.

4.4 HA micro-simulation review

The Highways Agency’s Traffic Appraisal Modelling and Economics (TAME) Unit have a current contract running with Faber Maunsell (FM) for carrying out a review of micro-simulation models used in HA contracts. The following software has been used:

- S-Paramics
- VISSIM
- AIMSUN
- FLOWSIM
- Cube Dynasim
- SISTM
- DRACULA
- Quadstone’s Paramics

The aim of this project is to produce 3 documents:

- **Software Review** – FM contacted the 8 suppliers (including TRL for SISTM) who were asked to complete a questionnaire. From this, the status of each package was determined and each supplier identified key user parameters which were likely to have most impact on model performance. A report has been completed and submitted to the HA (Faber Maunsell, 2005), but has not yet been issued in final form.
- **Technical Review** – FM in association with the HA then identified the four packages which had been most commonly used on HA projects; these were S-Paramics, VISSIM, AIMSUN and SISTM. Based on the information supplied by the suppliers, FM undertook modelling of a number of ‘typical’ HA network scenarios. This work involved the variation of the parameters and random number seeds. To date, TRL have only been provided with the results of the SISTM modelling. The final report is currently being approved and is expected to be issued at the end of January 2007.
Guidance Note – This will provide guidance on whether micro-simulation should be used in a study and how it should be used. A draft of the Guidance Note has been prepared but is awaiting feedback before completion.

A workshop was held to discuss the different packages used on HA projects and was attended by consultants who carried out work using Paramics, VISSIM and SISTM. The main reasons why the consultants did not choose SISTM was because:

- It did not model the surrounding road network; queues on motorways affect the roundabouts and signalised junctions, and vice versa.
- They had greater familiarity with Paramics and VISSIM, having used the packages for non-HA clients.
- They had a general lack of knowledge of what SISTM can do.

4.5 Brainstorming session

As part of this review into SISTM’s future development, a brainstorming session was held to discuss possible ideas for the future of SISTM. The session was attended by TRL traffic experts, micro-simulation users and developers and members of staff who had an involvement in SISTM in the past. The material presented at the session and the results of the discussion are given in full in Appendix B.

The ideas can be summarised as:

- There is increasing interaction between congestion on the motorway and the all purpose road network. Therefore some scope for increasing SISTM’s geographic coverage would seem desirable.
- If the data on lane and vehicle widths were obtained, SISTM would be able to model road works and would be a useful tool to maintenance contractors in setting up layouts.
- It was felt that sufficient work had already taken place on the car following and lane changing algorithms and that effort should be concentrated elsewhere.
- The 3D simulation appears unrealistic due to jerky movements by vehicles; their positions are only updated each time increment. 3D modelling could be improved by interpolating between time increments.
- Improvements to network definition could be made, as this is one of the most difficult parts for a user to understand at present. Overall it was felt that improving the usability was the key to making the software more widely used.

4.6 Future work

The decision has recently been taken by the HA to put on hold the current SISTM maintenance contract, as from the end of January 2007. This will mean that no further modifications will be carried out.

As for future work, a TRL re-investment project using SISTM (“Traffic Laws of Nature”) will be going ahead in Spring/Summer 2007. This will explore new traffic rules on motorways and modifications will be made to part of the code in order to investigate new scenarios. The proposed work programme consists of:

(i) Identification of new traffic rules e.g.:

- Undertaking is allowed (for cars and/or for all traffic classes)
- A minimum speed limit is applied, either globally or in certain lanes
- An HGV only lane is implemented
- HGVs are not allowed to overtake at all

(ii) Identification of suitable scenarios for simulation: this would involve a range of motorway geometries including gradients, number of lanes and traffic composition.
(iii) Modelling the scenarios using SISTM, possibly with different levels of compliance with the new laws.
(iv) Identification of promising new traffic laws to maximise throughput and minimise journey times.
(v) Summary and discussion of further research needs and practicality of introduction on selected roads.

The outcome of this research could result in the most promising new traffic laws being investigated more fully as part of an HA research programme.

5 Other traffic modelling software

Many microscopic traffic simulation models have been developed around the world. Some of them have been written for specific applications and their use is relatively limited, but others have been developed as full general purpose commercial packages. The market leaders in the UK seem to be:

- Paramics. This exists in two forms, one marketed by SIAS and the other by Quadstone. Most UK use of Paramics has been using the former, known as S-Paramics.
- VISSIM
- AIMSUN

All three are characterised by being able to model a complete road network (in a town or even a region) and have the following facilities:

- Traffic assignment modules
- Public transport modelling
- Parking
- Pedestrians
- 3D visualisations which can be as complex as the user desires (e.g. drawing of buildings and other roadside features)

Various reviews have been carried out on the different packages, including Halcrow Fox (2000) and Faber Maunsell (2005). However a literature search revealed no direct comparisons of results from the different models. It would be useful if a motorway section could be modelled with the different packages (including SISTM) and the results compared between each other and with real data.

6 Specific upgrades to SISTM

6.1 Scope of modelling

The brainstorming session considered 3 possible upgrades to the scope of SISTM’s modelling. In increasing order of complexity these are:

1) Both carriageways simultaneously
2) All purpose road junction with motorway
3) Full road network modelling with traffic assignment

6.1.1 Modelling both carriageways

The ability to model both carriageways in a single simulation run would require alterations to the input files, to the main simulation core engine, to the format of output files and to the 2D and 3D visualisations. The main advantage of modelling both carriageways would be greater realism especially in the 3D display.
However there are very few advantages from the modelling point of view over the alternative of modelling each carriageway separately. Motorway congestion is largely uni-directional and there is very little interaction between the carriageways, except for

- “rubber necking”, where drivers slow down to observe an accident on the opposite carriageway
- possible closure of an exit slip road during an incident causing drivers to retrace their path along the opposite carriageway to reach their intended destination
- assessment of noise levels
- contraflows in road works

The above can be assessed by modelling each carriageway separately and in the case of noise levels, using a logarithmic process to derive the total noise.†

It is not considered beneficial to extend the software to model both carriageways simultaneously as an upgrade on its own. The advantages are very few and the costs are relatively high, mostly in the changes to the 2D and 3D visualisation.

### 6.1.2 Modelling an all purpose junction

The extension of modelling to include the all purpose road junction (e.g. roundabout, signalised or priority junction) with the motorway entry and exit slip roads would have the following advantages:

- ability to take account of the performance of the junction
- ability to provide more realistic vehicle arrival patterns on the entry slip road (this could be a significant issue for ramp metering operations)
- ability to provide information on queues from the all purpose road junction blocking back on to the exit slip road and even the motorway main carriageway.

An example of modelling a roundabout is shown in Figure 4. In order to evaluate the junction completely all the roads shown would need to be modelled.

**Figure 4: Example of proposed extension of SISTM modelling to include a roundabout**

Modelling the all purpose road junction would require changes to the input files, the main simulation core engine, the format of output files and both the 2D and 3D visualisations. New rules to govern how drivers behaved at roundabouts and other junctions would have to be incorporated. The scale of the modifications

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† It should be noted that SISTM’s assessment of noise is on a comparative basis so that different scenarios can be compared; it does not produce absolute noise levels that can be compared with real measurements. The noise levels output from the model are not distance related, e.g. a traffic management strategy causing a shift in vehicles from lane 1 to lane 2 but no change in speed or acceleration would not result in any change in noise level.
Review of the future development of SISTM

would be large and require a feasibility study to determine what could be done and how best to achieve it within the current system.

The opposite carriageway of the motorway could also be included in this upgrade at a relatively low additional cost.

6.1.3 Full network modelling

The modelling of a full road network would bring SISTM up to the standard of the commercially available micro-simulation packages. This would enable the full assessment of motorway strategies on the surrounding road network, e.g. traffic diversions during incidents on motorways.

The costs for implementing this option will be very high and probably increase the amount of source code by a factor of 10. A traffic assignment module would be desirable.

If SISTM modelling were to be extended to a full road network, it is likely that the software development would have to start from scratch due to the major enhancement that this would represent. Some sections of the existing code may be usable, but because this would be a fundamental change it is unlikely that add-ons to the existing code would be successful or manageable.

6.2 Core algorithms

The core algorithms in SISTM can be considered to be car following and lane changing. They are executed every time increment (i.e. every \( P \) second) for every vehicle and govern the vehicle’s acceleration and lane for the following time increment. They also decide how the driver reacts to speed limits, traffic signals and diverge signs, and also how vehicles are placed on the motorway at the upstream ends.

Much work has recently been carried out by TRL on these two algorithms. This has resulted in an improved match between modelled and real lane changing rates and improved replication of shockwaves. It is considered that no further development of these algorithms is required and that a period of stability (to allow the package with the improved algorithms to be used) would be beneficial.

It would be possible to give the source code to universities for them to explore further changes, or even a total recast of the modules. However on completion of their study, it would be very important to consider their modifications very carefully and the implications in a wider context. The car following algorithm, for example, has one line of code for the Gipps’ equation, but the remainder of the logic has many interdependencies with other modules.

