MOBYSIM: MOBILITY SIMULATION SUITE

Martijn van Noort[1], Hans Godthelp[2]
1. TNO, P.O. Box 49, 2600 AA Delft, The Netherlands, +31 15 26 96765; martijn.vannoort@tno.nl
2. TNO, Soesterberg, The Netherlands, hans.godthelp@tno.nl

ABSTRACT

Research and societal questions in the area of mobility are becoming more and more complex, covering many different aspects of the traffic system. Simulation tools are an important aid in the study of such questions. Their complexity requires an *integrated mixed reality environment*, in which the tools are connected to each other and to external data sources.
At TNO, many simulation tools for mobility research are available. The MOBYSIM project aims to integrate them in a tool suite. This paper presents the methodology used in developing the architecture for such a tool suite, and presents the results to date.

KEYWORDS
keywords

INTRODUCTION

The complexity of research and societal questions in the area of mobility is steadily increasing. On the one hand, problems with the efficiency, safety and environmental impacts of traffic systems are becoming more prominent or prioritized by policy makers. On the other hand, developments in dynamic traffic management, advanced driver assistance systems, intelligent vehicle safety systems and cooperative systems create an increasingly complex traffic environment where many different aspects of the traffic system interact. In order to understand these interactions, knowledge about areas such as vehicle dynamics, sensors and other technical components, driver behavior, traffic network dynamics and communication systems has to be combined.

Simulation tools are an important aid in answering such questions. Often, they provide a flexible, cost-effective and safe way to research innovative concepts and applications. For example, traffic simulation can be used to estimate the network level impacts of an ITS system like C-ACC (Cooperative Adaptive Cruise Control). In this way, one can easily experiment with penetration rates or system settings to create hypothetical future scenarios. In order to properly simulate traffic, the simulation tool needs to incorporate knowledge about the technical functionality and limitations of the system, the way in which drivers use it, and the vehicle-to-vehicle communication. Such knowledge is typically available in simulation tools such as detailed vehicle or component simulators, driving simulators, and communications simulators. Other applications, for example in the area of real time support for traffic management, may require connections between simulation tools and external data sources.

Thus, there is need to integrate the various simulation tools to form a tool suite. A systematic approach is to define an architecture that describes the connections between the tools and between the tools and the data. This paper presents the architecture for the mobility tools used by TNO.

The paper is organized as follows: the next section describes the state of the art in integrated simulation tools. This is followed by several sections detailing the methodology used to derive the architecture, the tools, some of the steps of the methodology and the results obtained.

STATE OF THE ART

Traditionally, the various types of simulation tools that are mentioned above are used as stand alone software tools. However, recent developments show that connections between the tools are getting more and more attention. For example, the well known traffic simulator VISSIM supports a connection to the NS-2 communication simulator, see e.g. [1]. Similar connections exist in the traffic simulators of various organizations, such as DLR’s SUMO [2].

One of the aims of the EU FP7 project *PreDrive C2X* [3] is to develop an integrated simulation model for cooperative systems, and in particular define a standard for coupling traffic, application and communication simulators.

Finally, there are software environments that allow the coupling of simulation tools. The VSimRTI environment [4] is an environment for traffic simulation that allows the integration of time-discrete simulators, e.g. for network, traffic, and environment simulation. TNO is developing the MiReCol (Mixed Reality technology for Collaboration) general software architecture for the integration of simulation models and real world data.

METHODOLOGY

Market potential is an important driver for developing an integrated simulation tool suite. Indeed, the purpose of the tool suite is to enable TNO to improve her services to her clients, by providing a more complete and more reliable simulation package.
Therefore, the methodology for deriving the architecture starts with a market analysis. Based on this analysis, several use cases will be defined. Here, a use case is an application of the tool suite to answer a specific question for a specific stakeholder category. The use cases are prioritized based on potential and demonstration value.

Necessary connections between the tools are identified for each use case. One type of connection is a data transmission connection, where data is transmitted between two tools. This can be either offline (that is, the first tool produces output data, which is then used as input by the second tool), or dynamic (both tools run simultaneously and exchange data on the fly).

Another type of connection is the model library. A model is a mathematical description of a certain aspect of reality, often encoded in software. Examples are models that describe driver behavior or vehicle dynamics. Many of the tools in the suite have a need for models of a certain type, for example driver models. The model library stores models of a certain type and

makes them available for use in all tools in the tool suite.
Finally, an architecture is constructed based on the connections. The architecture gives a consistent and complete description of the connections and relations between the various tools.

