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User requirements and scenario definition

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Contents

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Executive Summary

This deliverable contributes to the project by defining the user requirements and scenario description.

Project and work package goals

SPEEDD will develop prototypes for proactive event-driven decision making and robust forecasting. The motivation for proactive computing stems from social and economic factors, and is based on the fact that prevention is often more active than cure. SPEEDD will contribute to the state of the art by:

1. Developing novel methods for real time event recognition and forecasting;
2. Providing innovative techniques for proactive event-driven decision-making;
3. Developing techniques for real-time visualization and explanation of large quantities of data.

WP8 – Proactive Traffic Management Use Case – aims to forecast traffic congestions before they happen and to make decisions in order to attenuate them. As a practical example, here the Grenoble case study is accurately defined with an analysis of users' requirements concerning traffic management, in the contest of innovative forecasting and proactive decision-making.

Work presented in the deliverable

The document consists of two parts:

1. Scenario description with respect to the Grenoble South Ring, availability of data and objectives related to this scenario. This first part is realized by the CNRS, with a contribution by ETH.

2. User requirements definition, a contribution of University of Birmingham (in collaboration with CNRS for the on-site visit to the operator centre), that analyzes the operators (users) activity in order to formalize the above-mentioned requirements.

This is the Amended version of deliverable D8.1. A first version was delivered on Month 6th of the project.. The modifications concern Section 2. A more complete description of data is presented in Section 2.2: Sect. 2.2.2 has been added, to describe simulator data. A new Section 2.3 gathers information about tools for decision making and action. Section 2.4, describing the objectives for this scenario, has been updated and improved.

How SPEEDD benefits from the work

As one of the first deliverables in the project, D8.1 defines the scenario which will be used through all the SPEEDD project as basis for the traffic use case, that involves WP3, WP4, WP5 (for the analysis of human operators), WP6 (for scalability and system integration), WP8.

Work to follow

Event forecasting under uncertainty (WP3) and decision-making (WP4)will take into account the scenario definition and users requirements, as well as the architecture design (WP6) to derive a scalable architecture for the design of the SPEEDD prototype. Also, the Cognitive Work Analysis of human operators will have impact on Real-Time Visual Analytics for Proactive Decision Support (WP5). Furthermore, this deliverable defines the ground for all the tasks in the WP8.

1. Introduction

1.1 History of the document

Version	Date	Author	Change Description
0.1	15/07/2014	C. Canudas de Wit, I. Bellicot, F. Garin, P. Grandinetti, A. Kibangou, F. Morbidi, M. Schmitt, A. Hempel, C. Baber, N. Cooke	Set up the document
0.2	28/07/2014	F. Garin, C. Baber	Content adjusted
1	30/07/2014	P.Grandinetti	Finalization
2	12/06/2015	P. Grandinetti A. Ladino R. Singhal F. Garin E. Lovisari	Content adjusted Update Sections 2.2 Added Section 2.3 Update Section 2.4
2.1	25/06/2015	A. Ladino P. Grandinetti F. Garin	Internal review comments incorporated

1.2 Purpose and scope of the document

Context

Transportation and traffic congestion are crucial aspects of human civilization, especially starting from the second half of the last century when the latter become predominant due to the rapid increase in the number of vehicles. Traffic congestion results in excess delays, reduced safety, and increased environmental pollution. Traffic analysis and forecasting, necessary for a good management of transportation systems, require the analysis of massive data streams storming from various sensors, and this brings further difficult tasks (mainly about real-time processing of big quantities, geographically distributed and noisy data).

The city of Grenoble plays a fundamental role in this context: the CNRS (Centre National de la Recherche Scientifique, a government-funded research organization, under the administrative authority of the French Ministry of Research) has access in real time to data from traffic sensors installed along a 12km highway stretch in Grenoble, thanks to the Grenoble Traffic Lab. Moreover, CNRS has an established collaboration with the local traffic authorities (DIR-CE operator centre).

Deliverable purpose

This document accurately describes the Grenoble study case, as a scenario for traffic analysis and forecasting. Extensive specifications of data format and sensors type are discussed, in order to allow integration in a high level system.

Furthermore, a Cognitive Work Analysis of traffic operator at DIR-CE is detailed, in order to provide users requirement to explore the impact of real-time proactive decision computation on human decision-making in large data applications.

1.3 Relationship with other documents

D8.1 is delivered at month sixth of the project, so it provides the basis for all the future works. Every deliverable regarding the traffic use case will be related to D8.1.

For scientific references, bibliographies are suggested at the end of the document.

2. Grenoble Scenario

2.1 Scenario description

In this chapter we describe the scenario for the traffic use case, regarding both the urban and the peri-urban networks.

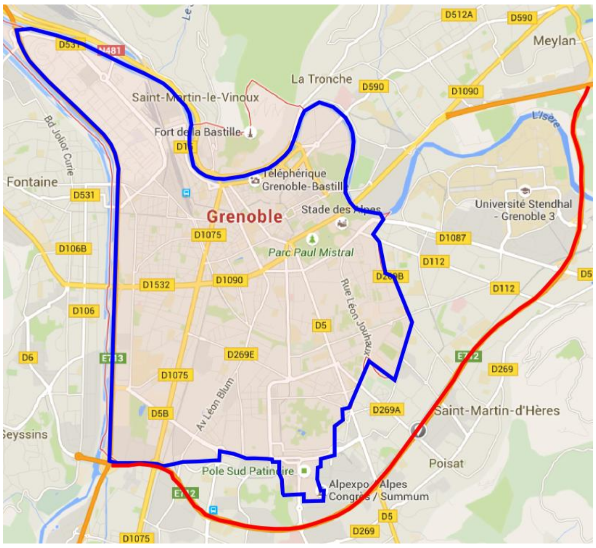


Figure 1 - Grenoble scenario

Grenoble South Ring

The road considered in this scenario is Grenoble South Ring (in red in the map in Fig. 1), that links the city of Grenoble from the south-west to the north-east. In addition to sustaining local traffic, this road has a major role, since it connects two highways: the A480, which goes from Paris and Lyon to Marseille, and the A41, which goes from Grenoble to Switzerland. Moreover, the mountains surrounding Grenoble prevent the development of new roads, and also have a negative impact on pollution dispersion, making the problem of traffic regulation on this road even more crucial.

Grenoble city

The city of Grenoble is located in the Isere Department and in the Rhone-Alpes region, of which is the third biggest in the Rhone-Alpes region (after Lyon and Saint-Etienne), and is placed at 45°11'16'' North and 5°43'37'' East, with an average altitude of 300 meters and an extension of 18, 13 Km2, with a population of around 160.000 habitants (and a density of 8.734 hab/Km2).

In this scenario we consider the Grenoble city as depicted in blue in Fig. 1.

2.2 Available data

There will be two sources of data: real data from sensors (available only for the South Ring), and synthetic data generated by a micro-simulator (for both South Ring and urban area).

2.2.1 Data from GTL (South Ring)

Data are provided by CNRS, thanks to GTL (Grenoble Traffic Lab, see (Canudas et al., 2015) and http://necs.inrialpes.fr/pages/grenoble-traffic-lab.php).
The real data come from 130 magnetic wireless Sensys sensors (7.4 cm x 7.4 cm x 4.9 cm, 0.3 kg) buried in the road (http://www.sensysnetworks.com/).

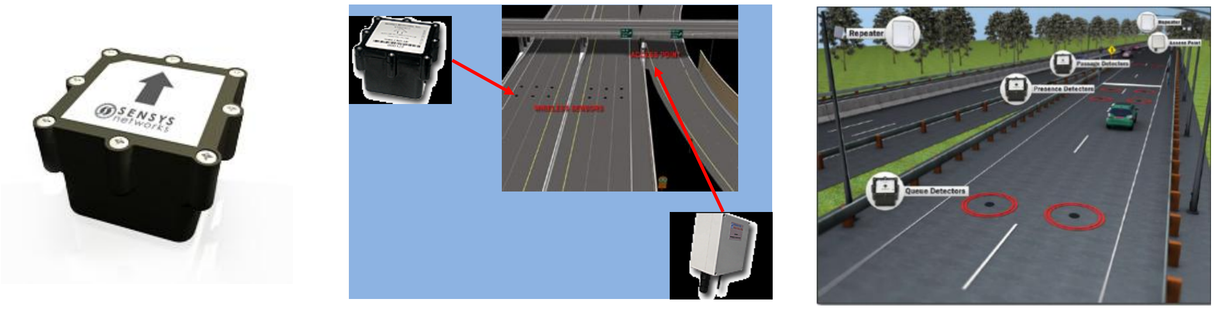
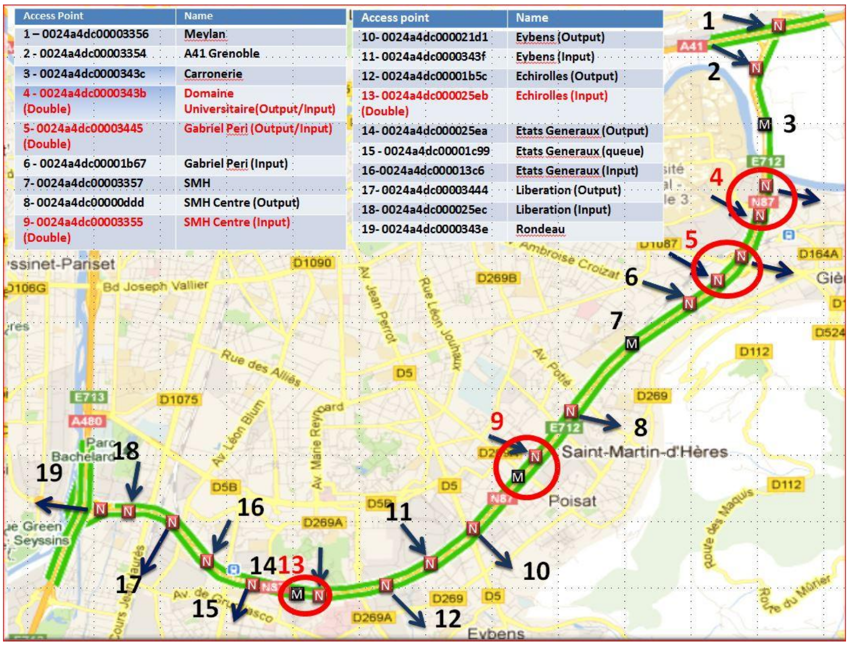


Figure 2 - Sensys sensor and its placement on the road (image courtesy: Sensys Networks)

Sensors are located in 19 collection points. Each collection point has a sensor per lane (slow and fast lane), and, where applicable (see Fig. 2), also has sensors on the on-/off-ramps.



Access Point	Name	Access point	Name
1 – 0024a4dc00003356	Meylan	10- 0024a4dc000021d1	Eybens (Output)
2 - 0024a4dc00003354	A41 Grenoble	11- 0024a4dc0000343f	Eybens (Input)
3 - 0024a4dc0000343c	Carronerie	12- 0024a4dc00001b5c	Echirolles (Output)
4 - 0024a4dc0000343b (Double)	Domaine Universitaire(Output/Input)	13- 0024a4dc000025eb (Double)	Echirolles (Input)
5- 0024a4dc00003445 (Double)	Gabriel Peri (Output/Input)	14- 0024a4dc000025ea	Etats Generaux (Output)
6 - 0024a4dc00001b67	Gabriel Peri (Input)	15 - 0024a4dc00001c99	Etats Generaux (queue)
7- 0024a4dc00003357	SMH	16-0024a4dc000013c6	Etats Generaux (Input)
8- 0024a4dc00000ddd	SMH Centre (Output)	17- 0024a4dc00003444	Liberation (Output)
9- 0024a4dc00003355 (Double)	SMH Centre (Input)	18- 0024a4dc000025ec	Liberation (Input)
		19- 0024a4dc0000343e	Rondeau

Figure 3 - Location of sensors' collection points

Data from sensors are collected at GTL in real time and stored in a database. More precisely, data are collected in real time by the sensors and sent every 15 seconds to GTL. The latency between their sending and their receiving is less than 6 seconds.

Such data can be either individual (concerning every single vehicle), or aggregated (over the 15-seconds time span); individual and aggregated data cannot be collected simultaneously. Individual data are available from Nov 2012 to Dec 2013 and aggregated data are available from Jan 2014 to current date. We will keep collecting the aggregated data.

Detailed description of data

Individual data:

Time stamp	Time when an event occurs
Sensor ID	Identifier of the sensor (collection point + lane)
Speed	Speed of the vehicle (km/h)
Counting (flow)	A new event per each vehicle passing above the sensor
Length	Length of the vehicle (meters)
Gap	Inter-vehicular time (seconds)

Individual data are created every time a vehicle is detected by a sensor, that is to say a vehicle goes where a sensor is located. Every 15 seconds, we receive one file per location containing n lines, where n is the number of vehicles that were counted. The velocity of each vehicle is then provided, as its length or the gap with the previous vehicle (more information below). Different times are given, corresponding to every single vehicle that was registered.

Aggregated data:

Time stamp	Every 15 seconds
Sensor ID	Identifier of the sensor (collection point + lane)
Speed	Average speed (km/h) + speed histogram
Counting (flow)	Number of vehicles in the 15-seconds interval
Length	Length histogram
Occupancy	Fraction of time that the cross-section of the sensor is occupied (%)

Aggregated data are sent to us in a file that summarizes events for every access point. Every 15 seconds, we receive one file per location containing one line giving the total number of vehicles, the average speed, and the occupancy of every sensor. One single time is given, corresponding to the time the file was sent to us (i.e., when summary was done).