6.3 Exhaust emissions

Exhaust emission modelling was first included in v5.1 in February 2000 (Abbott et al., 2000). The requirement was for SISTM to assess the amount of each of five pollutants (CO, CO\(_2\), NO\(_X\), hydrocarbons and particulates) for each modelled vehicle so that different simulation scenarios can be compared. However due to differences in data availability, different methods were adopted for determining emissions from light and heavy vehicles.

For light vehicles, the instantaneous amount of each pollutant is available in a look-up table for a range of speed and acceleration values. This is calculated each time increment for each vehicle and then summed for the length of the vehicle’s journey. For heavy vehicles, a more macroscopic approach is adopted; the average speed of each vehicle over 500m is calculated and formulae (which assume typical acceleration and deceleration over that period) provide the amount of each pollutant for that vehicle. This can then be summed over the heavy vehicle’s journey.

The main area for improvement in SISTM’s modelling of exhaust emissions comes from incorporating more recent data, notably using instantaneous emissions data from the Passenger car and Heavy-duty Emission Model (PHEM) (Rexeis et al., 2005). This will provide more detailed modelling of HGV exhaust emissions and take into account more driving cycles, vehicle loading, gradient and additional vehicle types.
A full description of modelling exhaust emissions in SISTM and the possible enhancements are given in Appendix C.

### 6.4 Noise

Noise modelling was also included in v5.1 and the requirement was to produce an overall noise level for a simulation run so that different simulation scenarios can be compared. However, modelling of noise is somewhat different to exhaust emissions in that noise from individual vehicles cannot be added arithmetically, i.e. the noise level resulting from two vehicles passing an observer at the same time is not the sum of the noise produced by each vehicle; the calculations must be carried out logarithmically. The modelling also had to be laterally independent across the carriageway, i.e. take no account of the lane the vehicle was in.

The calculation of noise is carried out by having noise ‘detectors’ every 200m along the modelled section of motorway. The Sound Exposure Level from each vehicle passing the detector is calculated based on the speed and acceleration of the vehicle and whether it is a light or heavy vehicle. The Sound Exposure Levels from different pass-by events at this detector are added logarithmically. To measure the total noise produced in a simulation run, the logarithmic sum of the noise recorded at a detector throughout the simulation period is calculated, then the total logarithmic sum of the noise from all detectors is calculated.

As with the modelling of exhaust emissions, the main area for improvement in SISTM’s modelling of noise comes from incorporating more recent data and more up to date information on vehicle types. In the last few years a European consortium has produced a state of the art model of source noise from road vehicles (HARMONOISE) that is intended for use in all member countries (Watts, 2005).

Full details of the proposals for enhancing the noise model in SISTM are given in Appendix D.

### 6.5 Driver stress

The third new modelling feature introduced in v5.1 was driver stress. At the time although there was much discussion in research literature on the subject, there was no universally accepted method of calculating driver stress.

Stress in a driving environment is believed to be caused by:

- Fear, i.e. being subject to an element of risk or danger. This can manifest itself through being pressured by a vehicle behind (tail-gating) or having to brake severely to avoid a collision
- Frustration, i.e. not being allowed to do what one likes. This may arise through not being able to travel at one’s desired speed (for any reason)
- High workload, i.e. being on a high alert state and having to make many decisions at the same time
- Uncertainty, i.e. being unsure of what actions to take. This could occur if the driver was unsure which exit to take

The last category cannot be implemented in SISTM as it is assumed all drivers have perfect knowledge of the network. The other categories are modelled through five measurable events in SISTM:

1. Short headway with the vehicle behind (fear)
2. Short headway with the vehicle in front (fear & frustration)
3. Travelling at below desired speed (frustration)
4. Desire to change lanes (fear, frustration & high workload)
5. Severe braking (fear)

Current parameters for the stress calculations in SISTM are shown in Table 6.
Table 6: Current parameter values for SISTM’s driver stress calculations

<table>
<thead>
<tr>
<th>Category</th>
<th>Values where stress occurs</th>
<th>Value at which maximum stress is reached</th>
<th>Maximum stress value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short headway with the vehicle behind (seconds)</td>
<td>Below 2.0</td>
<td>0.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Short headway with the vehicle in front (seconds)</td>
<td>Below 2.0</td>
<td>0.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Travelling at below a speed threshold (km/h)</td>
<td>Below 75.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Desire to change lanes (lane change stimulus units)</td>
<td>Above 0</td>
<td>500</td>
<td>1.0</td>
</tr>
<tr>
<td>Severe braking (km/h/s)</td>
<td>Below -5.0</td>
<td>Maximum braking rate</td>
<td>10.0</td>
</tr>
</tbody>
</table>

In all 5 cases the driver stress is assumed to increase linearly from zero to the maximum value; any values beyond the point where the maximum is reached result in the maximum stress; e.g. headways under 0.4 seconds result in a stress of 2.0 for a headway behind and 1.0 for a headway in front. Driver stress is calculated in SISTM’s own internal units each time increment and then summed over the vehicle’s journey to give an overall stress value for the journey. This is then summed over all vehicles in order to produce an overall stress value for the full simulation run.

Improvements in the driver stress calculations could be made by incorporating new factors, for example:

6. Frequent changes in speed (high workload)
7. Complexity of road layout and/or traffic management (high workload)
8. Density of traffic in current and adjacent lanes with greater stress according to the speed the traffic is moving at (fear & high workload)

However due to the subjective nature of all these measurements, any further enhancements should concentrate on obtaining evidence for the existing methods of determining stress.

### 6.6 Safety

There is no direct safety assessment carried out in SISTM and as with driver stress, the research literature does not reveal any generally accepted method for calculating this in microscopic models. Possible indirect methods of assessment used in SISTM are:

- **Time-to-collision (TTC) value.** This is the time in seconds when a collision between two vehicles in the same lane will occur, if both vehicles continue at their current speeds. Positive values of TTC under 10 seconds can be considered to represent an unsafe situation.

- **Headways.** Short time headways (e.g. under 0.5 s) between one vehicle and the one in front can be used as a measure of safety.

- **Severe braking.** The amount of braking at or close to the maximum achievable can be used as a measure of safety.

It would be possible to introduce a safety indicator based on a combination of these three factors. The second and third factors are also used in SISTM’s driver stress calculations because they indicate a high driver workload. However unsafe situations can also arise due to a low driver workload, e.g. boredom, tiredness or complacency. These could be measured by lack of lane changing, lack of changes in speed, driving for long periods at the driver’s desired speed and high headways with vehicles in front.
6.7 **SISTM Simulator**

The SISTM Simulator, of which SISTM 6.2N is a constituent part, was developed for testing NASS using SISTM models of the M42 Active Traffic Management (ATM) section (J3A-J7). Further development of this system could consist of:

1) Creating validated models of the ATM section so that suitable traffic control strategies can be devised and tested.

2) Upgrading the core algorithms in SISTM 6.2N so that they reflect the current implementation in the standard version of SISTM; SISTM 6.2N was taken from v6.0.000 of the main product which has since been updated to v6.0.008.

3) In the longer term there would be benefits in creating an interface between the SISTM Simulator and the HA’s Portable Standard, which is used for testing equipment.

These upgrades are discussed further in Appendix E.

6.8 **Development environment**

As described in Section 4.2, SISTM consists of many different components and uses many different third party software packages for its development. The scope for reducing the number of components (which would also benefit the end user) would be:

- Combine DataInput and SIMDAT so that all data preparation and verification is carried out within one product; it would still be desirable, however, to allow the user to continue to create and edit data files in a text editor.

- Combine the 2D and 3D visualisations of the main simulation program SIMRUN, whilst still allowing the user to run the simulation in batch mode.

Additionally account must be taken of new software development products available such as Visual Studio .NET as the current products may no longer be fully supported in future.

This is discussed further in Appendix F.

6.9 **Other upgrades**

6.9.1 **Road works**

SISTM has only had a minor role up to now in modelling road works. This is primarily because road works involve special layouts (e.g. contraflows, narrow lanes) that are not found under normal situations and where driver behaviour is different. Data collected on speeds and flows when road works were in operation could be used to calibrate SISTM. This would be done by invoking new code in the car following and lane changing algorithms, and new user parameters.

Motorway road works in the UK have been traditionally assessed using the QUADRO package; this contains macroscopically based equations for predicting speeds and throughputs. The advantage that SISTM could offer over QUADRO is that it could model the road works in greater detail and could assist in the placement of signs. Different arrangements could then be compared.

