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DITCM roadside facilities for cooperative systems testing and evaluation

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Abstract— **Cooperative systems are being developed for large scale deployment in the near future. Validation of the performance of cooperative systems, and evaluation of the impact of cooperative applications is crucial before large scale deployment can proceed. The DITCM test site facilitates testing, evaluation, and validation of cooperative systems in normal traffic. The test site spans the urban roads in two cities and the connecting motorway. This paper presents the architecture of the road side facilities and its compliance to standards. It also shows the flexibility to configure the facilities to a wide range of validation and evaluation setups in a series of international and national projects.**

I. Introduction

Concepts and prototypes of cooperative systems have been developed, demonstrated and field tested over the last decades. A maturity level of cooperative systems has been reached that enables larger scale field operational tests with hundreds to a few thousands of vehicles, and first series of commercial products are expected to enter the market soon.

Cooperative systems are developed in many different ways, such as in-vehicle systems from different vehicle manufacturers or aftermarket devices provided by third parties, using either 3G cellular communication or G5 vehicle ad-hoc networking communication. Traffic industry develop different road side units and a variety of interfaces to legacy road side systems. The variety of applications and their implementations is also increasing rapidly.

The behavior of cooperative systems is inherently more complex than that of the individual systems alone due to the interactions of the cooperative applications, and differences in sensing and communication devices, communication media etc. Technical evaluation of the correct, safe and reliable operation of these systems and ultimately the verification and validation thereof, is a necessity for efficient, clean and safe traffic.

A permanent test site for cooperative systems can facilitate the development and deployment of cooperative systems. It allows to test and optimize the quality and performance of cooperative systems, to ensure interoperability, and to determine their impact for a more efficient, cleaner, and safer traffic environment. Therefore, more than 20 partners ranging from universities, research organizations, commercial partners and governmental organizations have joined forces in DITCM, the Dutch Integrated Test Site for Cooperative Mobility [1]. DITCM operates an extensive set of facilities, including simulation environments, hardware in the loop facilities, and car labs. A central facility is the test site in and between the cities of Helmond and Eindhoven, The Netherlands. Over the last several years, the partners of DITCM have created the test site in several European and Dutch projects, including SPITS [2], GCDC [3] [4], DRIVE C2X [5], and Contrast [6]. In the (near) future, it will be used in projects like Mobinet [7], and Compass4D [8], and for testing and validating products of individual or groups of suppliers.

In the following sections, the design and implementation of the DITCM test site will be described, and how it can be used as an open innovation environment focused on improving the quality of cooperative systems and on facilitating a rapid deployment of these systems.

II. Objectives for a Test site Facility

A test site facility is an invaluable tool in many stages of the development of cooperative systems:

1. Development and testing of innovative measures to improve traffic efficiency, safety, environmental impact, driver support, that can be added to the existing portfolio of road operators, vehicle manufacturers and service providers.
2. Technical evaluation and validation of components, systems, and applications in controlled and/or naturalistic tests, e.g. to test performance, compliance to (industry) standards (IEEE, CEN, ETSI, C2CCC) and interoperability;
3. Evaluation of the impact of driver assistance and cooperative systems on traffic efficiency, safety, comfort, and environmental impact in Field Operational Tests, and their contribution to the targets of governments, road authorities, and industries;
4. Improving traffic and driver models based on detailed observation of the use of innovative driver support systems and behavior in traffic. Improved models are required in other facilities to improve the fidelity of simulation and evaluation environments used during the development and evaluation of cooperative applications.

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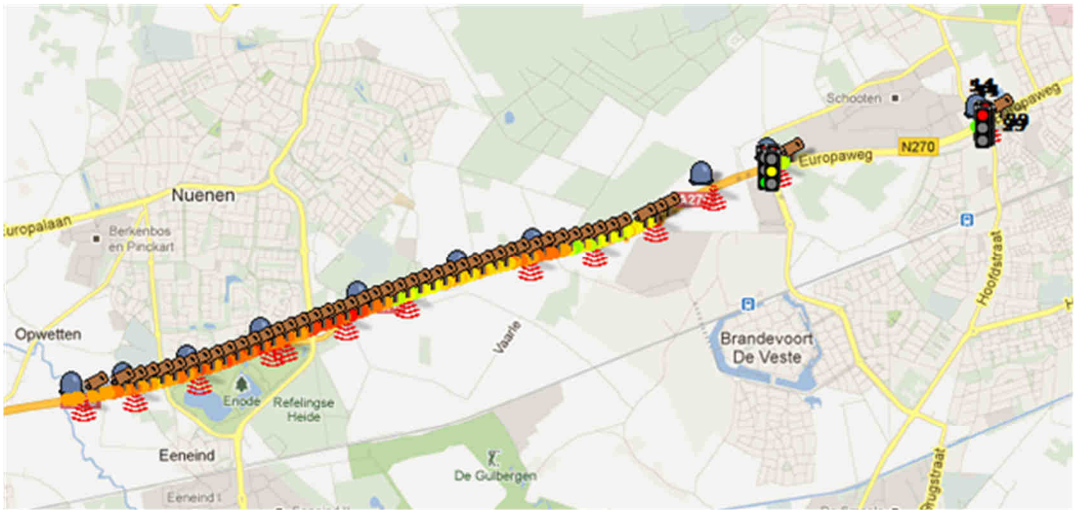