Data quality

Concerning data availability, there is an issue of missing data. There can be both occasional missing data (packet loss in transmission towards GTL server), and more extended losses at the same location

for a relevant time span (hours, days, or weeks) due to the breakdown of a sensor or of an access point, either in a planned way (as in June-July 2014 for road maintenance works) or due to accidents that need human intervention for repair.
Concerning accuracy, Sensys data are reported to have an error of around 1% (see http:/www.sensysnetworks.com/white-papers), on real test beds but in somewhat ideal conditions of sensor calibration and traffic conditions. Grenoble Traffic Lab has been monitoring quality of its data, finding a precision of 4% or better in normal operation of the sensors. However, some significant exceptions have happened, with some sensors temporarily having a very high error, due to various reasons and accidents.

The databases

We have 2 different databases depending of the data we receive. The structures of these databases are the following:

Individual database

- date, format YYYY-MM-DD
- time, format hh:mm:ss GMT
- location, which is represented by the identity of the access point collecting data
- lane, whose value match the kind of lane the sensor is installed in: slow (lane), fast (lane), on-ramp (entry), offramp (exit), etc.
- speed, in kilometers per hour
- length of the vehicle,
- gap, which is the time in seconds between 2 vehicles

Aggregated database

- date, format YYYY-MM-DD
- time, format hh:mm:ss GMT
- location, which is represented by the id of the access point collecting data
- lane, whose value match the kind of lane the sensor is installed in: slow (lane), fast (lane), on-ramp (entry), offramp (exit), etc.
- occupancy, that is the percentage of time the sensor had vehicle above itself
- vehicles, the number of vehicles that were counted by a sensor during the last 15 seconds
- speed, in kilometers per hour
- histogram of speeds: 20 bins of 10 kilometers per hour each (0-10, 10-20, …, 190-200)
- histogram of lengths: 100 bins of 0.5 meters each (0-0.5, 0.5-1, 1-1.5, …, 49.5-50)

Data file examples

Individual data

date, time, location, lane, speed, length, gap

2013-06-19, 07:58:24, 0024a4dc00003354, onramp, 62.2, 5.2, 10.02

2013-06-19, 07:58:18, 0024a4dc00003354, fast, 90.0, 5.7, 4.66

2013-06-19, 07:58:26, 0024a4dc00003354, onramp, 48.6, 7.8, 1.89

Remarks:
1) one line = one vehicle.
2) time is the actual time a vehicle was detected.

Aggregated data

| date , time , location , lane , occupancy , vehicles , median_speed , average_speed , speed_0_10 , … , speed_190_200 , length_0_50 , … , length_4950_5000

2014-03-01, 12:02:00, 0024a4dc00003354, slow, 2.94, 2, NULL

82.0, 0 ,…, 0, 0, … , 0

2014-03-01, 12:02:00, 0024a4dc00003354, fast, 0.00, 0, NULL

-1.0, 0,…, 0, 0, … , 0

Remarks:

1) if no speed was computed during the 15 seconds (because there was no vehicle for example), the value returned is -1.
2) median_speed may not be provided (value is then NULL).
3) time is always a multiple of 15 seconds.
4) speed_0_10 represents the number of vehicles whose speed is between 0 and 10 km/h; length_0_50 represents the number of vehicles whose length is between 0 and 50 cm.

The locations

Sensors and Access points

Data created by the sensors are collected by access points. Sensors are magnetic. Transmission between sensors and access points is done through Wifi. Data are then sent to Inria via optic fiber or GPRS (radio) network.

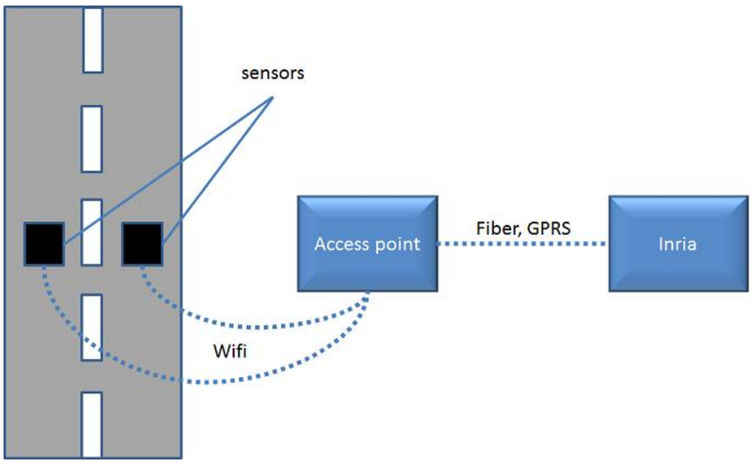


Figure 4 - From sensors to INRIA

Locations of the access points

19 access points are located along the south ring. They are referenced by their id: 0024a4dc00003356, 0024a4dc00003354, 0024a4dc0000343c, 0024a4dc0000343b, 0024a4dc00003445, 0024a4dc00001b67, 0024a4dc00003357, 0024a4dc00000ddd, 0024a4dc00003355, 0024a4dc000021d1, 0024a4dc0000343f, 0024a4dc00001b5c, 0024a4dc000025eb, 0024a4dc000025ea, 0024a4dc00001c99, 0024a4dc000013c6, 0024a4dc00003444, 0024a4dc000025ec and 0024a4dc0000343e.

The figure below shows their positions.

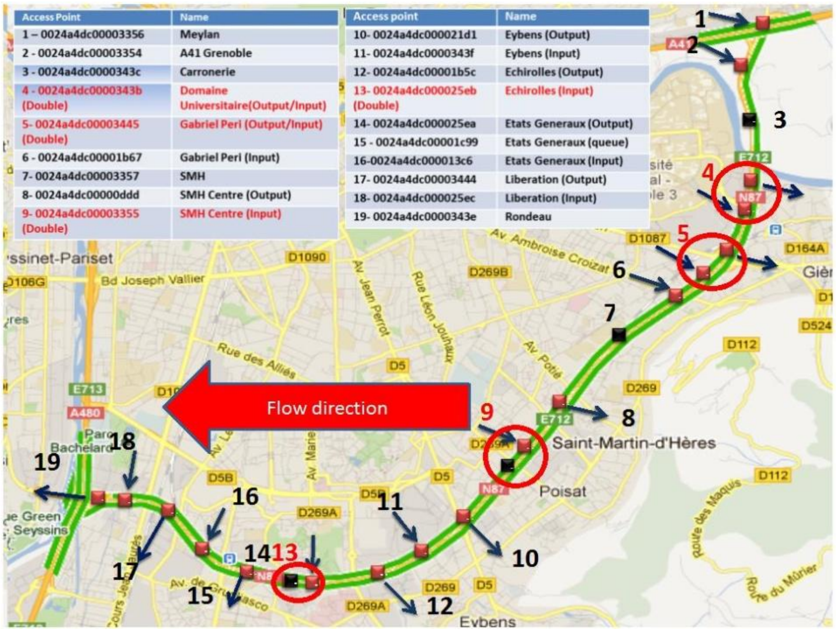


Figure 5 - Location of the access points

A sensor can be retrieved thanks to the couple (access point, lane). Each group of sensor is described below. You will find in particular its coordinates and the kind of lanes linked to it.

flow direction : from 0024a4dc00003356 to 0024a4dc0000343e				
location	lane	coordinates		number in Powerpoint
0024a4dc00003356	slow	45.205348	5.783643	1
0024a4dc00003356	fast	45.205327	5.783690	1
0024a4dc00003356	onramp	45.205385	5.783560	1
0024a4dc00003354	slow	45.201891	5.781650	2
0024a4dc00003354	fast	45.201881	5.781696	2
0024a4dc00003354	onramp	45.201900	5.781605	2
0024a4dc0000343c	slow	45.195015	5.781893	3
0024a4dc0000343c	fast	45.195020	5.781947	3
0024a4dc0000343b	onramp	45.188033	5.781614	4
0024a4dc0000343b	offramp	45.189538	5.781835	4
0024a4dc0000343b	slow_entry	45.189536	5.781912	4
0024a4dc0000343b	fast_entry	45.189538	5.781956	4
0024a4dc0000343b	slow_exit	45.188022	5.781756	4
0024a4dc0000343b	fast_exit	45.188018	5.781806	4
0024a4dc00003445	onramp	45.182490	5.778956	5
0024a4dc00003445	offramp	45.183515	5.779847	5
0024a4dc00003445	slow_entry	45.182446	5.779049	5
0024a4dc00003445	fast_entry	45.182434	5.779082	5
0024a4dc00003445	slow_exit	45.183500	5.779890	5
0024a4dc00003445	fast_exit	45.183487	5.779938	5
0024a4dc00001b67	slow	45.181012	5.777537	6
0024a4dc00001b67	fast	45.180982	5.777604	6
0024a4dc00001b67	onramp	45.181040	5.777474	6
0024a4dc00001b67	middle	45.181001	5.777569	6
0024a4dc00003357	slow	45.176403	5.769505	7
0024a4dc00003357	fast	45.176375	5.769542	7
0024a4dc00000ddd	slow	45.167742	5.759076	8
0024a4dc00000ddd	fast	45.167727	5.759121	8
0024a4dc00000ddd	offramp	45.167782	5.758982	8
0024a4dc00000ddd	queue	45.166233	5.757410	8
0024a4dc00003355	slow	45.163850	5.755315	9
0024a4dc00003355	fast	45.163826	5.755355	9
0024a4dc00003355	onramp	45.163866	5.755275	9
0024a4dc00003355	slow_bis	45.162428	5.753762	9
0024a4dc00003355	fast_bis	45.162407	5.753808	10
0024a4dc000021d1	slow	45.157527	5.748489	10

location	Lane	Coordinates		Number in Powerpoint
0024a4dc000021d1	fast	45.157510	5.748524	10
0024a4dc000021d1	offramp	45.157567	5.748415	10
0024a4dc000021d1	queue	45.156224	5.746456	10
0024a4dc0000343f	slow	45.154415	5.744285	11
0024a4dc0000343f	fast	45.154393	5.744317	11
0024a4dc0000343f	onramp	45.154437	5.744254	11
0024a4dc00001b5c	slow	45.151581	5.737079	12
0024a4dc00001b5c	fast	45.151549	5.737100	12
0024a4dc00001b5c	offramp	45.151638	5.737041	12
0024a4dc00001b5c	queue-right	45.150953	5.733072	12
0024a4dc00001b5c	queue-left	45.150985	5.733065	12
0024a4dc000025eb	slow	45.150713	5.730067	13
0024a4dc000025eb	fast	45.150681	5.730072	13
0024a4dc000025eb	onramp	45.150762	5.730067	13
0024a4dc000025eb	slow_bis	45.150862	5.726683	13
0024a4dc000025eb	fast_bis	45.150830	5.726680	14
0024a4dc000025ea	slow	45.151679	5.721838	14
0024a4dc000025ea	fast	45.151649	5.721822	14
0024a4dc000025ea	offramp	45.151710	5.721857	14
0024a4dc00001c99	queue	45.152829	5.717611	15
0024a4dc000013c6	slow	45.153981	5.715648	16
0024a4dc000013c6	fast	45.153970	5.715600	16
0024a4dc000013c6	onramp	45.153985	5.715696	16
0024a4dc00003444	slow	45.157273	5.712295	17
0024a4dc00003444	fast	45.157303	5.712343	17
0024a4dc00003444	offramp	45.157333	5.712402	17
0024a4dc000025ec	slow	45.158759	5.707607	18
0024a4dc000025ec	fast	45.158721	5.707607	18
0024a4dc000025ec	onramp	45.158797	5.707607	18
0024a4dc0000343e	middle	45.158677	5.703829	19
0024a4dc0000343e	right	45.158759	5.703827	19
0024a4dc0000343e	left	45.158638	5.703829	19

Closer look on some access points

Each lane has a value among slow, fast, onramp, offramp, middle, slow_bis, fast_bis, right, left, slow_entry, fast_entry, slow_exit , fast_exit, queue, queue-right, queue-left. In order to facilitate the reading, names will be shortened from 0024a4dc000013c6 to 13c6 (0024a4dc0000- is a common radical for all names). This section will provide examples of each of them, thanks to a more detailed description of some access points: 343b, 3445 and 1b67, 3357, 1b67, 3355, 21d1, 25ec and 343e (see Figure 6).

To follow, some explicative figures.