6.9.2 **Journey time data**

Journey time data is being used by the Highways Agency and the Department for Transport in the compilation of statistics used to assess whether targets for reducing road congestion are being met. The journey times are obtained from a range of sources, including MIDAS loops, Automatic Number Plate Recognition (ANPR) cameras and instantaneous speed data from in-vehicle Global Positioning Systems (GPS). New sources, such as mobile phone data, are also being considered.
Most of the journey times obtained are subject to approximations and errors, and careful use of the data is needed. Although there have been validation studies to assess data quality, this has mostly involved comparing one source with another and not comparing a source with exact data. SISTM offers the scope to replicate the approximations (and possibly the errors) inherent in the data sources and therefore evaluate the performance of each system. Refinements in the data cleaning process could also be tested.

7 Future options for SISTM

The possible future options for SISTM development can be summarised as:

- **A)** Hibernation of the software
- **B)** Minor upgrades to the software
- **C)** Major upgrade of the software to incorporate features found in other modelling packages

Each of these is discussed in the following Sections.

7.1 Option A: Hibernation of the software

This option would result in no further work being carried out to SISTM, i.e. no new features added and no maintenance carried out. Studies requiring the use of SISTM could still continue, but they would have to accept these limitations.

The advantages of this option for the HA are that no further funds would be spent on the package and that an assessment of the use of the package could be made whilst the development was frozen. The disadvantages are that it is unlikely that any SISTM study could proceed on the basis that the package was not being maintained. If a fault was discovered during the study and this was not corrected or a work-around found, the value of the study could be in jeopardy.

A modified version of option A would be where the official version of SISTM was hibernated, but the source code was given to outside parties (e.g. universities) for them to modify. They could explore different algorithms for car following or lane changing. At the end of their study the HA could decide which of their modifications would be worthwhile incorporating.

7.2 Option B: Minor upgrades to the software

This option would be a continuation of the existing arrangements whereby corrections and enhancements are implemented on a priority basis and according to the funds available. Some wider scale improvements could be done, for example:

- Increasing the scope of modelling to include the opposite carriageway and/or the all purpose road junction (as described in Sections 6.1.1 and 6.1.2).
- Updating the exhaust emissions and noise modelling to reflect more recent data (as described in Sections 6.3 and 6.4).
- Upgrading the software environment as the third party software used to develop SISTM evolves (as described in Section 6.8).

The advantage of this option is that the upgrading is incremental, i.e. each upgrade is implemented in a controlled manner and there is always a useable version of the software available. After each upgrade tests can be carried out to ensure that the modifications introduce no adverse effects in the remainder of the software.
7.3 Option C: Major upgrade of the software

This option would involve enhancing SISTM to include features found in other micro-simulation packages available. In order to do this the scope of SISTM’s modelling would have to be extended to include all purpose roads and a traffic assignment module would need to be added. Other features such as modelling public transport and pedestrians, which the commercial micro-simulation packages can simulate, would also be desirable.

The costs of this option are likely to be very high. It is difficult to estimate the financial sums required without precise specifications, but it is likely to be of the order of £300-£400k. The costs are likely to be the same whether the existing code is modified or new code is written from scratch.

The advantages of this option are that SISTM would be able to compete with the other micro-simulation packages and if successful, could bring in a significant income stream for the HA. SISTM could also become the modelling package that consultants had to use on HA projects and this would ensure a uniform approach to modelling.

The disadvantages are the costs and the risks that such a large upgrade poses. Also since the timescales for major upgrade would be fairly significant (e.g. 1-2 years) no further development of the existing software would be possible during this time and SISTM would effectively be frozen at the current release.

8 Conclusions

SISTM has evolved considerably since its first release in 1990, both in terms of its modelling capabilities and the range of applications it can be used for. It has been used extensively in studies for the Highways Agency and Department for Transport, in direct applications on real motorways and to explore more wide ranging traffic scenarios in hypothetical networks.

The purpose of this review has been to present the current state of SISTM and explore options for the future. To a large extent which option is to be adopted depends on the Highways Agency’s work programme over the next few years. A major upgrade (option C), to include complete modelling of an all purpose road network, would probably not be justified in terms of its likely cost and the availability of other micro-simulation packages which already do this. Hibernating the package (option A) would be the option to pursue if the HA considered SISTM’s role to be limited and wanted to wait for applications that would require its use.

The option that provides the HA with the greatest flexibility is to continue with minor upgrades (option B). The existing version of SISTM is a robust product, but modifications are required to correct some faults in the code and to provide enhancements that will increase the number of features it can handle. Additionally some of the data it uses, notably on the exhaust emissions and noise modules, is out of date.

The decision has recently been taken by the HA to put on hold the current SISTM maintenance contract, as from the end of January 2007. A TRL re-investment project using SISTM will be going ahead in Spring/Summer 2007. This will explore new traffic rules on motorways and modifications will be made to part of the code in order to investigate new scenarios.

The conclusion of this review is that option B (minor upgrades) represents the most flexible approach as it will provide for incremental upgrading to ensure that there is always a usable version of the software available. Another advantage of this option is that it will regularly improve the software which will lead to a greater number of applications.

9 Acknowledgments

The author is grateful to several members of TRL staff who contributed to individual sections of this report: Dr Ian McCrae for the review of modelling of exhaust emissions, Dr Greg Watts for the review of noise...
modelling. Neal Harwood for future developments of NASS and Dr Simon Wilson for the review of the software development environment. The author is also grateful to the individuals who attended the brainstorming session and contributed ideas for the future of SISTM.

10 References


# Appendix A. Reports produced on SISTM 1992-2007

## Applications

<table>
<thead>
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<th>Reference</th>
<th>Title</th>
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<tr>
<td>PR-TF-009-92.pdf</td>
<td>SISTM - Full scale assessment and some potential applications</td>
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<td>WP_TO_094_1992.pdf</td>
<td>SISTM - a computer simulation of traffic on motorways</td>
</tr>
<tr>
<td>P036.pdf</td>
<td>An assessment of ramp metering strategies Using SISTM</td>
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<tr>
<td>PR-TF-042-93.pdf</td>
<td>SISTM. Preliminary assessment of single level junctions for link road systems</td>
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<tr>
<td>PR054-93.pdf</td>
<td>Management of 4- and 5-lane carriageway motorways: inception report</td>
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<tr>
<td>PR-TF-043-94.pdf</td>
<td>SISTM. Assessment of four merge and four diverge slip road arrangements</td>
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<td>PR-TF-114-94.pdf</td>
<td>The effect of restricting lane changing on the approach to a merge at roadworks - SISTM modelling</td>
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<tr>
<td>PR_TT_027_1995.pdf</td>
<td>The potential uses of virtual reality in traffic modelling</td>
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<td>PR091-95.DOC</td>
<td>Investigation of strategies on 4-lane motorways using SISTM</td>
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<td>Site parameters - strategies for 4-lane motorways</td>
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<td>N212 - Management of 4- and 5-lane carriageway motorways using SISTM - final report</td>
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<td>PR-T-089-96.pdf</td>
<td>N203 - The ability of SISTM to replicate speed flow behaviour on the M25</td>
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<td>The selection of M3 and M27 sites for ramp metering</td>
</tr>
<tr>
<td>PR-T-159-97.pdf</td>
<td>The selection of further M3 and M27 sites for ramp metering</td>
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<tr>
<td>PR-T-092-98.pdf</td>
<td>N608 - Modelling MIDAS using SISTM - feasibility study</td>
</tr>
<tr>
<td>PR-T-115-98.pdf</td>
<td>N409 - Enhancement of SiSTM to include route choice assignment</td>
</tr>
<tr>
<td>PR_TT_178_1998.pdf</td>
<td>The capacity and safety of motorway weaving sections</td>
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<td>PR-T-059-99.pdf</td>
<td>SISTM enhancement phase 1 - replicating shockwave propagation using classical car-following models</td>
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<td>PR064-99.pdf</td>
<td>N608 - Optimisation of MIDAS parameters on M25</td>
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<td>PR_TT_117_1999.pdf</td>
<td>N609 - Customer project plan and cost profile</td>
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<td>PR_TT_186_1999.pdf</td>
<td>T809 - Incident detection on D5 and D6 - scenarios to be modelled</td>
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<td>PR029-00.pdf</td>
<td>N608 - Creation of a prototype version of SISTM to model MIDAS</td>
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<tr>
<td>PR-T-052-00.pdf</td>
<td>Inception report - Traffic responsive intelligent speed and headway adaptation (TRISHA)</td>
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<tr>
<td>PR-T-086B-00.pdf</td>
<td>T809 - Modelling of wide motorways using SISTM</td>
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<tr>
<td>PR-T-147-00.pdf</td>
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<td>PR-T-169-00.pdf</td>
<td>N609 - Driver behaviour at congested merges: Phase 1 report</td>
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<td>M2 (N Ireland) at Sandyknowes: modelling of ramp metering using SISTM</td>
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<td>PR-T-023-01.pdf</td>
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<td>PR-T-107-01.pdf</td>
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<td>N510 - Tactical traffic control on motorways: final report</td>
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<td>PR-T-024-02-draft1B.pdf</td>
<td>M25 J15-16 business case: Predictive modelling and sensitivity testing using SISTM</td>
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<td>PR_T_143_02.pdf</td>
<td>Simulator Compatibility - Final Report</td>
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<td>PR-T-152-03.pdf</td>
<td>Review of modelling of motorway lane changing</td>
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<td>SISTM modelling of incident screens.doc</td>
<td>SISTM modelling of incident screens</td>
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<td>UPR T/015/04.pdf</td>
<td>SISTM modelling of different options for modelling roadworks on Glasgow's Kingston Bridge</td>
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<td>UPR T/118/04.pdf</td>
<td>Review of microscopic modelling of ramp metering</td>
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<td>UPR T/004/05.pdf</td>
<td>Development of an enhanced lane changing algorithm for SISTM</td>
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<td>UPR T/025/05.pdf</td>
<td>Review of shockwaves using SISTM's enhanced lane changing algorithm</td>
</tr>
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<td>UPR T-065-05.pdf</td>
<td>Modelling of ramp metering options at M6 J20 using SISTM</td>
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<td>UPR T-127-05.pdf</td>
<td>Improvement in replication of shockwaves using SISTM</td>
</tr>
<tr>
<td>PPR176 - Incident Screens on Motorways.PDF</td>
<td>Incident screens on motorways: driving simulator, SISTM and desk-top studies</td>
</tr>
<tr>
<td>UPR T-005-07.pdf</td>
<td>Future development of the SISTM micro-simulation model</td>
</tr>
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### User Guides