Figure 1. High level overview of the DITCM testsite. Shown are the dome cameras (blue symbels) and fixed cameras (brown symbols), communication units (red symbols), and traffic light controllers.

III. DITCM Test site Architecture and Implementation

The DITCM test site is located on the A270 and N270 roads in and between the cities of Helmond and Eindhoven. It consists of both a motorway and urban environments. A high-level overview of the sections managed from the test management center is shown in Figure 1. This site is 8 km long, with 6 km of motorway. Roadside equipment is responsible for vehicle detection and V2X communication. All other equipment is placed indoor and includes sensor fusion facilities, application platforms, a traffic management center. See the figure below for the high level architecture. The neighboring urban sections in the cities are not directly managed from the test management center. The test site is connected to these sections and other information sources via a high speed internet connection.

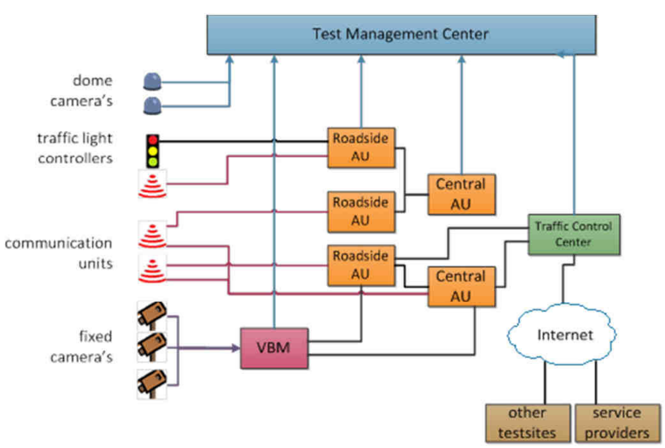

Figure 1. The road side architecture of the DITCM testsite, showing the roadside systems on the left (dome and fixed cameras, communication units, and traffic light controllers), and the sensor platform (VBM). Local, regional, or strategic applications are deployed on Roadside, and Central Application Units (AU), and the Traffic Control Center, respectively. The Test Management Center host all test facilities.

For testing, validation and evaluation of a system under test, an independent observation system is required. The setup of the test site is such that the available functions can either be used as a system under test, or as part of the independent observation system. The functions are discussed in more detail in the following paragraphs.

A. *Architecture of permanent test site facilities*

According to ETSI standards, the central component of a cooperative system is an ITS Station [9], which can be divided in an Application Unit (AU) and Communication Unit (CU). At the DITCM test site, two flavors of ITS stations are implemented: Roadside ITS Stations (RIS), consisting of a CU and an Roadside AU, responsible for local applications like at a single intersection; and central ITS Stations, consisting of a Central AU and multiple communication units, responsible for applications covering larger sections, like shockwave traffic jam detection and mitigation. Both types of application units are fed by information from the Sensor fusion platform. An important component in the sensor fusion platform is the Video Based Monitoring system (VBM), providing independent observations of all vehicles on the test site.

A Traffic Control Center (TCC) is implemented above the CIS and RIS. The TCC operates at an even higher level than the CIS, even outside the DITCM test site. Currently, the TCC is mainly used for information exchange with other test sites or service providers. A Test Management Center, responsible for the control and management of experiments on the test site complements the complete test site environment. The various components are discussed in more detail in the following sections.

The CUs, road side sensors and traffic light controllers are all connected via a high speed fiber network to the nearby central ICT facilities at the premises of TNO. The application units are deployed in a dedicated virtualization environment in the central ICT facilities. Every project uses its own application unit, and the virtualization environment facilitates the flexible creation of additional AUs.