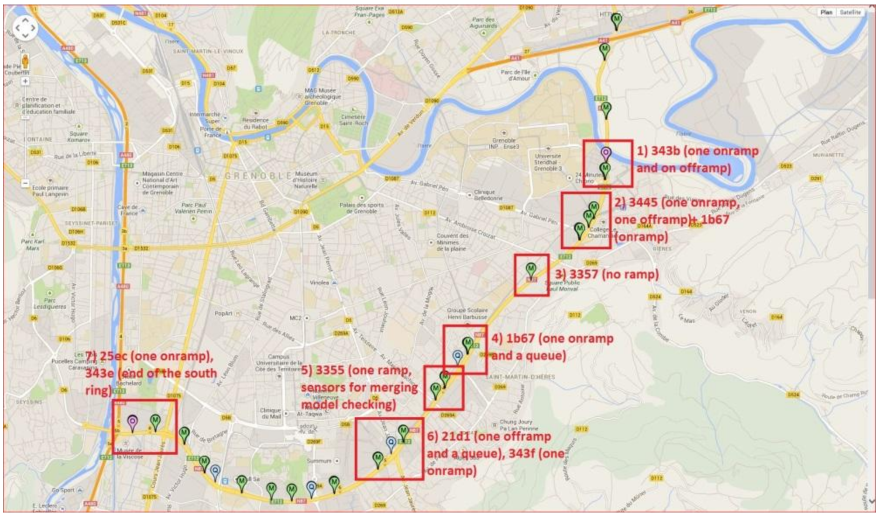


Figure 6 - The whole south ring

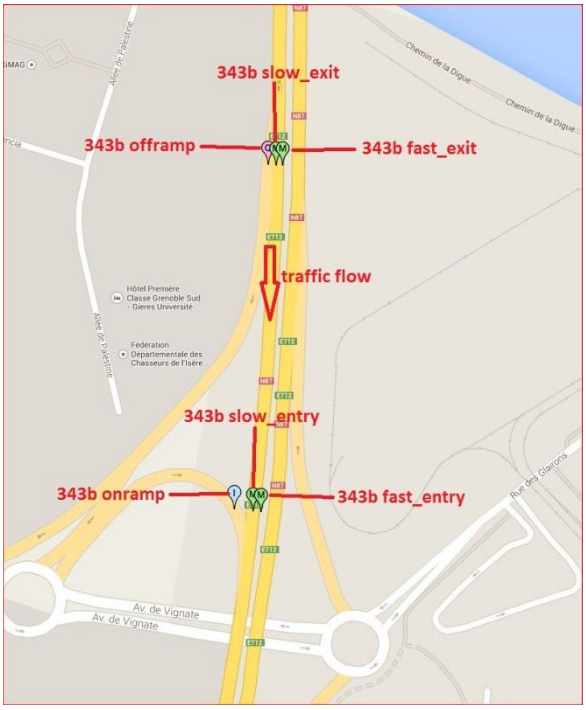


Figure 7 - Access point 343b

343b collects data from an offramp and the following onramp.

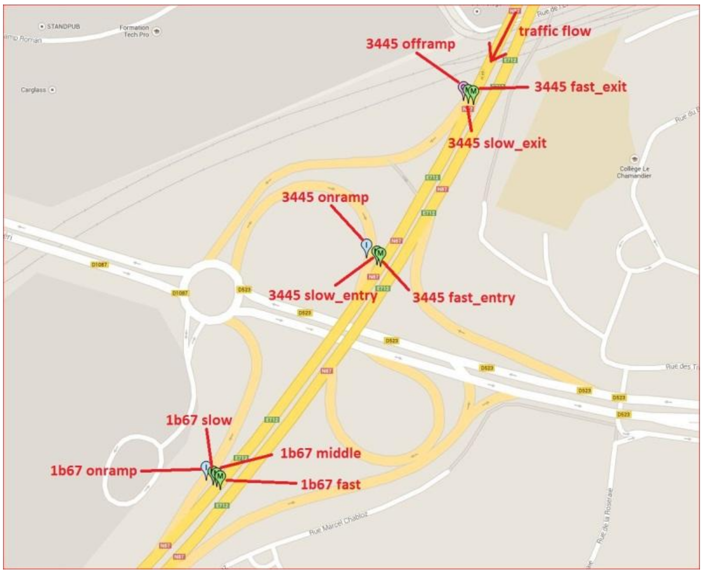


Figure 8 - Access points 3445 and 1b67

3445 collects an onramp and an offramp points. 1b67 has 4 lanes: fast, slow, middle and onramp.

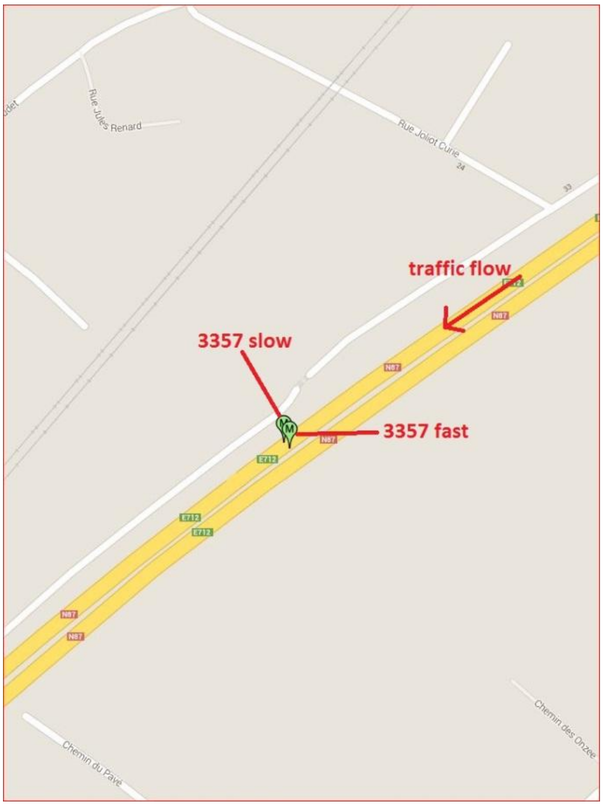


Figure 9 - Access point 3357

This access point has no ramp.

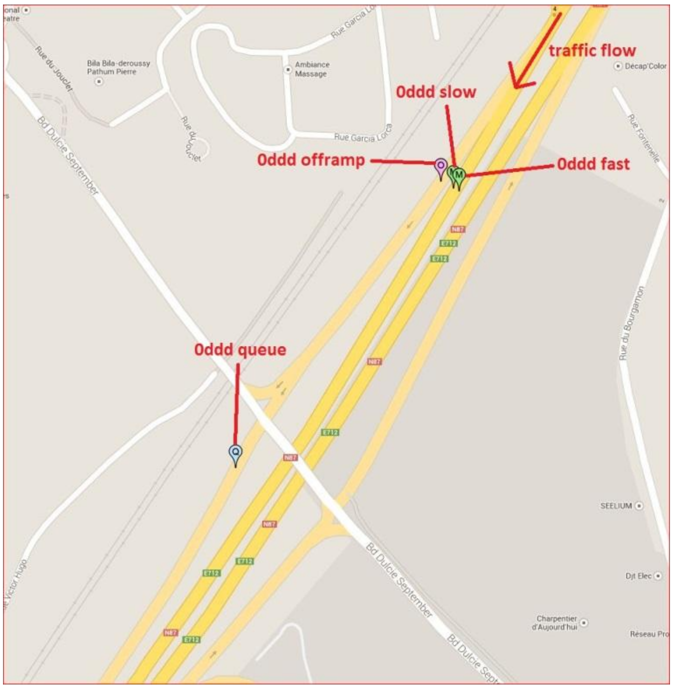


Figure 10 - Access point Oddd

This access point has a queue sensor. This sensor helps us compute the number of vehicles waiting to enter the south ring when ramp meterings are used to control input flows.

Figure 11 - Access point 3355

This access point has 5 sensors. 3355 slow_bis and 3355 fast_bis are used to check our merging models of flows coming from the main road and from the onramp.

Figure 12 - Access points 21d1 and 343f

Figure 13 - Access points 25ec and 343e

343e is located at the very end of the south ring. It has 3 lanes: left, middle and right.

2.2.2 Data from micro-simulator for South Ring and urban area

The simulator used for generating synthetic traffic data is the commercial micro-simulator by Aimsun (http://www.aimsun.com/wp/). The simulator for South ring has been calibrated using real traffic data from Grenoble South Ring (see the fig.14) and simulator for Grenoble town has been calibrated using real life experience and local information from traffic authorities. We have real data for Grenoble South Ring and simulated data for both South Ring and town. More detailed information about simulation of south ring and Grenoble town and data from AIMSUN can be found in deliverable (D8.2) and the simulator for full Grenoble city is due the 24th month, and will be detailed in deliverable (D8.4).

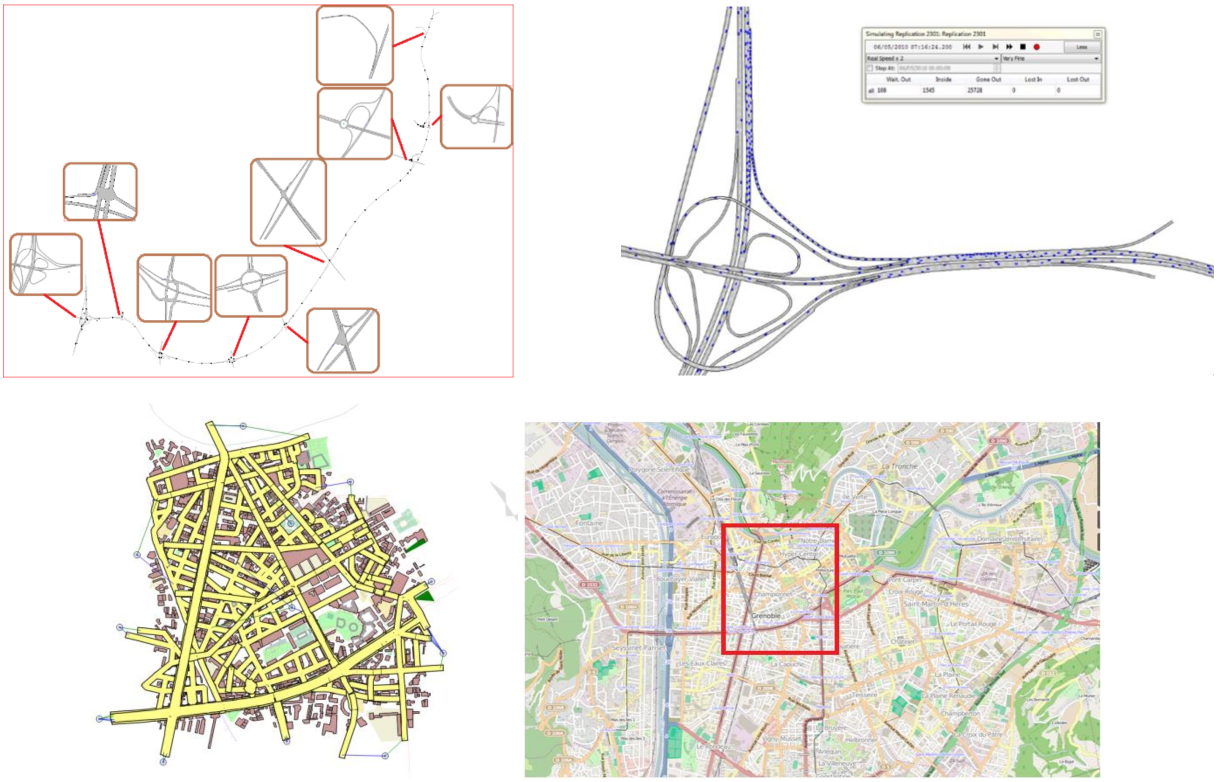


Figure 14 - Aimsun / Grenoble City

The figure above shows the different simulation map for south ring and part of Grenoble which shows the first version of simulator(D8.2) and final version of simulator will be extended to full Grenoble city map in upcoming deliverable(D8.4), the format of data will remain same for both the map of the simulator.

Data produced by the micro-simulator are in the following form:

- **Simulator sensors:** Same data as real sensors on Rocade (at given locations: speed, occupancy, number of vehicles)
- **Floating car data**: traces of individual vehicles (position or speed)
- **Statistical information of the whole system:** density, flow, delay time, speed, travel time, number of vehicles inside the network
- **Meta-data:** pollutant emission, fuel consumption, total travel time, total travel distance

The exported data can be loaded into Matlab by partners using the Matlab's *csvread* function or it can be easily processed using the SQLite module of Matlab or alternatively using *sqlitebrowser* (http://sourceforge.net/projects/sqlitebrowser).

The table below shows the output data exported from AIMSUN for the virtual sensors placed in the simulator, representing a sensor placed in the road, similar to the real sensors that Grenoble Traffic Lab has on the South Ring. Virtual sensor can produce a range of data from simulation, but for project purpose, we are mainly concerned to these attributes: vehicle count (column "countveh"), occupancy, density, headway, etc. The suffix "D" for each field shows the Standard deviation for that particular field. This table also gives a list of sensors names (column "eid") and types of vehicles (column "sid") used in the simulation. Several type of environments can be created within AIMSUN according to the type of vehicles: both regular small size vehicles and trucks, only small size vehicles or only trucks. Column "ent" is for time intervals: it contains an integer from 1 to N, where N is the number of elapsed time intervals at the end of the simulation; the duration of an interval can be set manually through AIMSUN interface, and the default value to be used in this project will be 15 seconds. A special value of 0 in the column "ent" denotes that data, instead of corresponding to a particular time interval, are an aggregated average over all time intervals of the simulation.