<table>
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<tr>
<td>Batch User Guide 6-0-007.PDF</td>
<td>Batch User Guide</td>
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<tr>
<td>Step_by_Step_User_Guide_v0.3.PDF</td>
<td>Step-by-step User Guide</td>
</tr>
<tr>
<td>UG021863.PDF</td>
<td>Interactive User Guide</td>
</tr>
</tbody>
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Appendix B. Brainstorming session to discuss future ideas for SISTM

BRAINSTORMING SESSION HELD ON 04/12/06

Present
Pat Baguley  Neal Harwood
Ian Burrow  George Lunt
Abs Dumbuya  Bob Smith
Ewan Hardman

Apologies
Glyn Rhys-Tyler  Simon Wilson
Ian Summersgill

Presentation
Outline of session
• Presentation (15 min)
• Discussion (70 min)
• Summary (5 min)
• Job number = 11107300

SISTM development
• Developed since 1988
• Many enhancements since first release
  • Controlled Motorways
  • Ramp metering
  • 3D visualisation
• Now 2 versions:
  • v6.0.007 main release
  • V6.2N special version for NASS-SISTM Simulator
• Occasional development and use outside TRL
• Owned by Highways Agency (responsibility for SISTM recently taken over by Jo White)
• Review now being carried out

SISTM use
• Used on real motorways
  • M25 J10-J16 Controlled Motorways
  • M42 J3A-J7A ATM
  • M27 EB J10-J11 Ramp metering
  • M8 WB Kingston Bridge Road works
  • M60 J13-J18 Widening
  • M6 NB J20 Ramp metering
• Used on many hypothetical sections
  • Autonomous Intelligent Cruise Control
  • Weaving
  • Lane changing rates
Purpose of review
- List previous activities
- Identify possible enhancements
- Identify ways of increasing its use within the Highways Agency

Current work
- 3-year call-off maintenance contract ends in June 2007
- 3D visualisation is being improved/corrected
- Current fault list (excluding 3D): 47 faults
  - 13 high priority
  - 30 medium priority
  - 4 low priority
- Current enhancement list (excluding 3D): 32 items
  - 3 high priority
  - 13 medium priority
  - 16 low priority

Possible ways forward
- Hibernation
- Continue as at present, i.e. minor upgrades and fault fixing
- Outside development of parts of the code, e.g. the car following algorithm by universities
- Upgrading the modelling to the level offered by Paramics, VISSIM, AIMSUN, …

Things to be considered
- Increase scope of modelling
  - Both carriageways simultaneously
  - All purpose road junction with motorway
  - Full road network modelling with traffic assignment
- Further develop core algorithms
  - Car following, lane changing, exhaust emission, noise
- Introduce more traffic management features
- Introduce additional output measures
- Improve presentation of output
  - 3D visualisation
- Improve usability
- Improve development environment

Discussion

Increase scope of modelling

1. There is increasing interaction between congestion on the motorway and the all purpose road network. Therefore some scope for increasing SISTM’s geographic coverage would seem desirable, accompanied by a simple modelling of route choice. The original version of SISTM (before v5.0) included macroscopic modelling of the surrounding roads. The possibility of re-incorporating this code should be investigated.†

2. More detailed driver behaviour modelling, including driver distraction

† Post discussion note: this facility was supplied in binary form only as it contained proprietary Wootton Jeffreys’ code; this cannot be re-incorporated into the present software.
3. If the effect of lane (and vehicle) widths were modelled, after deriving suitable relationships using real data, SISTM would be able to model road works and would be a useful tool to maintenance contractors in setting up layouts.

4. Links with Driving Simulators could be established to provide data to SISTM on driver stress.

5. Similarly SISTM could provide data to the Simulators, e.g. greater realism for autonomous vehicles.

Core algorithms

6. It was felt that sufficient work had already taken place on the car following and lane changing algorithms and that effort should be concentrated elsewhere.

7. Releasing code to universities was being considered by the HA and TRL could have a role in monitoring/supervising their activities

Traffic management features

8. Hard Shoulder Running, as implemented on the M42 ATM Section, could be implemented with some small modifications

9. Mobile Barrier Crossings are being considered during incidents; the effect of these and the best means of implementing them could be studied using SISTM (would need modifications)

10. Integration of ramp metering and all purpose road signals. This would require the scope of modelling to be extended to the all purpose road junction.

11. SISTM could be used as a piece of testing kit, similar to how v6.2N has been used to test NASS

Output facilities

12. Traffic data available during a simulation run is limited; live plots would be useful

13. There are many output files and the amount of output can be excessive and difficult to understand; this could be simplified

14. A safety assessment is already included in the form of a time-to-collision calculation; other measures of road safety (e.g. short headways, lane changing conflicts) could be investigated

15. A carbon footprint (using CO₂ emissions) could be presented in a similar format to the speed and occupancy contour plots

Presentation

16. The 2D simulation drawing could be improved so that slip roads are truly 2D (i.e. drawn as diagonal lines)

17. The 3D simulation appears jerky due to vehicle positions only being updated each time increment; this could be improved by interpolation

18. The 3D simulation could replace the 2D visualisation as the standard
Usability

19. Improvements to the network definition could be made; this is one of the most difficult parts at present. A system of choosing motorway features from a list (e.g. merge, diverge, lane drop) would be the way forward.

20. Enable SISTM to accept other micro-simulation softwares’ input files

21. A simulation rewind facility would be useful to identify particular driver behaviour

22. Overall it was felt that improving the usability was the key to making the software more widely used.

Improve development environment

23. Changes to the software development platform are being considered outside the meeting.
Appendix C. Upgrade of the exhaust emission model in SISTM

C.1 Introduction

Road transport emission modelling approaches are dominated by the use of average speed emission functions. These are derived from the measurement of emissions over a series of real world driving cycles, each with a specific average speed. The results of these emission measurements are subsequently compiled into average speed (km/h) – emission (g/km) algorithms. This ‘traditional’ approach remains the most widely employed for the estimation of vehicle emissions, due in part to the simple input data requirements. However, over the last 10 years there have been significant developments in both traffic modelling, with the specific development of traffic micro-simulation tools, and the development of instantaneous emission models.

A range of atmospheric pollutants are emitted from road vehicles as a result of combustion and other processes. Exhaust emissions of carbon monoxide (CO), volatile organic compounds (VOCs), oxides of nitrogen (NOx) and particulate matter (PM) are regulated by EU Directives, as are evaporative emissions of VOCs. A range of unregulated gaseous pollutants are also emitted, including the greenhouse gases carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). However, with the exception of CO2 unregulated pollutants have been characterised in less detail than the regulated ones.

Emission levels are dependent upon many parameters, including:

- Vehicle type
- Technology level
- Fuel type
- Operation (speed, acceleration, gear..)
- Weight
- Gradient
- Mileage
- Level of maintenance

Models for estimating emissions from road vehicles can be classified in different ways, as summarised in Table C-1.