TOOLS

The following tools are considered in MOBYSIM:

- INDY is a macroscopic traffic model on the regional or national level. INDY is a macroscopic multi-userclass dynamic equilibrium assignment model for road traffic. It is used to investigate traffic load as a function of traffic demand.
- ITS Modeller is a microscopic traffic model on city level. ITS Modeller can model ITS applications and the corresponding vehicle and driver behavior, and assess their throughput, safety and environmental effects.
- PreScan is a detailed sub-microscopic traffic simulator on the local level, providing a platform for dynamic world objects with detectors, actuators, ego world model, hierarchical control, vehicle and driving tasks. It is used, among other things, for developing intelligent vehicle systems and local traffic analysis.
- The driving simulator is an interactive tool with visual, audio, motion, and steering force feedback, and full experimental control over road, environment and traffic. It is used to investigate the effects of ADAS, road design and driver state on driver behavior, workload and acceptance.
- OPNET is an environment for high fidelity simulation of communication networks. OPNET supports detailed modeling of communication networks and their components, and can be used for technical assessment, performance analysis, design and training.

With the exception of OPNET, all tools are designed and maintained by TNO. TNO has several other tools in the area of mobility, for example tools that deal with emissions modeling, travel time forecasting, traffic demand, urban planning, and logistics. These tools, although of interest for mobility research, are left outside the scope of this project for practical reasons. More detailed descriptions of the tools can be found in [5] – [8].

MARKET ANALYSIS

An analysis of the market potential of an integrated tool suite was performed based on expertise and experience from the project team and business developers within TNO. For various client categories, issues of interest were identified that lie in the area of mobility research that is covered by the tools.

The following categories of potential clients were considered:

- Policy makers (supranational, national, regional and local);
- Road authorities (national, regional and local);
- Automotive industry and its suppliers;
- Telecom industry;
- Traffic industry;
- Service providers, such as providers of navigation systems or travel information, insurance companies, lease companies;

- Construction companies.

Over 20 different categories of questions on mobility were collected that are of interest for these clients. Some prominent examples of issues covered by these questions are:

- Assessment of system effects (locally and on the network level), in various contexts, such as scenario analysis, evaluation of FOT's, etc;
- Testing and validation;
- Traffic prediction;
- Traffic management support.

USE CASES

The general view that is provided by the market analysis is made more concrete by designing a number of use cases that each cover a certain aspect of the market potential. A use case defines a specific application of the tool suite, and the related client categories and questions. About 15 use cases were identified in total. Of these, three were selected by applicability, diversity and demonstration value, namely:

1. Mixed reality driver assistant: an in-car system that creates a virtual environment (e.g. via a HUD) and can support various applications that assist with driving tasks, for example C-ACC and other driver assistance applications, or information services;
2. Multimodal evacuation: planning and operational management of the evacuation of a region, for example in case of flooding. There are two phases: a policy phase (long before the emergency) where plans are developed, and an operational phase where these plans are applied and adapted to circumstance in case of an emergency;
3. Traffic prediction and road works: planning and operational management of road works with the aim of minimizing nuisance and costs (of travel time losses etc). Like in the previous case there are policy and operational phases.

For each case, research questions have been identified that the tool suite should be able to answer. The research questions in turn lead to requirements on the connections that need to be established.

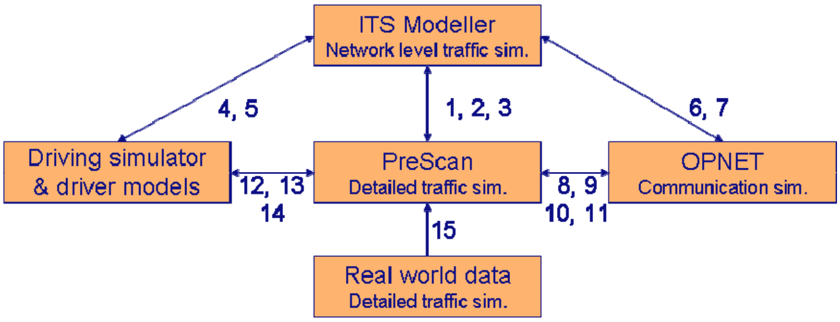
For the first case, many the research questions revolve around design issues such as reliability, robustness, accuracy, timeliness, consequences of failure, HMI design and behavioural effects. Further of interest are more policy oriented questions regarding the effects on traffic flow, and standardization and cooperation of cooperative systems. For design issues there is a strong need for detailed modelling and runtime information exchange between communication simulator, driving simulator and local traffic simulation. For policy issues, the results of the detailed analysis need to be scaled up to traffic network level effects, obtained through traffic simulation. This involves an offline connection, where the results of the detailed analysis are translated into models and input data for the network level traffic