1	did	oid	eid	sid	ent	countv	countv	flow	flow_D	speed	speed_D	occupancy	occupancy	density	density_D	headway	headway_D
2	12079	12700	Sensor-2	0	1	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
3	12079	12701	Sensor-3	0	1	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
4	12079	12703	Sensor-1	0	1	1	-1	240	-1	55.41582	-1	3.525961	-1	4.273908	-1	-1	-1
5	12079	12700	Sensor-2	1	1	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
6	12079	12701	Sensor-3	1	1	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
7	12079	12703	Sensor-1	1	1	1	-1	240	-1	55.41582	-1	3.525961	-1	4.273908	-1	-1	-1
8	12079	12700	Sensor-2	2	1	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
9	12079	12701	Sensor-3	2	1	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
10	12079	12703	Sensor-1	2	1	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
11	12079	12700	Sensor-2	0	2	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
12	12079	12701	Sensor-3	0	2	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
13	12079	12703	Sensor-1	0	2	3	-1	720	-1	53.8901	-1	10.69514	-1	12.33688	-1	4.414449	-1
14	12079	12700	Sensor-2	1	2	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
15	12079	12701	Sensor-3	1	2	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
16	12079	12703	Sensor-1	1	2	3	-1	720	-1	53.8901	-1	10.69514	-1	12.33688	-1	4.414449	-1
17	12079	12700	Sensor-2	2	2	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
18	12079	12701	Sensor-3	2	2	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
19	12079	12703	Sensor-1	2	2	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
20	12079	12700	Sensor-2	0	3	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
21	12079	12701	Sensor-3	0	3	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
22	12079	12703	Sensor-1	0	3	2	-1	480	-1	54.25145	-1	7.180911	-1	8.736336	-1	2.951555	-1
23	12079	12700	Sensor-2	1	3	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
24	12079	12701	Sensor-3	1	3	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
25	12079	12703	Sensor-1	1	3	2	-1	480	-1	54.25145	-1	7.180911	-1	8.736336	-1	2.951555	-1
26	12079	12700	Sensor-2	2	3	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
27	12079	12701	Sensor-3	2	3	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
28	12079	12703	Sensor-1	2	3	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
29	12079	12700	Sensor-2	0	4	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1
30	12079	12701	Sensor-3	0	4	3	-1	720	-1	56.91246	-1	11.08334	-1	12.99711	-1	0.779375	-1
31	12079	12703	Sensor-1	0	4	4	-1	960	-1	52.87468	-1	14.3734	-1	16.89318	-1	3.280399	-1

Figure 15 - Data from Aimsun

Actuators

Actuators are traffic lights and variable speed limits. In the South Ring, traffic lights have been added in the simulator on some on-ramps (those corresponding to a sufficient space for accumulating a queue of vehicles), so that ramp-metering control can be implemented.

In the urban area traffic Lights are the most prominent type of actuator. They have been placed in the network of Grenoble town in AIMSUN according to the real location of traffic lights in the town. In AIMSUN, actuators are working according to their respective signal groups. A signal group is the set of turn movements that have right to pass intersection when a given traffic light turns green. A phase-based approach is applied, in which the cycle of the junction is divided into phases, each one activating a particular set of signal groups.

Urban and South Ring (simulated) sensors

In the South Ring simulator, data are generated such that demand profiles are consistent with reality. Virtual sensors are placed respecting the locations of real sensors from GTL, with the exception of 7 additional sensors at the beginning of each metered onramp. These are currently not present on the real freeway since they are useful only in the context of ramp metering for measuring the length of the queue on the on ramps, and ramp metering is not implemented yet.

In the simulated urban city sensors are placed at the beginning and the end of every section of interest, as shown by the following figure.

Figure 16 - Urban (simulated) sensors

In this way the number of vehicles inside the section, denoted it N, (and hence the density) can be computed by a first order equation:

$$N(t + T_s) = N(t) + Veh_{in} - Veh_{out}$$

Where t is the current time instant, T_s is the sampling time, Veh_{in} and Veh_{out} are the number of vehicles entered and exited the section during the last sampling period.

2.2.3 Manual annotations from traffic operators (South Ring only)

Records of manual annotations from the traffic operators are stored at DIR-CE traffic control center. It has been possible to access these data for the project, although not in an automated manner, and hence not too often. These data are courtesy of DIR-CE's staff, who is not committed in any way to provide them.
The file that is provided to us is a .ods file (Open Document Spreadsheet), reporting all events reported on the Grenoble South Ring in a given period of time, e.g., some months. Every line in the file corresponds to an event, and has been created as described below.

Events are created manually by an operator. Most of the detection is done visually. Once an event is detected, the operator chooses the kind of event, which is reported in the filed description:

- Accident
- Bouchon = congestion
- Obstacles et incidents
- Travaux = works
- Pollution = high level of pollution has been officially declared, and speed limit reduced to 70 km/h (otherwise and in normal conditions, speed limit is always 90 km/h).

The operator also manually fills the localization (localization) and a line is added to the file. Time of creation is also filled (date de début).

When the event is over, the operator closes the event. The state (état) is then closed, the time of closure (date de fin) is filled.

Sens indicates the flow direction; we only consider annotations where sens=2, indicating the east-west direction corresponding to our scenario.

The localization code can be read as follows. The first item is the codename of the southring (RN87). The following item gives the position of the event. PR is a milestone on the highway. PR0 is located on Le Rondeau, PR11 is located in Meylan. PR0 + 500 means 500 meters after the PR milestone.

In addition to manual annotations, some further annotations could be generated using real data and numerical thresholds, or other well-established detection patterns; these annotations could then be used for training and/or testing algorithms for the challenging objective to forecast events.

Concerning the simulator, all simulated data will be associated with a description of the corresponding simulation conditions, including precise information about possible accidents or other events having been simulated.

2.3. Tools

2.3.1. Showroom

For the decision-support actions, a new interface will need to be developed, allowing for human-in-the-loop operation mode. This new interface will leverage the existing GTL show-room, an office in which demos can be offered for the public. An additional interface will be added, to allow humans to interact with the simulation.

Figure 17 - GTL showroom

2.3.2 APIs

While AIMSUN has in-built tools for exporting data, the interaction required to see in real time the effect of decision making requires new APIs. One is being developed within the SPEEDD project, and concerns SPEEDD prototype, while the other has been developed by CNRS and concerns Matlab, thus allowing for easy test of control algorithms. The alternative to the latter is to directly implement the algorithms in Aimsun as scripts (Python or C++).

Communication between simulator and integrated prototype

An API to communicate between AIMSUN and SPEEDD components has been developed in order to send data from AIMSUN to SPEEDD architecture; the API from SPEEDD architecture to AIMSUN is being developed. Both APIs will be delivered as part of the final version of simulator (D8.3). The KAFKA message streaming systems is the technology we have chosen to transfer data between SPEEDD component and AIMSUN (for further details see deliverable on integrated prototype D6.1 and D6.3). Using this API, we will be able to do two types of action control in AIMSUN:

1. Control the traffic light phases
2. Control the Speed limit of each section

The detailed interface architecture of above API is shown below:

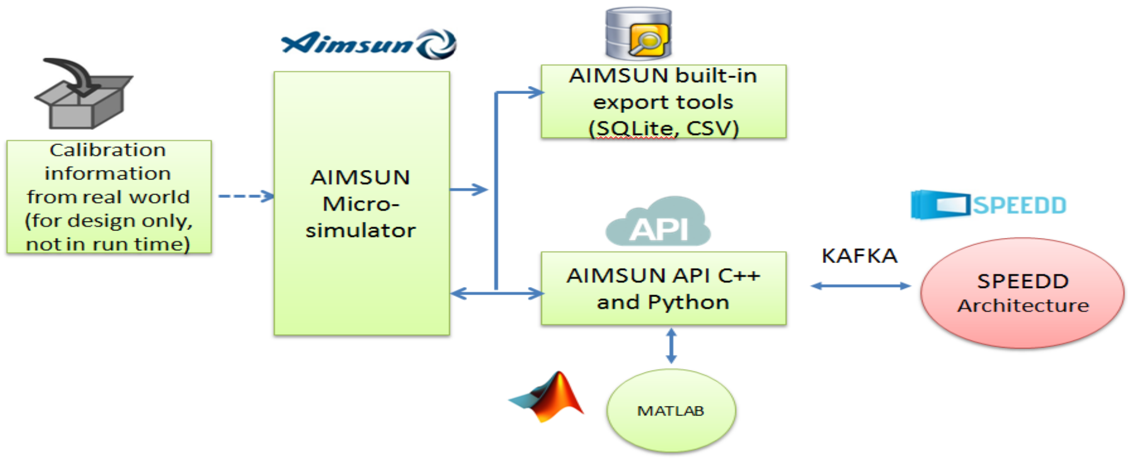


Figure 18 - Aimsun/SPEEDD interface

API Matlab to Aimsun

An API to Matlab has been developed by CNRS, so that new control algorithms can be easily tested in the Aimsun programming environment.
The interface comes in two parts

1. A library, used by Aimsun
2. A set of Matlab scripts

Library and scripts communicate as pictured below:

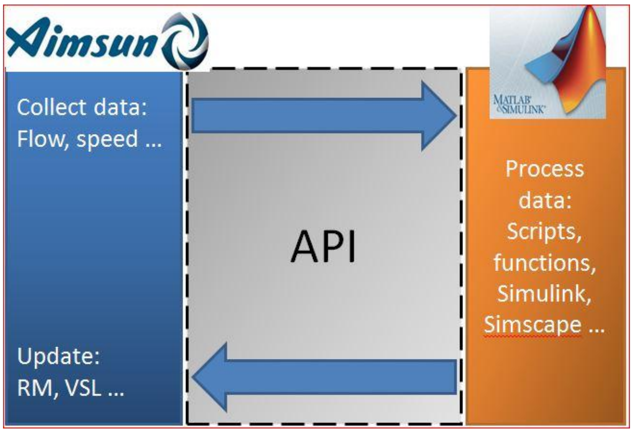


Figure 19 - MatLab2Aimsun API

Technical description

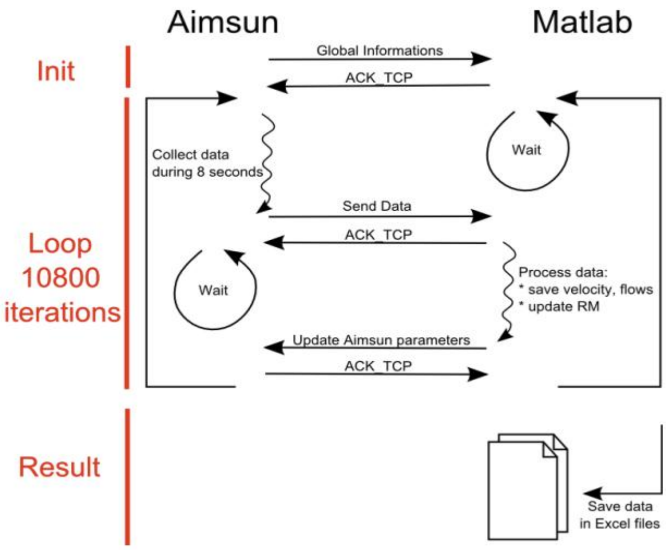


Figure 20 - Description of the MatLab2Aimsun API

Messages are exchanged through TCP protocol, in order to synchronize them without using too much CPU. Figure 20 gives brief information about exchange process between AIMSUN and Matlab.

Initialization: AIMSUN sends global variables to Matlab: number of sensors, their ID, the number of iterations, time step duration, etc.

Result: data are saved in Excel files. Currently only flows and velocity have been computed.

2.4. Objectives related to this scenario

Given the above-described set of data, the objectives will be to detect, forecast, give suggestions to users and operators, and control, as it will be described in detail below.

- Detection: Congestions, incidents, emissions peaks.
- Forecast: Evolution of traffic state, travel time, speeds, congestion.
- Decide: Compute optimal speed limits, traffic signals and ramp metering.
- Act: Apply changes to the aforementioned variables.

The following sections explain in detail the problem and challenges in each situation.

2.4.1 Detection and Forecast

The aim of detection is to perceive the existence of events when they occur by extrapolating information in real-time data. Detection of an event is regularly performed in real time, based on actual measured or simulated conditions of the traffic network. On the other hand, forecast provides information about the future occurrence of an event. Historical data and real time data combined support this task to provide an outcome that suggests the existence of future events. Some events can be detected and forecasted; others can just be detected.

For all forecasted events, it should be taken into account that, if control decisions are made based on the predicted events, then the system will behave differently from the forecasted evolution (e.g. if a forecasted congestion triggers adjustment of ramp metering rates, this might prevent the congestion altogether).

The following sections will provide more information on these events.

Congestion

Congestion can be defined as a situation when traffic is moving at speed below the designed capacity of a roadway (Downs, 2004) or as state of traffic flow on a transportation facility characterized by high densities and low speeds, relative to some chosen reference state (Bovy and Salomon, 2002).

Detection of congestions will be based on information received from the sensors. Special behaviors of variables that describe the system such as speed, density, occupancy allow to infer the existence of congestion. In particular, the complex event processing (CEP) module in the envisaged SPEEDD prototype uses the information received by the sensors in real-time and forecasts congestion events with some probability.

Forecasting of congestions can also be performed for regular bottlenecks identified to be recurrent in particular hotspots. The forecast makes use of historical and present data, in order to predict occurrence and/or qualify levels of intensity of events, and to predict traffic-related quantities. Alternatively, model based techniques or combination between historical information and model based approaches can also be used to forecast.

Congestion in Grenoble South Ring

Effect of the congestion is observed in direct measurements provided by sensors, in particular the increment of occupancy and reduction of speed are the most notorious effects. Detection of this event is not a task that can be performed instantaneously. For this it is required to examine a window of time and detect particular threshold values of patterns that yield congestion regimes as seen in Figure 21.