<table>
<thead>
<tr>
<th>The scale of application</th>
<th>The generic type</th>
<th>Emission calculation approach</th>
<th>Type of input data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macrow-scale (Country, region, city)</td>
<td>Aggregate emission factors, Average speed, Adjusted average speed, Modal, Instantaneous</td>
<td>Discrete, Continuous, Discrete/continuous mix, Continuous by operational mode</td>
<td>Trip-based, Link-based</td>
</tr>
<tr>
<td>Meso-scale (District)</td>
<td>Modal, Traffic situation</td>
<td>Continuous, Discrete/continuous mix</td>
<td>Link-based</td>
</tr>
<tr>
<td>Micro-scale (Road link, road subsection)</td>
<td>Multiple linear regression</td>
<td>Continuous by operational mode</td>
<td>Continuous by operational mode</td>
</tr>
</tbody>
</table>

Model classification systems tend to be based upon a combination of the geographical scale of application, the generic model type, and the nature of the emission calculation approach - a distinction can be made between models which use continuous emission functions, and models which use discrete emission values. The links between these different classification systems, with examples are broadly explained in Table C-2. The generic types of model are discussed in the following paragraphs. Some examples are provided, and their limitations are discussed. A large number of other models incorporate the databases of the models listed.
C.2 Modelling approaches

C.2.1 Aggregated emission factor models

Aggregated emission factor models operate on the simplest level, with a single emission factor being used to represent a particular type of vehicle and a general type of driving – the traditional distinction is between urban roads, rural roads and motorways. Vehicle operation is therefore only taken into account at a very rudimentary level, and the approach cannot be used to determine emissions for situations which are not explicitly defined. The emission factors are calculated as mean values of measurements on a number of vehicles over given driving cycles, and are usually stated in terms of the mass of pollutant emitted per vehicle and per unit distance (g vehicle$^{-1}$ km$^{-1}$) or per unit of fuel consumed (g litre$^{-1}$). Given their simplicity, these factors are of most use in applications on a large spatial scale, such as national and regional emissions inventories, where little detailed information on vehicle operation is required.

C.2.2 Average speed models

Average-speed emission functions for road vehicles are also widely applied in regional and national inventories, but are currently used in a large proportion of local air pollution prediction models. The average-speed approach is exemplified by the model incorporated within the UK Design Manual for Roads and Bridges (DMRB) (Highways Agency et al., 2003) and the European Environment Agency’s COPERT III model (Ntziachristos and Samaras, 2000). Average-speed models are based upon the principle that the average emission factor for a certain pollutant and a given type of vehicle varies according to the average speed during a trip. The emission factor is again usually stated in grammes per vehicle-kilometre (g vehicle$^{-1}$ km$^{-1}$). Figure C1 shows how a continuous average-speed emission function is fitted to the emission factors measured for several vehicles over a range of driving cycles, with each cycle representing a specific type of driving, including stops, starts, accelerations and decelerations.

![Figure C1: Average speed emission function (red line) for NOx emissions from Euro III diesel cars <2.0 litres. The blue points show the underlying emission measurements (Barlow et al., 2001)](image-url)
### Table C-2: Summary of instantaneous emission models (Boulter et al., 2006)

<table>
<thead>
<tr>
<th>Model</th>
<th>Original MODEM</th>
<th>Extended MODEM</th>
<th>DGV</th>
<th>PHEM (HDV)</th>
<th>VeTESS</th>
<th>CMEM</th>
<th>EMPA model</th>
<th>PHEM (PC)</th>
</tr>
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<tr>
<td>Developer/Supplier</td>
<td>TRL, INRETS, TÜV</td>
<td>TRL</td>
<td>TUG</td>
<td>MRA/ VITO</td>
<td>University of California</td>
<td>Internet</td>
<td>ARTEMIS/COST 346</td>
<td>US$20</td>
</tr>
<tr>
<td>Cost</td>
<td>£1,000 for research and £6,000 for commercial use</td>
<td>Not available</td>
<td>ARTEMIS/COST 346: Input data 4,000 €</td>
<td>Source code free, input data 3,000 €. Source code (Euro 3) 5,000 €. Source code (Euro 4) 7,500 €. Not known</td>
<td>Not commercially available</td>
<td>Not commercially available</td>
<td>Source code (Euro 3) 4,500 €. Source code (Euro 4) 7,000 €. Source code free, input data 3,000 €. Not known</td>
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</tr>
<tr>
<td>Source</td>
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<td>Direct approach to TUG</td>
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<td>CO, HC, NOx, CO₂, PM, (FC)</td>
<td>CO, HC, NOx, CO₂, PM, (FC)</td>
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<tr>
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<td>v(t), gradient</td>
<td>v(t)</td>
<td>v(t)</td>
<td>v(t)</td>
<td>v(t)</td>
<td>v(t)</td>
<td>v(t)</td>
</tr>
<tr>
<td>Outputs</td>
<td>E_{total}</td>
<td>E_{total}, E(t)</td>
<td>E_{total}</td>
<td>E_{total}, E(t)</td>
<td>E_{total}</td>
<td>E_{total}, E(t)</td>
<td>E_{total}</td>
<td>E_{total}, E(t)</td>
</tr>
</tbody>
</table>

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a. The price for the original MODEM model was set by the project consortium at the time of its release (over 10 years ago).

b. All costs relating to PHEM (HDV part and PC part) are provided by TUG, and are provisional. The price for the full set includes 20 hours consultancy. If the PHEM source code is bought, 8 hours training and a user manual are included (without travel costs).

c. For a given vehicle category, v(t) = driving pattern (vehicle speed as a function of time).

d. E_{total} = total emissions over driving cycle. E(t) = emissions for each second of driving cycle.

FC = Fuel consumption.
A number of factors have contributed to the widespread use of the average-speed approach. For example, it is one of the oldest approaches, the models are comparatively easy to use, and there is a reasonably close correspondence between the required model inputs and the data generally available to users. In principle, the input is the trip-based average speed, although in practice it is also common for local speed measurements taken at discrete locations to be used. However, there are now considered to be a number of limitations associated with average-speed models, including the following:

(i) Trips having very different vehicle operation characteristics, and therefore different emission levels, can have the same average speed. Clearly, all the types of operation associated with a given average speed cannot be accounted for by the use of a single emission factor. This is less of a problem at higher average speeds, for which the possible variations in vehicle operation are more limited, but at lower average speeds the range of possible operational conditions associated with a given average speed is much greater.

(ii) In response to the tightening of emission control legislation, vehicles have been equipped with increasingly sophisticated after-treatment devices. For modern catalyst-equipped vehicles a large proportion of the total emission during a trip can be emitted as very short, sharp peaks, often occurring during gear changes and periods of high acceleration. The use of after-treatment devices, manufacturer-specific engine management software, and regenerating after-treatment systems also make it much more difficult to predict emissions. Average speed has therefore become a less reliable indicator for the estimation of emissions for the newest generation of vehicles; the average speed model provides an impression of reality that is often too simplistic.

(iii) The shape of an average speed function is not fundamental, but depends on, amongst other factors, the types of cycle used in development of the functions. For example, each cycle used in the development of the functions typically represents a given real-world driving condition, but the real distribution of these driving conditions is not normally taken into account (e.g. via weightings).

(iv) Average speed models do not allow for detailed spatial resolution in emission predictions, and this is an important drawback in dispersion modelling.

One of the limitations of average speed models mentioned earlier was the inability to account for the ranges of vehicle operation and emission behaviour which can be observed for a given average speed. In this context the concept of ‘cycle dynamics’ has become useful for emission model developers (e.g. Sturm et al., 1998).

In qualitative terms, cycle dynamics can be thought of as the ‘aggressiveness’ of driving, or the extent of ‘transient’ operation in a driving pattern. Quantitatively, the term refers to the variation in various properties or statistical descriptors of a vehicle operation pattern. Researchers have examined a range of variables in an attempt to understand the links between cycle dynamics and emissions. As the vehicle operation information available to model users and developers has tended to be very limited, and almost invariably speed-based (e.g. spot speeds measured using traffic counting equipment), interest has inevitably focussed on parameters which describe speed variation in some way. Some of the more useful parameters appear to be relative positive acceleration (Ericsson, 2000) and positive mean acceleration (Osses et al., 2002). However, there are even problems with this simplest concept of cycle dynamics, for example:

(i) Most model users have little or no straightforward means of relating to descriptors of variation in vehicle operation, as these describe the properties of entire driving patterns (of course, this does not only affect speed). Most model users will only tend to have traffic flow and average speed information, and relationships between these parameters and those describing cycle dynamics on urban roads are not well-established. As a consequence, cycle dynamics has not usually been taken into account quantitatively.

1 In this Appendix the term ‘vehicle operation’ refers to a wide range of parameters which describe the way in which a driver controls a vehicle (e.g. average speed, maximum speed, acceleration pattern, gear-change pattern), as well as the way in which the vehicle responds (e.g. engine speed, engine load).

2 In this context, the term ‘transient’ refers to a driving cycle in which the operation of the vehicle is continuously varying, as opposed to being in a steady-state.
Several studies have concluded that emissions should be described in terms of engine speed, load, power, and the changes in these parameters, not just variables relating to vehicle speed (Leung and Williams, 2000; Kean et al., 2003).

Nevertheless, the concept is a useful one, especially when there is a need to discuss more advanced forms of modelling than the average-speed approach.