Connection	From	To	Type	Data exchange	Measures
USE CASE 1: Mixed Reality Driver Assistant					
1	PreScan	ITS modeller	off-line model	vehicle model	
2	PreScan	ITS modeller	dynamic	vehicle state	speed, position, acceleration
3	ITS modeller	PreScan	off-line	traffic flow	speed-density relation, origin-destination matrix
4	Driving simulator	ITS modeller	off-line model	driver model	headways, gap-acceptance, speed choice, etc
5	ITS modeller	Driving simulator	off-line	traffic flow	speed-density relation, origin-destination matrix
6	Opnet	ITS modeller	off-line model	communication performance model	message loss, e2e-delay
7	ITS modeller	Opnet	off-line	traffic scenario	vehicle positions, communication equipment, traffic flow, messages
8	Opnet	PreScan	off-line model	communication performance model	message loss, e2e-delay
9	Opnet	PreScan	dynamic	messages	message loss, e2e-delay
10	PreScan	Opnet	off-line	hi-fi traffic scenarios	antenna direction, transmission power, message size + as nr. 7
11	PreScan	Opnet	dynamic	present vehicle state, messages	antenna direction, transmission power, message size + as nr. 7
12	PreScan	Driving simulator	real-time	virtual world scenario	present vehicle positions
13	Driving simulator	PreScan	off-line model	driver model	headways, gap-acceptance, speed choice, etc
14	Driving simulator	PreScan	real-time	driver actions	accelerations, pedal use, etc.
15	Real world/Video based monitoring	PreScan	off-line	vehicle state, weather data, traffic control scheme	speed, position, acceleration, traffic lights, …

simulator.

Figure 1 shows the connections that are identified for this case.

The second and third use cases have similar requirements and are therefore discussed together. The policy phase focuses on the optimal distribution of trips over modalities and routes. In the operational phase, the focus lies on the evaluation of operational traffic management scenarios based on real time data and “fast forward” simulation.



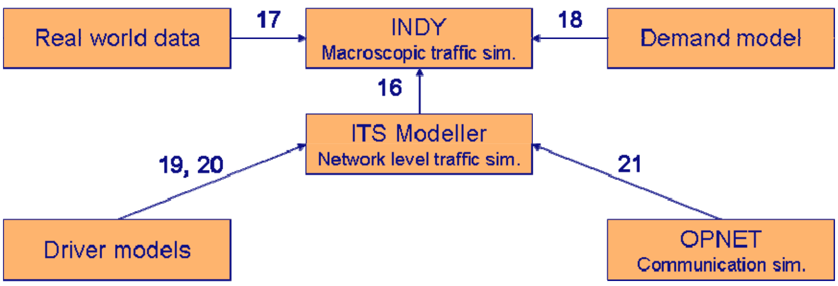
Connection	From	To	Type	Data exchange	Measures
		USE CASE 1: Mixed Reality Driver Assistant			
1	PreScan	ITS modeller	off-line model	vehicle model	
2	PreScan	ITS modeller	dynamic	vehicle state	speed, position, acceleration
3	ITS modeller	PreScan	off-line	traffic flow	speed-density relation, origin-destination matrix
4	Driving simulator	ITS modeller	off-line model	driver model	headways, gap-acceptance, speed choice, etc
5	ITS modeller	Driving simulator	off-line	traffic flow	speed-density relation, origin-destination matrix
6	Opnet	ITS modeller	off-line model	communication performance model	message loss, e2e-delay
7	ITS modeller	Opnet	off-line	traffic scenario	vehicle positions, communication equipment, traffic flow, messages
8	Opnet	PreScan	off-line model	communication performance model	message loss, e2e-delay
9	Opnet	PreScan	dynamic	messages	message loss, e2e-delay
10	PreScan	Opnet	off-line	hi-fi traffic scenarios	antenna direction, transmission power, message size + as nr. 7
11	PreScan	Opnet	dynamic	present vehicle state, messages	antenna direction, transmission power, message size + as nr. 7
12	PreScan	Driving simulator	real-time	virtual world scenario	present vehicle positions
13	Driving simulator	PreScan	off-line model	driver model	headways, gap-acceptance, speed choice, etc
14	Driving simulator	PreScan	real-time	driver actions	accelerations, pedal use, etc.
15	Real world/Video based monitoring	PreScan	off-line	vehicle state, weather data, traffic control scheme	speed, position, acceleration, traffic lights, …

Figure 1: connections for use case 1.