The typical observed measurements suggest the existence of rush hours broadly classified in two times during the work-day. During morning, congestion initiates around 7:30 am and regularly finishes before 10:00 am. During the afternoon typical congestions occur in between 4:30 pm – 7:00 pm. Starting and duration are parameters that depend on the flow entering the South Ring.

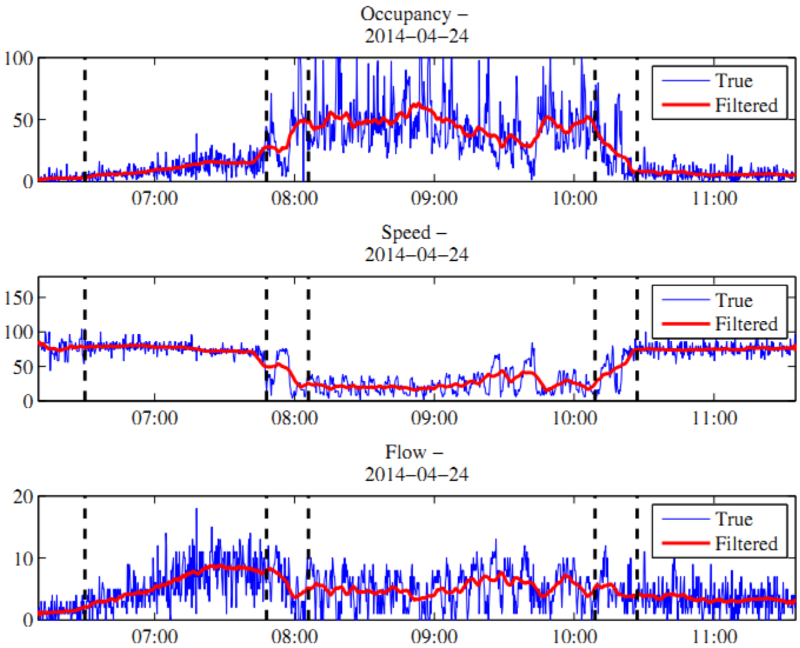


Figure 21 - Example of variable change during congestion phase

Particular locations along the highway are hotspots for congestion. Typical congestions are mainly observed at two locations. The first hotspot starts in Rondeau and finishes around États généraux. The second starts around Eybens and finishes around Carronerie. Once congestion is triggered in a particular hotspot the effect spills back in space, therefore permanent monitoring of the measurement in different locations can be executed in order to detect the spatial effect.

Figure 22 - Typical congestion hotspot

The following two figures show an example of visualization of patterns that can be used for detection purpose. They show a space vs. time plot: space on the horizontal axis, with traffic flowing from left to right, and time in hours on the vertical axis, from bottom to top. Both figures show congestions (low-speed, in red color). However, the patterns are quite different: in the first figure congestion appears suddenly due to an accident (detected between around 8:30am between Meylan and Carronerie), while the second figure shows a usual congestion, which propagates up-stream.

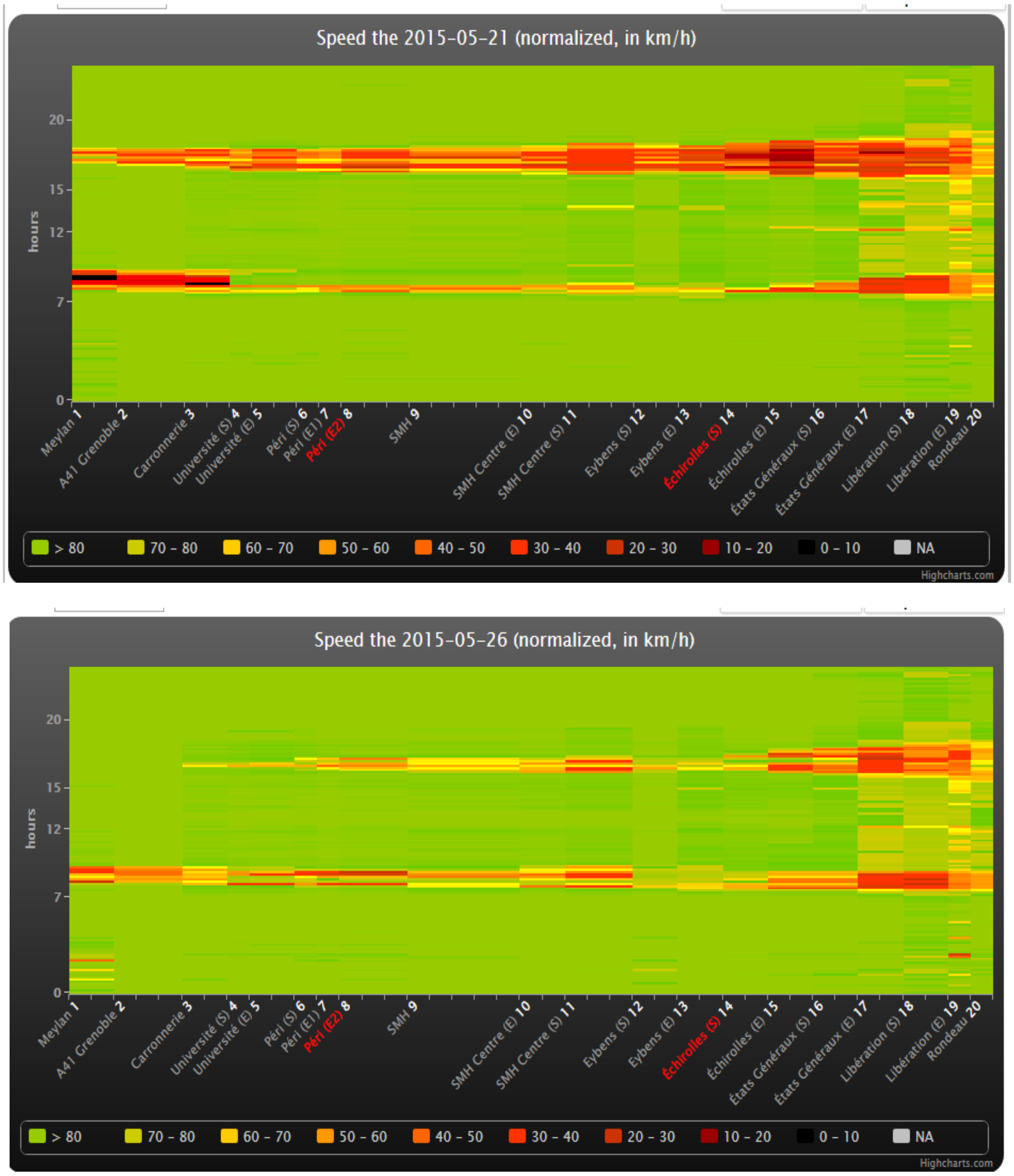


Figure 23 - Examples of speed visualization

Congestion Urban Traffic Case

The features of bottlenecks in urban traffic networks are more complex than in the freeway case. In general, perception from the driver's point of view is increment of travel time (time between origin and destination in the network) and low speed. In a macroscopic model perspective, the effect of the congestion is seen in augmentation of the number of vehicles within a specific road, and a corresponding reduction of the average speed.

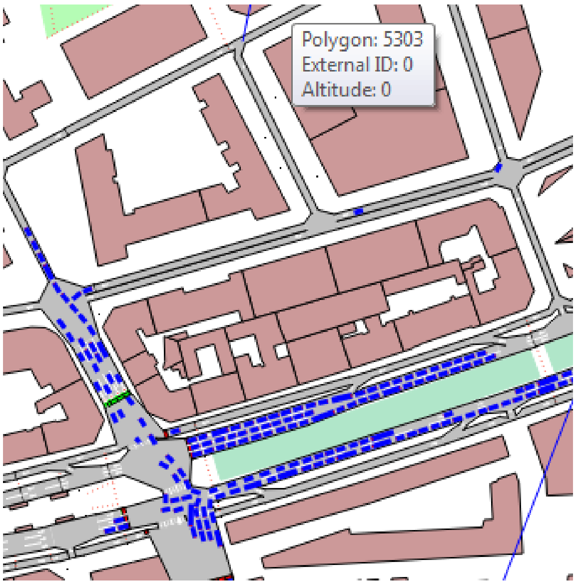


Figure 24 - Typical congestion in urban case

Figure 24 shows an example of a typical congestion of a city. For this case detection will be supported by constant monitoring of variables such as speed and number of vehicles in each section, the detection will be triggered based on real time trends of the supervised variables. The output of the detection will also provide the locations involved affected by the event.

In the case of urban traffic networks synthetic data from the micro simulator will be used to perform the forecasts. Forecast can be based on historical data as well model based approach in order to perform predictions ahead in the future. In particular for the micro simulator, specific rush hours of the day will be selected. During this time multiple simulations will provide data that will contribute historical information for the forecast.

Incidents

An incident is an unexpected event that causes an abrupt change in vehicles' speeds and densities. This may happen, for instance, when an accident occurs. Incidents often reduce road capacity and therefore cause congestion, usually having characteristics very different from a regular peak hour congestion. Due to their nature of being unexpected, incidents can be only detected, and not forecast. However, detection itself is challenging, and in particular finding the location where the incident occurred without camera or reporting from drivers or witnesses is a difficult task.

Incidents Grenoble South Ring

In the case of the Grenoble South Ring detections of abrupt patterns can be performed by examining the measurements provided by the GTL sensor network. As an example, let us consider the case in Figure 25; the figure describes the speed profile in space and time. As reported by authorities at 7:30 AM a car crash happened along the highway the morning of 21st May 2015. As it is seen abrupt changes in speed are observed in the measurements, leading to specific patterns that can be identified. Annotations provided by local authorities are important sources of information for validating the existence of incidents.

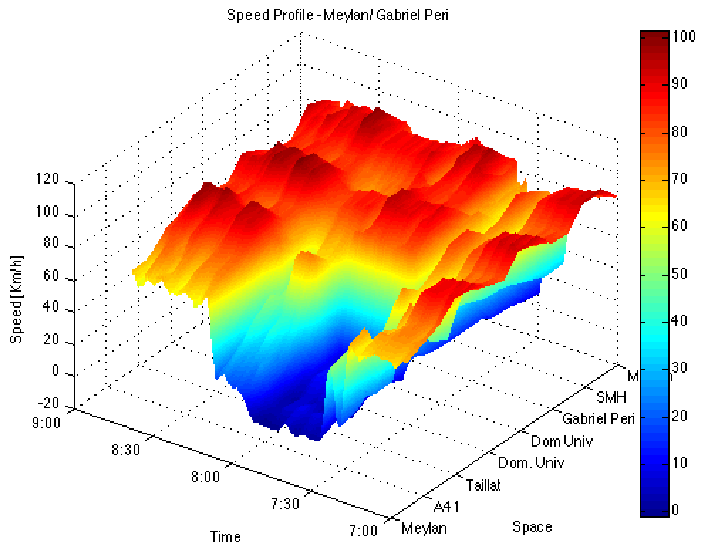


Figure 25 - Effect of an incident over the South Ring – 21/ 05 /2015

Incidents Urban Traffic Case

Traffic urban incidents can be artificially created by the micro simulator. Parameters for this incident include a specific section of the network that is affected, lanes affected, length of the incident, duration.

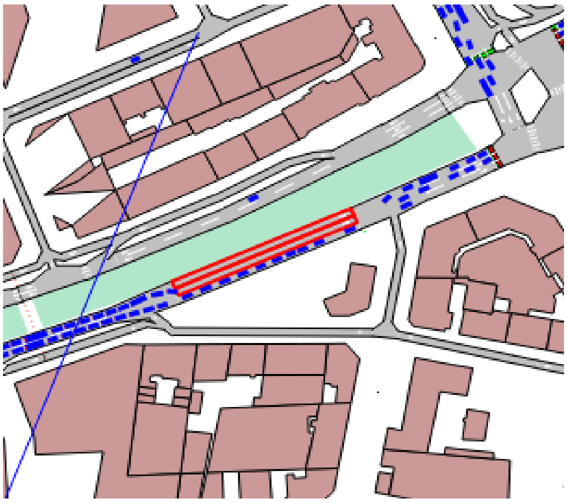


Figure 26 - Effect of an incident in a section of the urban network

The detection of incidents is also associated on a macroscopic level with the speed and the densities at affected sections. The main objective is to use existent patterns occurring in the roads or streets and to make use of the relation between those streets and intersections to detect incidents and their locations.

Emissions peaks

Driving behaviors of commuters create accelerations and particular speed waveforms that may increment the fuel consumption and generate more emissions. The effect of these emissions can be estimated based on macroscopic models. Detection of peak of emissions during the rush hours is possible given the information that is provided by the sensors in the Rocade or the synthetic data from the micro simulator.

Detection of emissions peaks is a challenging task since stop and go drivers' behavior during congestion's creation may induce high peaks that vary in time. For this case the aim is to detect a peak on indices of emissions such as CO_2 and NO_X and the particular section where it occurs. The detection will be based over desired thresholds in emissions.

Emissions peaks can be both detected and forecasted. In this framework, forecast performance can be measured by means of standard metrics such as square errors with respect to the real measured trajectory; hence due to high variability of traffic quantities, achieving good performance is, in general, a difficult task, especially if the forecasting horizon is long. For this reason, we shall concentrate on a short-term horizon of 30 mins. The forecasted information of the aforementioned variables (speed, densities) will be considered as an input for determining increments on the peaks of emissions in the future and their characteristics.