C.2.3 ‘Corrected’ average speed models

The TEE (Traffic Energy and Emissions) model (Negrenti, 1998) incorporates a ‘corrected average speed’ modelling approach. The model assumes that the effect of congestion on emissions at a certain average speed can be expressed by means of a ‘correction factor’ derived from average speed, green time percentage, link length, and traffic density. The emission factor for the average speed is then adjusted using the correction factor. The congestion level is used to calculate the fractions of time spent during cruising, acceleration, deceleration and idling, and the end result is a reconstructed speed profile produced by the model itself. In fact, the TEE model uses emission factors from a simple instantaneous model (MODEM – see later) to calculate emissions for each of the phases, based on the reconstructed profile. The limitations of this part of the approach are discussed in the Section on simple instantaneous models.

C.2.4 Traffic situation models

One alternative approach for incorporating both speed and cycle dynamics into emission estimations involves ‘traffic situation’ modelling, whereby cycle average emission rates are correlated with various driving cycle parameters. These, in turn, are referenced to specific traffic situations which are known by the model user. Different traffic situations relate to conditions for which there is a specific emission problem, and for which the average speed may not be the best indicator of emissions. Traffic situation models tend to be best suited to local applications, in which emission estimates are required for individual road links, but can also be used for regional and national inventories.

The user must be able to relate to the way in which the traffic situations are defined in the model. For example, the Handbook of Emission Factors (HBEFA), used in Germany, Austria and Switzerland, is based on reference emission factors for different categories of vehicle. Each emission factor is associated with a particular traffic situation, characterised by the features of the section of road concerned (e.g. ‘motorway with 120 km h⁻¹ limit’, ‘main road outside built-up area’). The speed variation (dynamics) variable is not quantified by the user, but is defined by a textual description (e.g. ‘free-flow’, ‘stop and go’) of the type of traffic situation to which an emission factor is applicable (INFRAS, 2004). As with any other model, the emission factors produced by the Handbook for the various vehicle categories must then be weighted according to traffic flow and composition.

However, asking the user to define the traffic situation using a textual description of speed variation or dynamics may lead to inconsistencies in interpretation. Even qualitative descriptions, such as those employed in the HBEFA, may be beyond many users, and are obviously open to interpretation. Furthermore, there are no universally accepted definitions for traffic situations, and there are likely be significant differences between the absolute characteristics of traffic in different locations. In addition, the Handbook employs definitions which are road- or traffic-based, rather than emissions-based. Although it is known that there are fundamental underlying relationships between the characteristics of the road (e.g. number of lanes, carriageway width, topography), the prevailing traffic (e.g. flow, composition) and the operation of vehicles, relationships with vehicle emissions are less well known.

C.2.5 Multiple linear regression models

The VERSIT+ model (Smit et al., 2005) employs a weighted-least-squares multiple regression approach to model emissions, based on tests on a large number of vehicles over more than 50 different driving cycles. Within the model, each driving cycle used is characterised by a large number of descriptive parameters (e.g. average speed, RPA, number of stops per km) and their derivatives. For each pollutant and vehicle category
a regression model is fitted to the average emission values over the various driving cycles, resulting in the
determination of the descriptive variables which are the best predictors of emissions (the group of descriptors
being different in each case). A weighting is also applied to each emission value, based on the number of
vehicles tested over each cycle and the inter-dependence of cycle variables. The VERSIT+ model requires a
driving pattern as the input, from which it calculates the same range of descriptive variables and estimates
emissions based on the regression results. The physical meaning of the variables may not necessarily be
known. As with the other models requiring a driving pattern as the input, the use of the model will be
restricted to a comparatively small number of users.

C.2.6 Modal models

In modal models emission factors are allocated to the specific modes of vehicle operation encountered during
a trip. Different types of modal model are in use, and the terminology used can be rather confusing. In the
simpler type of modal model, vehicle operation is defined in terms of a relatively small number of modes -
typically idle, acceleration, deceleration and cruise. This type of model is indeed normally referred to as
‘modal’. A number of more detailed modal models aim to provide a more precise description of vehicle
emission behaviour by relating emission rates to vehicle operation during a series of short time steps (often
one second). These detailed modal models are the subject of this Appendix. However, several different terms
(as well as modal) have been used to describe the more detailed type of model, including ‘instantaneous’,
‘microscale’, ‘continuous’ and ‘on-line’ (De Haan and Keller, 2000). As the term ‘instantaneous’ has been
used quite widely in the literature, it will be retained for this Appendix, and will be used hereafter. In fact,
such models tend to be discrete in nature, and therefore the term ‘instantaneous’ is something of a misnomer,
but this will have to be overlooked.

C.2.7 ‘Simple’ modal models

As mentioned above, simple modal models categorise vehicle operation according to a relatively small
number of modes. For each of the modes the emission rate for a given vehicle category and pollutant is
assumed to be fixed, and the total emission during a trip, or on a section of road, is calculated by weighting
each modal emission rate by the time spent in the mode. For example, the Urban Road Pollution (UROPOL)
model (Hassounah and Miller, 1995) combines the numbers of vehicles that are accelerating, decelerating,
queuing or cruising at any point along a road segment, with emission rates relating to each driving mode.
The coarse model approach has usually been used to determine the impacts of traffic control measures and
signal improvements (e.g. Coelho et al., 2005). A similar approach been used by, for example, Frey et al.
(2001), Rouphail et al. (2001), Unal et al. (2003) and Hung et al. (2005).

C.2.8 Instantaneous models

Atjay and Weilenmann (2004) stated that the aim of instantaneous emission modelling is to map emission
measurements from tests on a chassis dynamometer or an engine test bed in a neutral way. In theory, the
advantages of instantaneous models include the following:

- Emissions can be calculated for any vehicle operation profile specified by the model user, and thus
  new emission factors can be generated without the need for further testing.
- The models inherently take into account the dynamics of driving cycles, and can therefore be used to
  explain some of the variability in emissions associated with given average speeds.
- The models allow emissions to be resolved spatially and temporally, and thus have the potential to
  lead to improvements in the prediction of air pollution.

Some instantaneous models, especially the older ones, relate fuel consumption and/or emissions to vehicle
speed and acceleration during a driving cycle, typically at one-second intervals (Figure C2). Other models
use some description of the engine power requirement. However, it must be noted that there are a number of
fundamental problems associated with instantaneous models. For example, it is extremely difficult to
measure emissions on a continuous basis with a high degree of precision, and then it is not straightforward to
allocate those emission values to the correct operating conditions. Atjay and Weilenmann (2004) noted that,
during measurement in the laboratory, an emission signal is dynamically delayed and smoothed, and this makes it difficult to align the emissions signal with the vehicle operating conditions. Such distortions have not been fully taken into account in instantaneous models until relatively recently.

Some consideration also ought to be given to the model user. In order to apply instantaneous models detailed and precise measurements of vehicle operation and location are required, otherwise any potential benefits may be lost. This is likely to be rather difficult for many emission model users, as such information is conventionally relatively expensive to collect. As a consequence, the use of instantaneous models has mainly been restricted to the research community. However, the corresponding developments in traffic micro-simulation models have the potential for reducing the costs associated with this primary data collection, through the direct provision of instantaneous driving characteristics along modelled links. Thus instantaneous emission models and traffic micro-simulation models are ideally suited.

C.3 The SISTM emission module

In the early 1990’s, INRETS (France), TÜV Rheinland (Germany) and TRL jointly developed the MODEM emissions model as part of the EU DRIVE project MODEM (Jost et al, 1992). The resulting functions allowed the estimation of individual vehicle emissions and fuel consumption from second-by-second vehicle speed traces. However, the original DRIVE project focussed on urban conditions, and thus in 1997, TRL produced an extended version of MODEM for motorway, high speed conditions (Barlow, 1997). Within this study instrumented cars were driven through the M25 Controlled Motorway section (junctions 10-15) to record typical driving characteristics. These data were subsequently analysed to develop a series of test cycles which were subsequently used in conjunction with a chassis dynamometer to record corresponding emissions.

The resulting data for each vehicle type were expressed as a series of tables, one for each pollutant (CO, CO₂, HC, NOₓ and in the case of diesel vehicles, PM) in milligrammes per second, and one for fuel consumption in millilitres per second. The tables contained entries for speeds (to the nearest km/h) in the range 0 to 153 km/h and speed and acceleration values (to the nearest m²/s³) in the range -40 to +30 m²/s³. Vehicles were then grouped by engine size and fuel type, and weighted averages calculated to produce a single table for each emission substance in each of 8 vehicle class categories. Empty cells were filled by extrapolation, and the resulting data smoothed. Validation of the emission functions was performed by comparing the actual measured emission quantities over the test cycle with the estimates produced by the
derived functions. The level of agreement was “very good” (Barlow, 1997). A full description of the SISTM emission sub models is available from Abbott et al., 2000.