The research questions address issues such as optimization of planning, robustness, effects of traffic management measures and information services on the traffic flow, the impact of in-car ITS applications, incorporation of real data, and training of operators. These cases have a need for network level (or macroscopic) traffic simulation tool, which in an operational setting should run faster than real time. There is no need for a runtime coupling to the other simulation tools from the suite. In fact, for efficiency purposes, it is better not to create a coupling in this case, but rather use statistical models with the traffic simulator, also see, e.g., [9]. However, in order that the simulation is as realistic and reliable as possible, it is desirable that these models are based on, or generated by the more detailed tools in an offline fashion.

Connection	From	To	Type	Data exchange	Measures
USE CASE 2 & 3: evacuation, road works					
16	ITSmodeller	Indy	off-line	fundamental diagrams	speeds, intensities
17	Real world data/ThinOBU	Indy	off-line	real traffic flow	speeds, intensities
18	Demand model	Indy	off-line	traffic demand / modal split	origins and destinations
19	Driving simulator	ITSmodeller	off-line model	driver model for normal situations	headways, gap-acceptance, speed choice, etc
20	Driving simulator	ITSmodeller	off-line model	driver model for special situations (evacuation, road works)	headways, gap-acceptance, speed choice, etc
21	OPNET	ITS modeller	off-line model	communication performance model	message loss, e2e-delay

Figure 2 shows the connections that are identified for these cases.



Connection	From	To	Type	Data exchange	Measures
USE CASE 2 & 3: evacuation, road works					
16	ITSmodeller	Indy	off-line	fundamental diagrams	speeds, intensities
17	Real world data/ThinOBU	Indy	off-line	real traffic flow	speeds, intensities
18	Demand model	Indy	off-line	traffic demand / modal split	origins and destinations
19	Driving simulator	ITSmodeller	off-line model	driver model for normal situations	headways, gap-acceptance, speed choice, etc
20	Driving simulator	ITSmodeller	off-line model	driver model for special situations (evacuation, road works)	headways, gap-acceptance, speed choice, etc
21	OPNET	ITS modeller	off-line model	communication performance model	message loss, e2e-delay

Figure 2: connections for use case 2 & 3.

ARCHITECTURE

Figure 3 shows MOBYSIM information architecture, showing the tools and brief descriptions of some of the information flows between them. It also indicates the level of detail and the scale on which the tools typically operate.

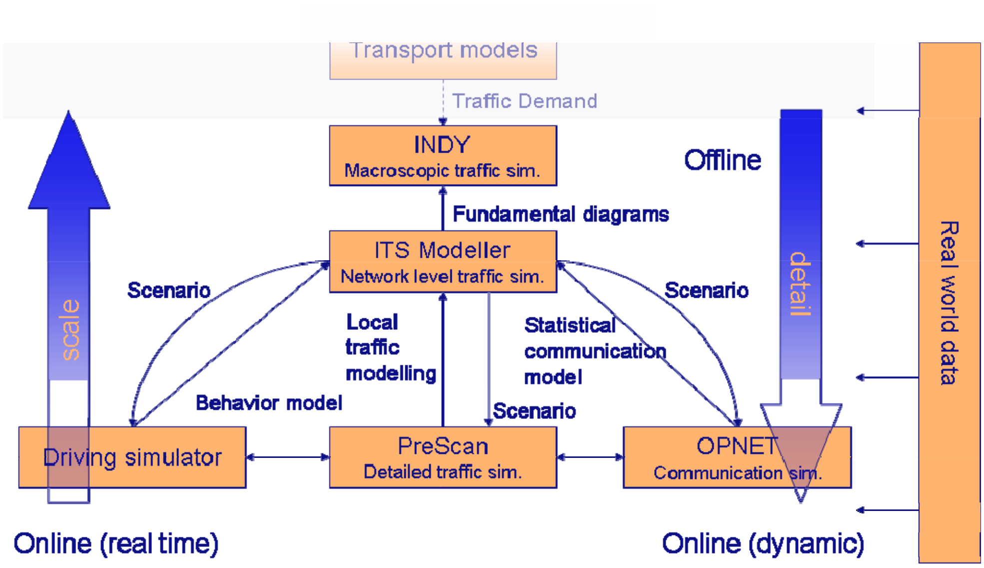


Figure 3: MOBYSIM information architecture

The analysis above has identified several types of connections:

1. Off-line data exchange between tools, that is, the output of one tool is used as input in another tool in order to improve its results or ensure consistency, but the tools are not dependent on each other and do not need to run simultaneously. This connection type can occur between all the tools, but is most common between the tools at the higher scale.
2. Model exchange between tools, that is, one tool generates a model for a certain aspect of traffic that can be used in another tool. This is also an offline connection, but of a different kind, as models are typically reused across different scenarios, whereas data exchange is typically limited to a specific scenario.
3. On-line data exchange between tools, that is, tools are dependent on each other and need to run simultaneously. A tool can finish its task only after receiving data from another tool. There are two subcategories, namely real-time (the tools have to run in real time) and dynamic (there is no speed requirement on the tools) connections. This type of connection typically occurs between the tools at the higher detail level.

Connection type 2 suggests the use of model libraries. These are filled by the tools that operate on the highest level of detail and by external sources, and can be used by all tools. The libraries act as plug-ins of the tools, which can be consulted by the simulation and will provide information on its specific area of expertise through a standardized interface. The advantage is improved reliability, consistency and ease of maintenance of the models, and improved efficiency of model development. In order to be useful, the library models have to be scalable to different levels of detail.

Five candidate model libraries have been identified:

1. Driver behavior model library, containing models that describe the behavior of drivers at various levels (strategic, tactical, operational) and in various circumstances (traffic situations, weather, ITS applications, etc), and depending on driver characteristics and driver state.
2. Communication performance model library, containing models that describe communication performance of various types of communication equipment in terms of

reliability and delay, under different traffic and environmental circumstances.
3. Application model library, containing models for ITS applications and their impact on vehicles and drivers.
4. Infrastructure model library, containing road network specifications, including roadside infrastructure and traffic demand.
5. Vehicle model library, containing models of the dynamics of various vehicle types.

For connection types 1 and 3, there are two possible structures: one-to-one data exchange where each connection between tools is created directly, or a structured data exchange where the tools connect to a middleware layer which provides connectivity between tools. While the first option is easiest to implement, the second provides more flexibility in the long run. The option currently under investigation is whether it is possible to conform both to TNO's internal MiReCol standard (which is of the second type) and the external standard that will be defined in PreDrive C2X.

CONCLUSIONS

Developments in traffic research and increasing complexity of societal issues involving traffic show the potential for a simulation platform that integrates various areas of expertise by combining simulation tools for traffic, behavior and communication. Integration involves consistency of scenarios between tools, model sharing between tools, and data exchange between tools. The following connections between TNO tools can be considered high priority:

- Offline connections between PreScan, OPNET one the one hand, and ITS Modeller on the other hand, for exchanging data on scenarios, traffic flows and traffic characteristics.
- Dynamic connection between PreScan and OPNET, for combined vehicle-driver and communications modeling.
- Real time connection between PreScan and the driving simulator, for combined traffic simulation and driving simulation.
- Model libraries for driver, communication, application, infrastructure and vehicle models, to be applicable in general, in the form of plug-ins.

REFERENCES

[1] M. Killat, F. Schmidt-Eisenlohr, G. Göbel, T. Kosch, H. Hartenstein, *On the accuracy of coupling a mobility and a communication simulator for VANETs*, In: Proceedings of the 4th International Workshop on Intelligent Transportation (WIT), pp. 137-142, Hamburg, Germany, 2007.

[2] SUMO project website, http://sumo.sourceforge.net/

[3] PreDrive project website, http://www.pre-drive-c2x.eu/

[4] T. Queck, B. Schuenemann, I. Radusch, *Runtime Infrastructure for Simulating Vehicle-2-X Communication Scenarios*. In: Proceedings of the Fifth ACM international Workshop on Vehicular inter-Networking, San Francisco (USA), 2008.

[5] Product information on various TNO tools, http://www.tno.nl/downloads/Intelligent driving 20082.pdf

[6] ITS Modeller product information, http://www.tno.nl/downloads/ITS modeller.pdf

[7] TNO driving simulators product information, www.tno.nl/downloads/DenV S080380 Driving Simulators.pdf

[8] PreScan product information, http://www.tno.nl/content.cfm?context=markten&content=product&laag1=59&laag2=354&item_id=1280&Taal=2

[9] M. Killat, F. Schmidt-Eisenlohr, H. Hartenstein, C. Rössel, P. Vortisch, S. Assenmacher, F. Busch, *Enabling efficient and accurate large-scale simulations of VANETs for vehicular traffic management*. In: Proceedings of the fourth ACM international workshop on Vehicular ad hoc networks