2.4.2 Decision support and decision making

In the project we will provide solutions both for decision support and decision making. Decision support is an operation mode which is intermediate between manual and automatic control, while the decision making module will be a fully automatic control, based on numerical optimization.

Decision and decision support are provided based on complex events generated by the complex event processing (CEP) module, including, but not limited to, the high level events described in the Detection and forecast section. Apart from those events, which are of interest to traffic operators, other events are indispensable for all state of the art traffic management solutions and have to be considered. In particular, it is favorable to maintain running averages of:

- Traffic densities (veh/km), respectively number of vehicles per section (dimensionless)
- Traffic flows (veh/h) , and
- Average velocities (km/h).

Further, auxiliary events will be defined in collaboration with the partners if needed.

Decision support

A decision-support mechanism will be built, in order to simplify the task of human traffic-control operators with recommendations: actions are suggested, but require manual activation by the operator.

Validation will be performed in the GTL show-room, using the micro-simulator and a cognitive interface allowing for real-time interaction with expert traffic operators.

Decision making

The decision making module will use feedback from the sensors in order to optimally control actuators (traffic lights, variable speed-limit panels, access from on-ramp).Validation and performance evaluation will be done using the Aimsun micro-simulator.

The goal of the decision-making process will be a trade off between various objectives that are formally defined in the next section.

Formal definition of control objectives

The improvement of the decision making module will be evaluated with respect to the following macroscopic objective functions, typically used in traffic engineering.

- Total Travel Time (TTT)

$$\mathrm{TTT} = \sum_{t=0}^{T} \sum_{x=1}^{\#\mathrm{sections}} \rho(x,t)$$

Such metric is the sum of vehicles' densities, denoted by ρ, within the temporal region [0, T] inside all the considered sections. The purpose of the decision making process will be to minimize the TTT, since it gives a qualitative indication of the time spent by vehicles in the network (Pisarski, 2012), (Gomes,2006).

- Total Travel Distance (TTD)

$$\text{TTD} = \sum_{t=0}^{T} \sum_{x=1}^{\#\text{sections}} f(x,t)$$

It represents the sum of all flows, denoted by *f*, within the temporal region [0,T] inside all considered sections. The goal of the control is to maximize such index, because it gives a qualitative indication of how well the infrastructure is used by the vehicles. Also, its maximization tends to drive the system towards the best working point (typically called *critical density*) (Grandinetti et al., 2015).

- Service of Demand

$$\text{SoD} = \sum_{t=0}^{T} \sum_{x=1}^{\substack{\#\text{entering} \\ \text{sections}}} f^{in}(x,t)$$

It represents the amount of users that want to enter the network and are actually served within the temporal interval [0,T]. The objective is to maximize such metric, since in case a few users are served, long queues can form outside of the network, with undesired effects (Grandinetti et al., 2015).

- Total Fuel Consumption (TFC)

$$\text{TFC} = \sum_{t=0}^{T} \sum_{x=1}^{\#\text{sections}} \rho(x,t)C(v(x,t),a(x,t))$$

Where *C* denotes the instantaneous consumption rate (typically in liters/s), *v(x,t)* the space-time speed distribution and *a(x,t)* the macroscopic acceleration within the temporal region [0,T] inside all considered sections. Minimization of the Fuel Consumption is a desired achievement, because its increment has negative environmental impacts, e.g., in terms of pollution (Treiber, 2013).

A tradeoff between these metrics will be realized by optimizing a weighted average of the aforementioned costs with weights tuned according to the desired outcome: for example, in case a peak of emission is detected the parameter relative to the TFC will be increased, in order to penalize, and thus reduce, emissions. In case of evacuation scenarios, instead, a high weight will be assigned to the TTT, therefore letting vehicles exit the network (and reach safety) as fast as possible. Finally, in ordinary situations, typical congestion management can be performed by assigning uniform weights to all four metrics.

2.4.3 Expected scenarios implementation

For the south ring and for the urban area the micro-simulator will be set according to:

- Calibration as in a typical traffic day;
- Definition of realistic demand profiles;
- Simulation of rush hours (e.g., 7.30-9.30, 16.30-19.00);

- Use of simulated sensors consistent with reality;
- Use of the following actuators:
  - Seven variable speed-limit panels and seven ramp meters, for the south-ring
  - Traffic lights at urban intersections and variable speed limits along the main roads, for the urban area

Three realistic scenarios will be implemented using the micro-simulator, in order to show the effectiveness of the SPEEDD approach.

1. *Congestion management*. It will consist in managing traffic signals (the decided variables) in order to reduce congestion and therefore improve the general behavior of traffic flows. The decision-making process will use data from sensors to elaborate the actions to be applied in the system. The congestion management mechanism will be triggered by events related to detected / forecasted congestions.
2. *Incident management*. Typical macroscopic effects of incidents are capacity drop in the involved portion of the network, and increasing demand around it. In Aimsun a cars accident will be simulated. In this case:
   a. *The detection module will notify the decision making process of the occurred event;*
   b. *The decision-making process will compute the best values for the actuators, according to the new state of the system, increasing the weights for the TTD and SoD metrics;*
   c. *The decided variables will be applied to the system.*
3. *Emission reduction.* We will simulate this event increasing the number of trucks inside the simulated area (this can be done setting an Aimsun parameter). Then:
   a. *The detection module will notify the decision making process of the undesired situation;*
   b. *The decision-making process will compute the best value for the actuators, according to the new state of the system, increasing the weight for the TFC metric;*
   c. *The decided variables will be applied to the system.*

3. User Requirements Definitions

3.1 Understanding Operator Activity

In order to understand the activity of operators in Road Traffic Control, an observational study was conducted. This involved the use of eye-movement recording in a control room, discussion with Subject Matter Experts, observation of activity in the control room and construction of a Hierarchical Task Analysis to describe this activity.

Road Traffic Control involves the monitoring of traffic, responding to incidents and influencing road user behaviour through the use of signs which can be updated remotely from the control centre. For this exercise, we were interested in gaining insight into the ways in which operators in a control room used the information sources available to them and the range of activity that they performed when handling routine incidents. Given that incidents can contribute to some 25% of the overall congestion levels on major roads (UK Highways Agency, 2009), it is important that any incident is detected and resolved as quickly as possible. Regional Control Centres, such as DIR CE, are the central focus of communications regarding major roads. Such centres will monitor traffic flow (through CCTV, through verbal reports or, potentially, through sensor data from the roads or vehicles) and control electronic signage on these roads. In broad terms, the goals of such as centre can be summarised, following the Folds et al. (1993), as:

- Maximize the available capacity of the roadway system
- Minimize the impact of incidents (accidents, debris, etc.)
- Contribute to demand regulation
- Assist in the provision of emergency services
- Maintain public confidence in the control centre operations and information provision

3.2 Using Eye-Tracking to Study Traffic Control Room Operations

The use of eye-tracking to study operator activity and decision making has been employed in a range of domains (see Moray and Rotenberg, 1989; Lin et al., 2003). This allows the activity of the operator to be captured in terms of the information sources to which they attend during the performance of their activity. We do not, of course, claim that fixation on an information source (i.e., a point where the eye-tracking system indicates that the eye is resting) is *definitely* related to attention (e.g., the person could be looking in one place but thinking about something else, or could be gazing into space). Having said this, eye-movement can provide useful data on the decision making strategy employed. For example, Moray and Rotenberg (1989) demonstrated that during, when dealing with incidents, operators tend to increase the frequency of looks at the failed system rather than look at the system for longer; that identifying an incident sometimes preceded a response action by many seconds; and that information processing becomes restricted to one information source at the expense of attending to subsequent or parallel incidents. A more detailed description of decision making strategy will be reported in D5.1. For this report, the focus is on the use of eye-movement data to construct a task analysis. While the decomposition of activity into component tasks is common across a range of disciplines, Human Factors (particularly in the UK) employs a methodology called HTA, Hierarchical Task Analysis (Annett et al., 1971; Shepherd, 2001).

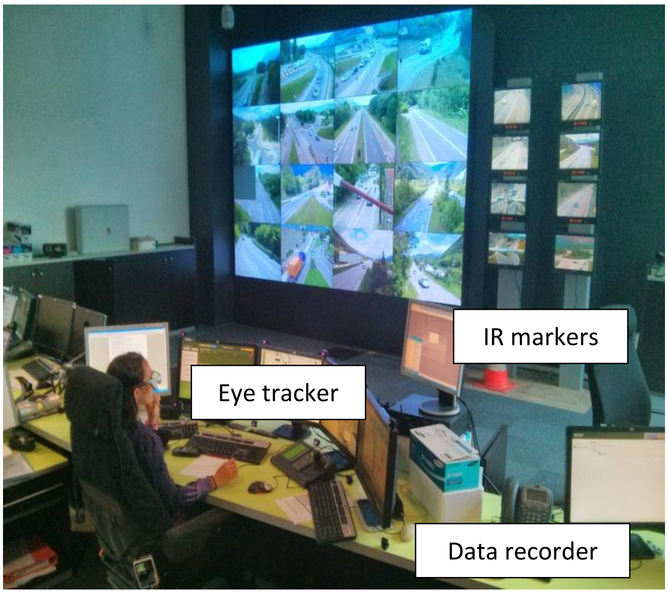


Figure 27 - DIR-CE control center

Staff at DIR Centre Est, Grenoble participated in a data collection exercise in May, 2014. Working with INRIA, researchers from the University of Birmingham (UK) used Tobii eye-tracking kit to study how operators deal with routine incidents. Infrared (IR) markers were positioned around the computer screens and the operator wore a headset that filmed their eyes. In this picture, there are four markers around the edge of the screen (numbered 1, 2, 8, 7) and the centre of the red cross-hairs indicate the fixation point of the gaze (in the eye-tracker's raw data).

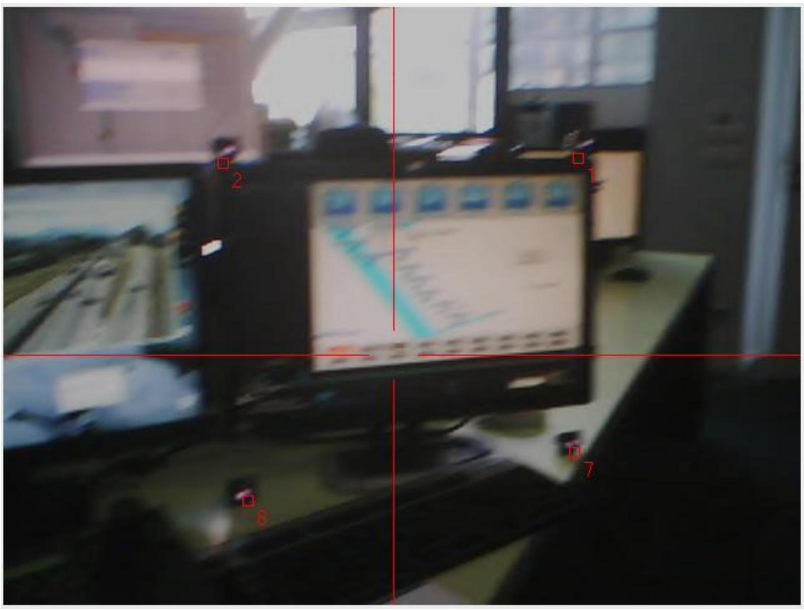


Figure 28 - Fixation point of the gaze

In the video recordings (see Figure 29), the green dots indicate where the person is looking at any time. You can see how the operators shift their attention from a display of the road network to the CCTV screens and then to the incident form.

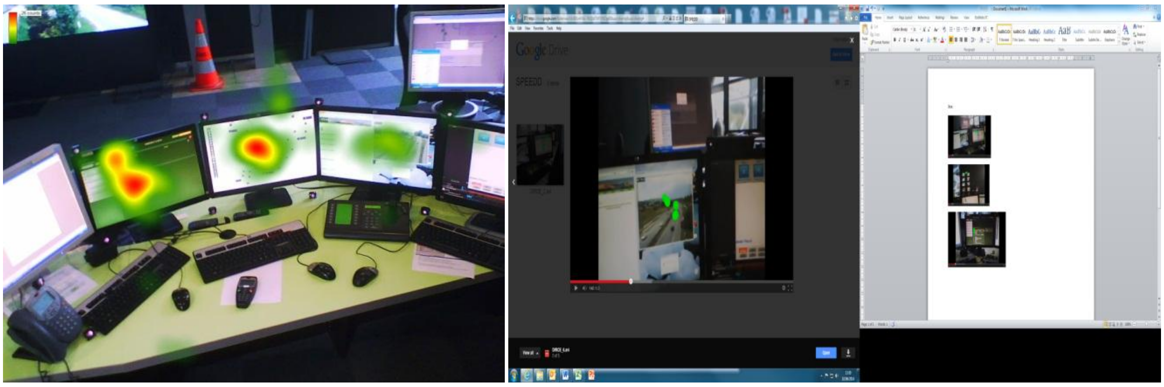


Figure 29 - Example of recording

By collating all of the eye-movement data from an operator, it is possible to show where they directed most of their attention. This is shown in the 'heat-map' of attention, and it is clear that, for the routine tasks we explored, the operator attends to the incident report screen and the map of the road network (as shown by the red centres of the heat-maps) with a little less attention to the CCTV feed (and the joystick to control the camera for this feed).

Data were collected from five operators[1].