In 2000, instantaneous emission functions for motorway vehicles other than cars were not readily available. Relatively little data existed on the exhaust emission rates for vehicles other than cars in any form, and this was one of the main rationales for the TRAMAQ project UG216, which characterised the emissions from a sample of approximately 50 heavy goods vehicles and buses (Latham et al., 2005), and the EU ARTEMIS programme. Therefore, average speed HGV emission factors were used within SISTM, derived from the EU 4th Framework MEET project (the fore-runner of the ARTEMIS project), TRL data and supplemented by data from the Swiss-German-Austrian handbook of emission factors (INFRAS, 1995). Although these functions did not permit the calculation of emission rates using instantaneous speed data, nor were they solely derived from motorway journeys, they did support the calculation of emissions for individual vehicles based on mean vehicle speeds. The MEET-SISTM HGV functions provided estimated exhaust emission rates for CO, CO₂, HC, NOₓ and PM. Supplementary functions were available that provided correction factors for the effects of travelling on roads with a gradient, and for the effect of different levels of vehicle loading.

SISTM incorporates the carbon balance method for the estimation of fuel consumption. Under this method, it is assumed that all of the carbon in the fuel is converted into four of the exhaust emission substances, CO, CO₂, HC, and PM, and consequently that the same mass of carbon is present in both the fuel and the resulting exhaust emission substances (Hickman, 1998).

### C.4 The development of a new emission module for SISTM

Instantaneous emission models aim to provide a precise description of vehicle emission behaviour by relating emission rates to vehicle operation during a series of short time steps (often one second) (Boulter et al., 2006). Instantaneous models allow emissions to be resolved spatially, and would thus lead to improvements in the prediction of air pollution. Air quality models typically assume that emissions are evenly distributed along a road section. It is therefore likely that such models will under-predict emissions and the resulting ambient concentrations at some locations, such as in the vicinity of junctions or other flow interruptions that might occur along an otherwise homogeneous link (Tate et al., 2005; Boulter and McCrae, 2006).

It is recognised that the existing MODEM/MEET emission module, currently employed within the SISTM model has a number of limitations, including the fact that it can accommodate instantaneous emissions for passenger cars only, and is based upon data collected during the early 1990s. Therefore for more recent Euro-emission classes, emission data are based upon statistical extrapolation, rather than dedicated measurements. TRL has recently undertaken a review of emission modelling approaches, and highlights within this review the significant developments arising from the EU fifth framework ARTEMIS project and the COST Action 346 project (Boulter et al., 2006). These projects have provided new insight into the emission behaviour of modern vehicles.

One of the main outputs of these projects was the development of a model capable of accurately simulating emission factors for all types of vehicles over any driving cycle and for various vehicle loads and gradients. The resulting tool – PHEM (Passenger car and Heavy-duty Emission Model) - estimates fuel consumption (FC) and the emissions of carbon monoxide (CO), total hydrocarbons (THC), oxides of nitrogen (NOₓ) and particulate matter (PM) based on the instantaneous engine power demand and engine speed during a driving cycle specified by the user. Carbon dioxide (CO₂) is estimated from the fuel consumption through the use of a carbon balance/combustion equation; the amount of carbon in the fuel is known and from this the amount of CO₂ can be derived. The model combines steady-state engine maps with correction functions for transient operation (Rexeis et al., 2005). Within PHEM, for a given driving cycle and road gradient, the required engine power is calculated each second, based on the driving resistance and losses in the transmission system. Engine speed is calculated from the transmission ratios and a gear-shift model. To allow for the

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3 http://trl.co.uk/artemis
4 http://www.cordis.lu/cost-transport/src/cost-346.htm
effects of transient vehicle operation on emissions, the results from the steady-state maps are altered using transient correction functions.

PHEM takes the form of a computer-executable program with a user-friendly interface. It is optimised for simulating fuel consumption and emissions from HDV fleets, but can also be used for simulations of single vehicles as well as passenger cars. The outputs from the model are engine power, engine speed, fuel consumption and emissions every second, as well as average values for an entire driving cycle. Figure C3 illustrates the structure of the model.

PHEM is thus an instantaneous emission model in which fuel consumption and emission values are interpolated from steady-state engine emission maps for every second of a given driving cycle. For interpolating emissions from the engine map, the actual power demand from the engine and the engine speed are simulated according to the vehicle data given as model input. The simulation of the actual power demand of the engine is based on the driving resistances and the transmission losses, and engine speed is calculated using the transmission ratios and a gear-shift model. The different emission behaviour over transient cycles is taken into consideration by ‘transient correction functions’, which adjust the second-by-second emission values according to parameters describing the dynamics of the driving cycle.

PHEM has some special features which were developed to enable the straightforward simulation of average vehicle classes. For example, the input data are modular, with different files being used to describe the vehicle characterisation, the driving cycle, the engine emission map and the full-load curve. This enables a rapid simulation of various vehicle and driving cycle combinations. In the input file for the driving cycle, the measured engine speed or the gear position can be given as an optional model input. If neither the engine speed nor the gear position is given in the input file, PHEM uses a gear-shift model to simulate engine speed.

The PHEM modelling approach has thus been identified as a state-of-the-art tool, suitable for use with SISTM. This would replace the existing MODEM passenger car and MEET HGV average speed-based models. One option would be to use the PHEM model as a supplementary add-on module for SISTM; an alternative would be to provide the output from PHEM as a series of look-up tables in SISTM (similar to the MODEM tables used at present).

Finally, to facilitate the revision of the SISTM emission module, it is proposed that the following steps are undertaken:

1) Development of software to link the outputs from SISTM with the required inputs for the PHEM model. This would include the development of a traffic post-processor to facilitate the conversion of the traffic model traffic classes, to the corresponding emission model traffic classes. An alternative
would be to extract data from PHEM and incorporate the instantaneous emissions in a look-up table in SISTM.

2) A comparison of the SISTM estimated driving characteristics with field measurements of driving characteristics. This would incorporate the use of existing data from instrumented vehicles, but would undoubtedly require additional field measurements.

3) A comparison of the emission estimates derived from SISTM-PHEM with on-board real world emission measurements. This process would provide initial validation data for the revised modelling approach.

C.5 References


Appendix D. Upgrade of the noise model in SISTM

The source model for the noise emission of vehicles in the SISTM model is based on a two vehicle model operating on a hot rolled asphalt (HRA) surface. The data on acceleration was based on data published in 1980 (Jones and Hothersall, 1980). Since then there have been significant changes in the propulsion units of both light and heavy vehicles making the need for a review of the model imperative if modern traffic is to be modelled accurately. In addition HRA is only now specified under special conditions and thin surfacings are become widespread. In the last few years a European consortium has produced a state of the art model of source noise from road vehicles (HARMONOISE) that is intended for use in all member countries (Watts, 2005). The timetable for implementation is expected when the 2nd phase on noise mapping is required by the Environmental Noise Directive in 2012.

Briefly in the HARMONOISE source model vehicles are divided into 3 main categories corresponding to light (category 1), medium heavy (category 2) and heavy vehicles (category 3). Two point sources are used for each vehicle category – one represents mainly the tyre sources (rolling noise) and the other represents mainly the propulsion noise sources (engine, transmission and exhaust). The tyre source is located 0.01 m above the road surface and the other, propulsion unit source, is located either at 0.3 m for light vehicles or 0.75 m for heavy vehicles. 80% of the tyre/road noise source is assumed to radiate from the lower source whereas 20% is assumed to radiate from the higher source. The opposite is the case for the propulsion noise source. This allows for some “smearing” of the source which in practice rarely takes the form of discrete point sources. Corrections to propulsion noise are made for road speed and acceleration rate. For rolling noise a different correction is made for road speed and there are no corrections for acceleration. However, there are corrections for the type of road surface, its temperature and whether it is wet. The model is based on predictions in third octave band frequencies from 25 Hz to 10 kHz and these are combined to give the overall A-weighted energy equivalent level $L_{Aeq}$ over the period required.

Using HARMONOISE it will be possible to accurately model the major sources of noise for the three main categories of vehicle currently operating on the road network. It is proposed to use the source model to assess the effects of different traffic management schemes by calculating the acoustic energy of each vehicle pass-by. The energy from these events would then be accumulated over 5 minute and 1 hour periods in order to obtain the corresponding $L_{Aeq}$ levels. The input data needed would include a specification of the vehicle’s class, vehicle speed and acceleration rate. A default surface type and condition representing an average texture would be assumed and the distance from the middle of the traffic lane would be 7.5 m. To obtain the overall noise dose produced by a section of highway, as opposed to a single location, it would be necessary to combine the predicted $L_{Aeq}$ levels at various receiver points along the length of the road.

References


Appendix E. Potential future uses of the SISTM Simulator

The SISTM Simulator is an adaptation of SISTM originally designed for the testing of the NASS system. It comprises a core SISTM model (currently of the M42 ATM section), and some extra software which interfaces between that SISTM model and NASS.