- Operator 1 dealt with a 'live' incident (a lorry that had broken down on the road and needed to be moved). This took approximately 15 minutes to resolve.
- Operator 2 dealt with a 'live' incident (a motorcycle that had broken down and was assisted off the road), and a 'simulated' incident (an object in road). The first incident took approximately 5 minutes to resolve and the second incident took 6 minutes.
- Operator 3, 4 and 5 all dealt with the 'simulated' incident (object in the road) and each took approximately 6 minutes to resolve.

Prior to data collection, the purpose of the study was explained to operators and they had the opportunity not to participate. The study has been approved by the University of Birmingham Ethics Panel. On agreeing to participate, operators were fitted with the eye-tracking unit and calibration performed. Calibration involved a two stage process: I. the camera fitted the wearer's eye was checked to ensure that the pupil was within the defined frame (if this was not the case, the headset was adjusted and the calibration repeated), II. the wearer was asked to look at a reflective marker as the experiment moved it in a grid pattern (this checked the reading of the IR camera and the tracking of the eye). If the calibration tests were passed, the experiment began. Generally, calibration had to be performed at least twice per participant prior the experiment. Calibration took approximately 5 minutes per participant.

The full analysis of the eye-tracking data will be reported in a later report (D5.1). For this report, it is useful to know that regions of interest were identified (as indicated in Figure 28) and the fixations were related to these regions. In figure 30, the blue circles indicate fixation (with size of circle corresponding to dwell time). The numbers on these circles indicate the order in which fixations were made. Thus, it is possible to read this figure not only as a map of fixations but also as the timeline that the operator followed in terms of looking at different displays. As with the heat-map shown earlier, one can see that the operator's attention is split between the form-filling screen (on the left-hand side) and the displays which show map or video. In this example, the operator concentrated on the map

[1]We would like to thank the DIRCE managers and operators who gave up their time and expertise to allow us to collect these data.

schematic display, with occasional checks of the CCTV screens (indicated by the small circles positioned above the main displays).

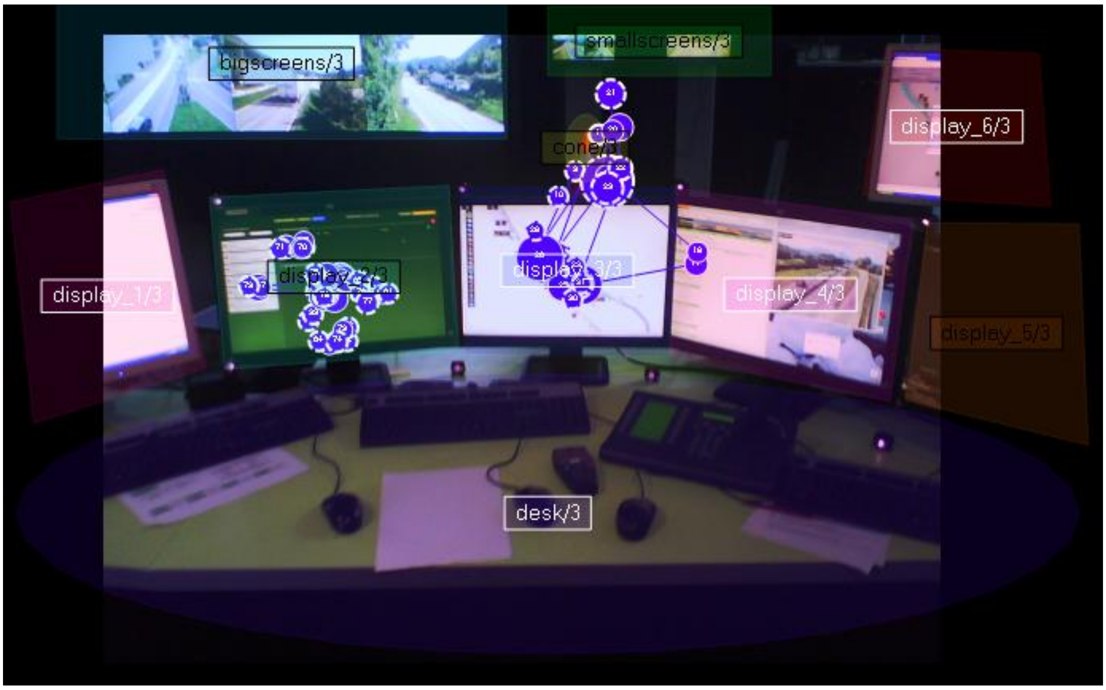


Figure 30 - Fixations

Hierarchical Task Analysis

For this report, the eye-tracking data, together with discussion with the Subject Matter Experts (SME), formed the basis for a task analysis of operator activity which leads to a set of user requirements.

Each video of eye-tracking was reviewed by the analyst. The process was as follows:

1. Note the time when eye-movement shifted from one region of interest to another.
2. At each region of interest, note the physical action that the operator was performing, e.g., writing notes, selecting menu item, typing into a form.
3. Relate each activity to the notes made during observation and discussion with SME.
4. Construct initial hierarchical decomposition of activity.
5. Repeat steps 1-4 for each video.
6. Refine hierarchical decomposition after each video.
7. Discuss resulting hierarchy with colleague and check consistency.

What is important in Hierarchical Task Analysis (HTA) is not simply the hierarchical decomposition but also the definition of ‘plans’. The hierarchy is typically described in terms of decomposition of a ‘goal’ into ‘subgoals’, moving from a high-level goal to lower-level subgoals. However, this hierarchy gives little indication of either the sequence in which tasks need to be performed or the conditions under which task completion is achieved. It is a mistake to assume that the numbering specifies the sequence of action or that all subgoals need to be achieved. Thus, HTA includes a set of ‘plans’ which indicate the ways in which the diagram can be read.

In the HTA that describes the observations and discussion with Subject Matter Expert for the Traffic Management case study, the primary goal of the operator is defined as ‘0 Respond to incident’. This goal reflects the focus of the observation sessions and is not intended to imply that this is the only goal that the operators need to satisfy. However, we decided to focus on routine incident handling for these observations for three reasons: i. if critical incidents or accidents had occurred, then the observers would have been asked to leave the control room; ii. routine incidents make up the bulk of the operators' work activity; iii. we believe that handling routine incidents provides a good sense of the nature of the work activity.

The HTA indicates that the primary goal is met through 7 subgoals. The subgoals are as follows:

Subgoal 1: Receive Notification

Basically, the operator responds to an incident notification. This could arrive through different media (phone, radio, auto-detect etc.) and the operator would make sure that the incident was from a credible source and then might recall similar incidents that had been encountered previously (this latter activity could provide the operator with an idea of the questions that they might need to ask of the information source as well as suggesting a course of action to take). If the incident is felt to be sufficient to require a response, an incident log is created.

Subgoal 2: Determine incident type

The operator needs to classify the incident in terms its type. The operators spoke of {Accidents, Bouchon (congestion), Obstacles et incidents, Travaux (road works)} as examples of type. The initial notification would have provided some information about the type of incident. For example, 1 of the observed trials involved the operator responding to a radio call concerning a lorry which had broken down. The operator needed to determine whether the lorry might be causing an obstruction. In order to do this, the operator discussed the incident with their colleague at the site (over the radio) and used the CCTV to view the lorry and the road. Having classified the incident, the operator updates the incident log.

Subgoal 3: Determine incident location

For the example in the previous section (a broken down lorry), the operator needed to determine the location before operating the CCTV (in order to know which CCTV to select). This illustrates how there is not a discrete, linear flow of activity in pursuing these subgoals. We observed two distinct strategies for determining incident location. In 4 of the sessions, the operators used the CCTV cameras to locate an incident and noted the location on the cameras and the nearest exit to define the location. In 2 of the sessions, the operators referred to the schematic map screen to define the most likely location and then used this information to select a CCTV to confirm this location. While the tasks are not complicated, this shows how operators could develop different strategies for achieving the same subgoal.

Subgoal 4: Determine incident impact

Having defined a specific incident at a specific location, the next subgoal is to decide what impact this incident will have on the performance of the road network. This can involve the operator relating the type of incident to particular consequences. The operators spoke of {risk, safety, journey time, average speed, traffic density and congestion, changes in demands on the road}. It was apparent that, while the incidents observed did not make significant demands on the operators, an understanding of the factors which contribute to the current situation, such as weather, road conditions, traffic conditions, and how these factors are likely to change during the course of incident. This ability to develop Situation Awareness is an important, albeit implicit, aspect of the operators' skill.

Subgoal 5: Initiate response

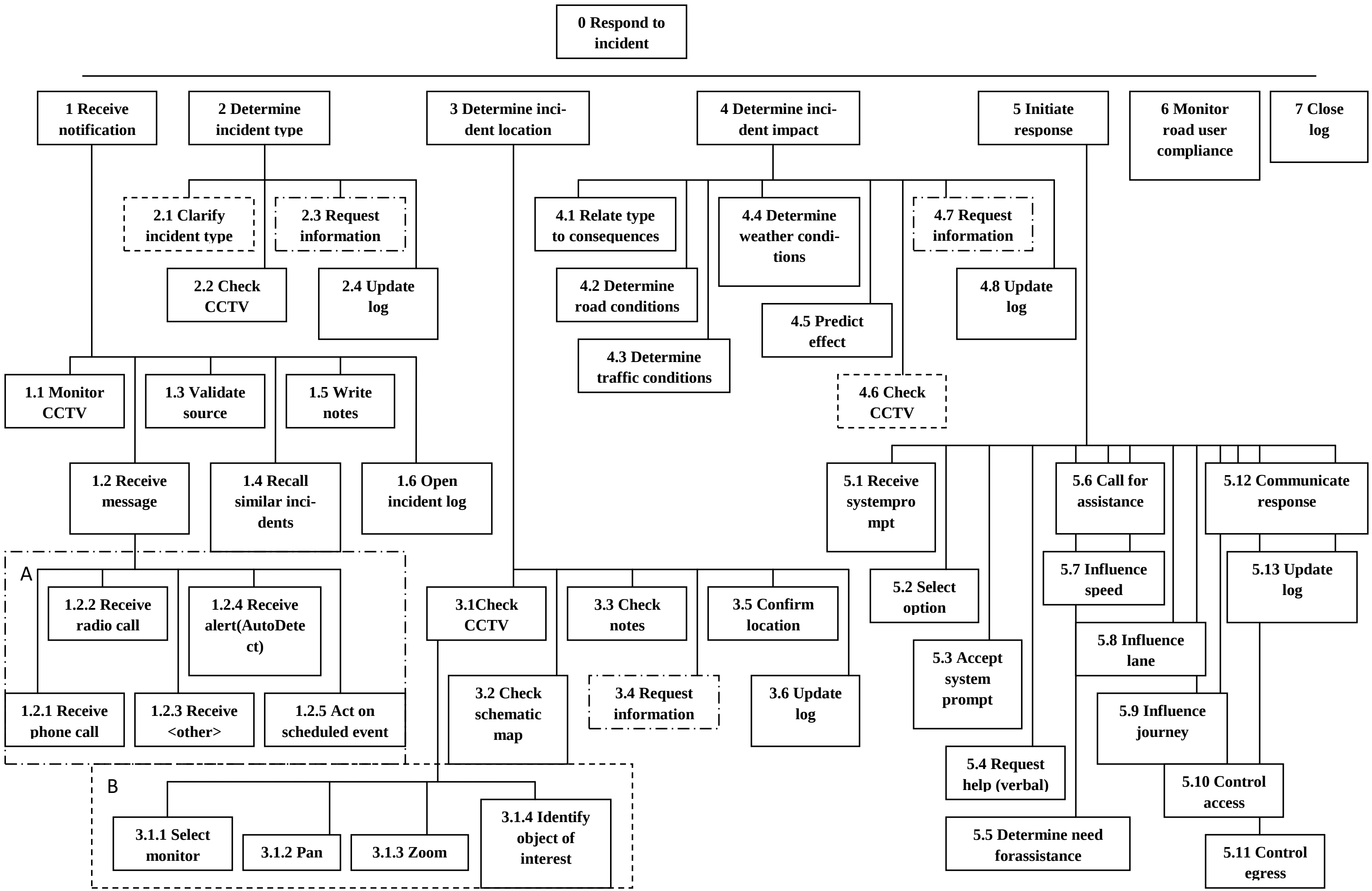
As the operator completes the incident log, the current software system they use relates the options available to the type of incident. The operator could accept the system prompt or could select another option. The response could involve changing the content of overhead signs on the road (either in terms of changing speed limits, indicating lane closures, providing advisory signs). The content of the signs is pre-defined and the operator selects from this set. If the incident cannot be dealt with by a sign from the set, the operator is not empowered to improvise or create new content; rather new content needs to be approved by the relevant Agencies. As well as modifying the signs, the operator can limit access to the road network (through control of junctions). Finally, the operator could call for road-side assistance to attend the incident. This assistance could help the vehicle or could be specialised support (paramedic or technical).

Subgoal 6: Monitor road user compliance

When a response has been initiated, the operator will check that the incident has been resolved and also that the road users affected by the response are complying with it.

Subgoal 7: Close incident log

Once the incident has been resolved, the operator closes the incident log. We noted that operators (and the control room) would have some incidents that remained open. This might be because it was taking longer to resolve than expected due to unforeseen circumstances or because the incident was open for a scheduled reason, such as road works.


0 Respond to incident
1 Receive notification
2 Determine incident type
3 Determine incident location
4 Determine incident impact
5 Initiate response
6 Monitor road user compliance
7 Close log
2.1 Clarify incident type
2.3 Request information
2.2 Check CCTV
2.4 Update log
4.1 Relate type to consequences
4.4 Determine weather conditions
4.7 Request information
4.2 Determine road conditions
4.5 Predict effect
4.8 Update log
4.3 Determine traffic conditions
4.6 Check CCTV
1.1 Monitor CCTV
1.3 Validate source
1.5 Write notes
1.2 Receive message
1.4 Recall similar incidents
1.6 Open incident log
5.1 Receive systemprompt
5.6 Call for assistance
5.12 Communicate response
5.7 Influence speed
5.13 Update log
5.2 Select option
5.8 Influence lane
5.3 Accept system prompt
5.9 Influence journey
5.4 Request help (verbal)
5.10 Control access
5.5 Determine need forassistance
5.11 Control egress
A
1.2.2 Receive radio call
1.2.4 Receive alert(AutoDetect)
1.2.1 Receive phone call
1.2.3 Receive <other>
1.2.5 Act on scheduled event
3.1Check CCTV
3.3 Check notes
3.5 Confirm location
3.2 Check schematic map
3.4 Request information
3.6 Update log
B
3.1.1 Select monitor
3.1.2 Pan
3.1.3 Zoom
3.1.4 Identify object of interest

Plans indicate a sequence of subgoals and their relationship to different conditions. By separating tasks from conditions, HTA provides a simple but powerful means of creating a description. In the notation for plans, '>' signifies "followed by" to indicate sequence, numbers indicates subgoals in the hierarchy, and text indicates 'conditions'. The following table provides some examples of Plans which could be applied to subgoals (we have provided three examples for each subgoal for illustrative purposes). The set of plans is not exhaustive but intended to illustrate the point that operators can achieve these subgoals in a variety of ways, depending on operating conditions and strategy employed by the operator. For each Plan, the numbers refer to the subgoals in the HTA and the word 'exit' indicates completion of this sequence of subgoals, i.e., the achievement of the subgoal.

Subgoal	Plan
1 Receive notification	p1a: 1.1 > 1.6 > exit p1b: 1.2 > as required and for specific information 1.5 > if appropriate 1.3 > if possible 1.4 > 1.6 > exit p1c: 1.2 > 1.1 > 1.6 > exit
2 Determine incident type	p2a: 2.4 > if unable to determine type > 2.4 > 2.1 > 2.3 > exit p2b: 2.1 > 2.4. > exit p2c: 2.3 > 2.1 > 2.4 > exit
3 Determine incident location	p3a: 3.3 > 3.6>exit p3b: 3.3 > 3.2 > 3.6 >exit p3c: 3.1 > 3.5 > 3.6 >exit
4 Determine incident impact	p4a: 4.7 > if system has option for type 4.1 > 4.8 > exit p4b: 4.1 > if familiar incident 4.4 > 4.8 > exit p4c: 4.1 > if unfamiliar incident 4.2, 4.3, 4.4 > 4.5 > if clarification required 4.7 > 4.8 > exit
5 Initiate response	p5a: 5.1 > 5.3 > 5.12 > 5.13> exit p5b: 5.2 > depending on decision 5.7, 5.8, 5.10, 5.11> 5.12 > 5.13> exit p5c: 5.1 > 5.3 > if long-term impact 5.9 > 5.12 > 5.13 > exit
6 Monitor road user compliance	No further description: this task will involve checking that road users are obeying the signs that have been set-up
7 Close incident log	No further description: once an incident has been declared terminated, the incident log will be closed.

Information Requirements

Each subgoal involves the interleaving of two tasks: i. searching for, and evaluating, information; ii. determining an appropriate course of action and updating the incident log. It is worth noting that not only do these tasks overlap with each other, but that, often the subgoals, also overlap. This means that the operator is continually cycling between information search and decision making, punctuated by updating the incident log. It also means that the subgoals can be performed in any order and can be performed in parallel (depending on the nature of the incident).

Subgoal	Information Requirements
1 Receive notification	a. Clear description of incident b. Previous experience of similar incidents c. Opportunity to clarify description or seek further information
2 Determine incident type	a. Clear description of incident b. Incident description can be related to defined set of types c. Incident type can be unambiguously assigned d. Incident type can be confirmed
3 Determine incident loca-	a. Clear description of location

tion	b. Location can be specified in terms of road, direction of travel, exit c. Location can be specified in terms of landmark d. Location can be specified on map
4 Determine incident impact	a. Incident type can be related to future congestion levels b. Incident type can be related to safety of road users (now and in the future) c. Incident type can be related to requirements for assistance (e.g., road repairs, vehicle assistance, paramedic assistance) d. Incident type can be related to environmental impact
5 Initiate response	a. System offers suggestion, based on incident type, which the operator can accept b. Operator can modify vehicle speed or use of lanes to affect traffic flow c. Operator can modify use of lanes or access / egress to affect traffic volume d. Operator can provide advisories to affect journey decisions of vehicles
6 Monitor road user compliance	a. Operator can monitor road user activity in response to warnings b. Operator can monitor road user activity in response to advisories
7 Close incident log	a. Operator can decide that incident has terminated

This list can be considered in terms of information requirements which support operator understanding of the current situation, operator prediction of future changes to the situation and operator understanding of the impact of both the incident and response that has been initiated. These Situation Awareness requirements relate to the use of available information by the operator. In addition, information requirements relate to the decision making of the operator, i.e., in terms of selection of response.

3.3 Translating User Activity into User Requirements

Having gained some insight into the nature of the operators activity (albeit during routine incidents), it is possible to offer suggestions as to Requirements and questions.

Subgoal	Requirement	Comment
Overall		The interleaving of information search and decision making is key to the operators' activity. This means that the operators need to be able to develop their Situation Awareness in order to fully engage with an incident.
1 Receive Notification	Allow operator to clarify notification	The operator needs to understand the situation described in the notification. This might involve seeking clarification by asking questions. Operators need to be able to question and understand the incident that the SPEEDD system is handling.
2 Determine incident type	Allow operator to draw on experience of incidents. Allow operator to select incident type option.	Incident types will be classified according to agreed types (to reduce ambiguity and ensure consistency). A given incident might be automatically classified but the operator would need to either select an alternative type or request explanation of the suggested type.
3 Determine	Allow operator to draw on	Location can be defined by sensor or CCTV posi-

incident location	several information sources to confirm location.	tion. The operator would want to check this location, e.g., from verbal reports or from checking CCTV footage.
4 Determine incident impact	Support operators' Situation Awareness concerning the current state of the incident and the future conditions (of the incident and contributing factors).	In order to predict the impact of a response, operators need to consider a range of situational factors. It was not clear that they had direct and easy access to information relating to these factors. Traffic conditions could be monitored via CCTV (within areas of camera coverage), but it was not clear that CCTV could provide information on road condition (operators might need to make a radio call to someone on the road if they need to check this). Current weather conditions could be inferred from CCTV but it was not clear how operators received weather predictions.
5 Initiate response	Allow operator selection of response. Allow operator to challenge or negotiate suggested response.	The system can suggest the response to make and the operator can accept this suggestion. However, the operator would want to be able to make an alternative selection or to receive explanation as to why the selection was proposed.
6 Monitor road user compliance	Support operators in gaining global and local Situation Awareness of road user behaviour	Operators check road user behaviour through CCTV. It might be useful to provide summary data from sensors to inform operators. This would represent additional information for the operator but could also represent new activity (with associated change in workload).
7 Close incident log	Support operators in determining that the incident has no unexpected consequences	When the incident log is closed, the immediate problem is assumed to be resolved. Operators might benefit from guidance in terms of future consequences arising from this incident.

3.4 Conclusions and Summary

A key theme in the user requirements outlined above was the need to support Situation Awareness for the operator. In broad terms, Situation Awareness can be considered in terms of three stages (Endsley, 1995): Perception of the current situation (i.e., what is happening); Comprehension of the situation (i.e., what needs to be done); and Projection (i.e., how will the situation develop). Conventionally, these stages would be performed by an individual. However, in complex systems, it is far more likely that the stages would be distributed between agents (human and automated) in the system (Stanton et al., 2006). This means that there is a challenge to determine how the 'knowledge' in a system in represented across the different agents in that system (Hutchins, 1995). Not only is the knowledge in a system distributed across agents, but the agents are likely to have different 'views' of the situation. These different views are not simply due to the vantage point that each agent might have (in terms of the visual information available to them), or to the type of data to which they have access, but also in terms of the different rules, procedures and goals which they apply. Thus, a traffic accident might create a different view for road traffic managers in comparison to police officers, who might have a different view to fire service personnel or paramedics, who might have a different view to the drivers in the tailback behind the accident. In this example, there will be much overlap between these views, e.g., in terms of where the accident has happened, how many cars are involved etc., but there will be differences as well, e.g., in terms of how to manage access to the scene or how to treat the casualties. There are two reasons why this observation is significant. First, if different people have overlapping but distinct views of a situation, then the ability to communicate information about the situation can be compromised (e.g., people might be referring to the same location or object but interpreting this in very different ways). Second, if different people have different goals in their response to the situation, then they are likely to differ in their projection of that situation (see above).

In terms of Road Traffic Management and the SPEEDD project, while this report has focused on routine incidents, it is possible to make a number of observations relating to situation awareness which will have a bearing on user requirements.

Perception

The Perception of the current situation primarily involves two processes. The first is the ability to collate sufficient information to determine the defining aspects of the situation. From the HTA conducted in this report, this information can be considered in terms of location, type and impact of an event. In routine (and planned) incidents, the definition of an 'event' can straightforward – there is a specific and discrete incident (e.g., a collision, a broken down vehicle, an object in the road) which can be unambiguously defined in terms of the information. In this case, the ability to clearly define the event in terms of the information is supported by the categorisation scheme applied in the menus which are used to select entries in the report form. Indeed, operators are not permitted to use individualised descriptions of events but must rely on the predefined categorisation (which has been designed to cover all eventualities that operators encounter). It is an open question as to how operators might use the predefined scheme to deal with complex incidents (involving multiple events) or with totally novel incidents. While such incidents are rare, it would be interesting to explore ways in which automation could support the definition of such complex or novel incidents.

However, there are other situations which can be less easy to define so precisely, e.g., pollution or congestion levels. In this instance, the concept of an 'event' requires either to be considered in terms of thresholds, e.g., when a given value exceeds a threshold then the operator perceives a given situation. This could, for example, apply to pollution levels, where a message from an air quality monitoring unit could serve as an 'event'. Or it could be in terms of a range of levels (in order to avoid problems of binary response) in which gradations are applied, e.g., low, medium, high levels. In this case, the role of the system is not simply to determine which 'event' is occurring but also what the progression to the next level might look like (see Projection below).

The second process which is relevant to Perception of an event is the ability to recall previous, related examples. In our observations, this ability was supported mainly through discussion with colleagues (although there is also the likelihood that the operator would simply remember similar events). The recollection of previous incidents will obviously depend on the experience of the operators working on a given shift. It might be the case that none of the operators have previously experienced an unusual incident. It would be interesting to explore ways in which previous examples could be made available to operators and how operators might make use of such information.

Comprehension

From the observations, we believe that 'comprehension' is performed hand-in-hand with response. The operators are monitoring the situation and choosing an appropriate response to make. We believe that this is not a two-stage process of comprehend and then respond, but rather an interleaving process in which both activities are performed in parallel, with one influencing the other. It would be interesting to explore ways in which operators could try out alternative responses, or to have alternative responses suggested to them. While they might continue with their preferred response, having an alternative could be beneficial in their exploration of the situation.

Projection

Once a response had been selected and performed, the operator monitors the situation and then, if the situation appears to have been resolved, closes the incident. We did observe situations in which the operators predicted the consequences of their response or predicted future states of the road network. Dealing with routine incidents is, by definition, reactive in nature. Even when operators have planned events, such as road-works, which could be deemed proactive, the planning is often sufficiently detailed to allow their response to be well drilled. In the case of planned activity, the planning is performed prior to the activity and leads to the production of a schedule. Thus, we are not sure that the current model of traffic management involves much projection (at least in terms of the immediate duties and activities of the operator).

There are, at least, two ways in which traffic management can involve projection. The first relates to the progression across levels, say in terms of congestion or pollution. In this case, changing states of the environment or the road network can result in the need for action in the future. One approach to this would be to align these changes in state to the work practices surrounding scheduled works. In other words, just as road works are planned and scheduled, and the operator implements the schedule, so changes in levels could be treated in terms of scheduled responses. In this manner, the operator would not be distracted from the need to react to immediate incidents (in terms of perception and comprehension). This could involve adding the projected changes in level to the list of tasks that the operator has to perform. Alternatively, the operator might be provided with a display showing current levels and future projections (graded in terms of low, medium, high levels) as a trend graph to provide information on when changes are likely to occur.

The second way in which traffic management can involve projection relates to the consequences of a response. This seemed to us to be quite ad hoc. If, for example, an incident requires the closure of a lane and rush hour was about to start, then the impact on congestion would be much higher than if the lane closure occurred in the middle of the afternoon. In order to manage the building congestion, traffic could be re-routed or speed restrictions could be applied. However, understanding the ways in which different combinations of response with future traffic conditions seems to be a matter of expertise and experience than something which current technical support can handle. It might be interesting to explore ways in which the consequences of different responses can be presented in terms of their interactions with changes in road, traffic or environmental parameters.

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