This interface is designed to replicate an NMCS2 COBS system and associated MIDAS system (including the automatic signalling aspects of MIDAS, if required).

Original Use
The SISTM Simulator was developed in order to test the NASS system software being developed by IPL. NASS is designed as a COBS subsystem which can set signals (and Hard Shoulder opening).

The SISTM Simulator acts, as far as NASS is concerned, like the ‘rest of the world’. It simulates the COBS LAN to which NASS connects and over which NASS sends and receives its data. It also simulates the effects of settings requested by NASS, and feeds back the appropriate COBS responses (signal settings etc.), along with the simulated traffic effects (in the form of MIDAS Traffic and Alert data).

Because the SISTM Simulator was designed to test the software, and not the traffic aspects of the NASS system, the SISTM model of the M42 within the Simulator was designed to be a reasonable representation of motorway traffic, and how it might react under various traffic control regimes. It was not, however, built as a fully validated model specifically for the M42. This was done partly for budget reasons (validating a model is a significant expense which was unnecessary for the software testing role), but also because no data on how a major traffic control system like Hard Shoulder Opening actually affects traffic behaviour was available.

Proposed Further Use
IPL have found the SISTM simulator to be useful in the development of the NASS software. The NASS software is now stable, and the next stage of development is underway. This stage (undertaken by WSP) is concerned with the development of control strategies for the practical use of the NASS system on the M42. These control strategies are formed from 2 parts:

- Congestion Patterns: Patterns of traffic behaviour (both current and predicted) which may warrant control action by NASS to prevent or ease congestion.
- Traffic Control Plans: Potential combinations of controls (speed limits, ramp metering, hard shoulder opening/closing) which may be used to ameliorate the congestion patterns identified above.

WSP (and Faber Maunsell) are working on identifying useful Congestion Patterns (and associated Traffic Control Plans). This is a difficult exercise, and there is potential for the SISTM Simulator to help in the development and testing of these.

It is understood that WSP and Faber Maunsell are already using the existing SISTM Simulator to generate ‘realistic’ traffic behaviour to aid them in this task. However, because the model is NOT a fully validated model of the M42, this approach has limited validity, and hence limited usefulness.
Since the start of the ATM trials, good data on Hard Shoulder use is now available, and so it should be possible to calibrate and validate the M42 SISTM model.

This validated model could then be used to identify and develop the control strategies described above. The Simulator could also be used to easily test those control strategies (setting up timed signal settings etc. in a standalone SISTM model requires a certain amount of expertise and time. Using the SISTM Simulator interfaced with NASS, this becomes very easy).

In order to create a validated model of the ATM Section, the core algorithms in the SISTM part of the SISTM Simulator (known as SISTM 6.2N) would need to be updated. These algorithms were taken from v6.0.000 of the main product which has since been upgraded to v6.0.008. In particular the following modifications have been carried out to the main product:

- The lane changing algorithm has been enhanced so that lane changing behaviour and rates has been calibrated with data obtained from real motorways
- The car following algorithm has been enhanced so that shockwaves can be replicated

If the creation of validated models is deemed useful (or even essential?) then any future roll outs of ATM (or similar) systems elsewhere in the country would then also benefit from a similar SISTM model, built in to the SISTM Simulator.

Other Potential Use

This more ‘blue sky’ thinking, explores potential use for an adapted version of the SISTM Simulator as part of the HA’s Portable Standard, which is used for testing COBS equipment.

During the development of the SISTM Simulator, TRL had use of a Portable Standard unit to help in testing. This is a hardware device developed for the Highways Agency by Cambridge Consultants Ltd. From a CCL press release:

“A Portable Standard can emulate and test the majority of the components within the motorway network, from the control office to the fog detectors and gantry signs. It is used for conformance testing at manufacturers’ premises, for compatibility testing in the laboratory and on-site for debugging problems. Several significant incompatibilities with suppliers’ equipment have already been identified by CCL, enabling the HA to minimise the cost of rectifying the situation after installation.”

The Portable Standard is a sophisticated piece of equipment for use in testing and debugging NMCS2 systems. It cannot, however, replicate traffic and the associated data derived from it. Most specifically, a MIDAS system can set signals in response to traffic levels building up on the motorway network. The Portable Standard can be used to test that MIDAS requests to set signals are handled correctly, but it cannot generate those signal requests itself. These would have to be set up manually by the tester. In contrast, the SISTM Simulator can generate those requests automatically, in response to predicted traffic behaviour generated by signals already set (i.e. a feedback loop).

There may be benefits to the development of an interface between the SISTM Simulator and the Portable Standard, in order to allow this more comprehensive testing.

The interface itself would not be hard to build, since it would essentially build on the COBS interface already existing in both systems. The SISTM Simulator would be ‘cut back’ slightly so that it only simulates a MIDAS subsystem (and the road network ‘behind’ it) rather than the COBS system it currently simulates.

The question is whether there is a need for this extra utility. There is a potential ‘blurring’ of functionality in adding traffic behaviour to what is, essentially a hardware testing system, albeit specific to NMCS2 COBS, which is itself heavily tied to traffic. Further consultation (with Cambridge Consultants, HA and potential end users) would be required before this idea could be taken any further.
Appendix F. Upgrade of software development environment for SISTM

The SISTM suite of C++ programs include:

- SimRunG (2D)
- SimRunG (3D)
- DataInput

SimRunG

Current Development Environment

The upgrading of the development environment has been explored. An attempt was made to integrate SimRunG 3D into Visual Studio .NET 2003 (currently development of SimRunG 2D and 3D is performed in Visual Studio 6) and this was met with partial success. Whilst the actual code for SimRunG 3D compiled successfully there was a problem with the lib files that were supplied by QinetiQ. These were compiled using libraries in Visual Studio 6.0 that have since been updated in VS 2003 therefore making the two incompatible. A future investigation will be required in order to determine whether we have the files necessary to re-compile and generate a lib file for the new environment.

The 2D version, however, was successfully integrated into Visual Studio .NET 2003 meaning that any future work to this version can be performed in the more up to date environment.

Possible enhancements

A possible enhancement to SimRunG would be to integrate the 2D and 3D versions into a single executable. Currently the 3D version runs as a separate executable and receives data from the 2D executable (via packets of information sent using Windows messages). It then uses this data to plot the motorway and vehicle positions (along with the new feature of displaying vehicle statistics). Integrating the two into a single executable would benefit from an increased execution speed since the 2D would no longer need to send data over to the separate 3D version and would give the user the option to switch between the 2D and 3D views (currently, the 2D version must be running for the 3D version to work – this would not be necessary if the two versions were integrated, i.e. the 3D version could be displayed without the 2D version being displayed). Having the ability to only run the 3D version of SimRunG would undoubtedly improve execution speed since only a single executable would be running showing a single view. As previously mentioned, currently to run the 3D version the 2D version needs to also be running which means there are two executables competing for processor time – this causes a noticeable slow down on both 2D and 3D versions.

A freeware graphics package known as ‘Blender’ has been obtained by TRL. This package will allow us to generate our own 3D models to be used in future versions of SimRunG 3D (such as new vehicles, signs etc). Currently, the 3D code relies on a Dynamic Link Library (DLL) that was supplied by QinetiQ and contains all of the current 3D models. Unfortunately, the code for this DLL was not released so making any changes to current models would be infeasible.

DataInput

Current Development Environment

DataInput has been successfully integrated into Visual Studio 2003 meaning that future enhancements can take advantage of the .NET tools.
Enhancements

It would be advantageous if DataInput was re-written in a more simple language such as C# .NET. There are tools available which will convert large sections of C++ code to C# which would mean that a complete re-write of the code would be avoided. However, such tools cannot perfectly convert from one language to another so some work should be expected to get the new version working correctly.

The benefits of converting to C# .NET are future enhancements to DataInput would take considerably less time than if they were performed in C++ which, although powerful, can be a far more long winded language. It would also remove the need for the FarPoint Spread and RoboHelp packages.
Abstract

SISTM (Simulation of Strategies for Traffic on Motorways) is a microscopic motorway simulation package that is owned by the Highways Agency and has been developed to evaluate methods of reducing congestion. The software has been continuously enhanced since the first release in the early 1990s, in order to model a wide range of applications, provide additional output measures and improve the graphical display of the model running. This report presents a review of past use of SISTM and considers possible future options for the package so that the Highways Agency can decide how the software fits in with their plans.

SISTM consists of a suite of programs which include both 2D and 3D representations of the motorway being modelled. It has been used in many motorway studies, mostly for the Highways Agency, including setting of parameters for the Controlled Motorways section of the M25 (J10 to J16) and improving the modelling of shockwaves. It has also been used with hypothetical networks in order to study a greater range of different scenarios including in-vehicle systems, such as Autonomous Intelligent Cruise Control.

This report describes possible enhancements that could be made to the software, in particular to the exhaust emission and noise modelling, and discusses the options for the future development of the package.
Review of the future development of SISTM

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