Figure 2. Overview of the test site, in use for the closed track experiments of the SPITS project. A fixed camera of the VBM system is installed on every pole, which are positioned 100m apart.

B. Sensor platform

The test site has a high density of road side equipment for monitoring, detection and tracking of individual vehicles. Traffic and test progress is monitored with 9 dome cameras every 500 m on the motorway and at both intersections. Road users are continuously tracked with the Video-Based Monitoring (VBM) system [10]. VBM uses 51 fixed cameras located at each intersection and every 100m along the motorway, see Figure 2. VBM is a real-time image processing system that detects and tracks road users at 10 Hz and detects incidents along the test site [11]. Every camera is connected to a VBM detector, detecting the positions of vehicles inside the camera field of view.

All vehicles detections are fed into a data fusion module. The fusion module produces vehicle tracks over the full length of the test site. To allow for proper handover of detected vehicles from one camera to the next one, the absolute calibration of the conversion from image pixels to road coordinates and then to GPS locations is crucial. To allow for consistent quality over time, the VBM system can be auto calibrated either based on cross calibration over the individual camera's, or based on reference tracks of vehicles equipped with a high-resolution positioning system.

The VBM system can be operated under most climate and lighting conditions, such as by day, night, dawn, rain, and snow [11].The absolute position accuracy is better than 1m, making it an excellent tool to independently evaluate the accuracy of in-vehicle positioning systems. Optionally, also vehicle information received in so-called Cooperative Awareness Messages, containing at least position and velocity information of the vehicles, can be fused in this module to further improve the quality of the resulting information or to correlate in-vehicle information with roadside information.

Additional sensor information is obtained from the two traffic light controllers. Both intersections are instrumented with multiple loop detectors to detect traffic approaching and at the stop line on every approach lane. At a 1 Hz frequency the actual state of these loop detectors is made available. No other loop detectors are available on the test site, but can be emulated if needed with the VBM system. Also the actual state of the traffic lights is available and the predicted switching time to the next phase. Requesting phase changes is not yet available, but is foreseen for the near future, allowing the validation of cooperative applications that also affect to operation of the traffic lights.

C. V2I communication platform

The application and communication environment adheres to the ITS Reference Station Architecture, as defined by ETSI [12]. The full reference station is divided over 2 units: an application unit and a communication unit, see Figure 3.

The V2X communication platform is made up of 16 CUs, installed near the intersections and every 500 m along the motorway and at the merging lane at the highway entry half way the test site, providing full coverage on the highway [13]. Every CU has 2 independent communication channels, which can either be used to support dual channel operation, or to use one channel as part of the system under test, and the other as part of the observation system. Furthermore, the data packets on both communication channels can be duplicated into two independent streams, where one stream is used for normal operation and the other stream for low level monitoring. Low level monitoring enables to evaluate time stamps on all layers of the communication stack, packet loss, and signal strength. Independent measurement systems for low level monitoring exist also exist, but by integrating this functionality in the fully operational CUs allows to correlate the performances of higher level functionality, including applications, with the low level performance of the wireless channel. The CUs include a fully ETSI ITS G5 compliant geonetworking/BTP network layer [12]. Also a ISO CALM Fast [14] implementation is available, and for e.g. testing and debugging IPv4 and IPv6 can be used.

The CUs can send and receive any type of data packet. In general, ASN.1 encoded messages are transmitted (e.g. CAM, DENM, SPAT, TOPO) on the wireless interface. These messages are generated and/or processed by the AUs.

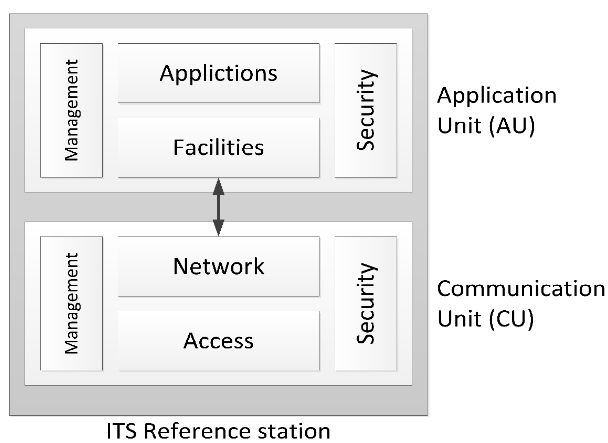

Figure 3. Definition of an ITS Reference station, divided in a application and communication unit.

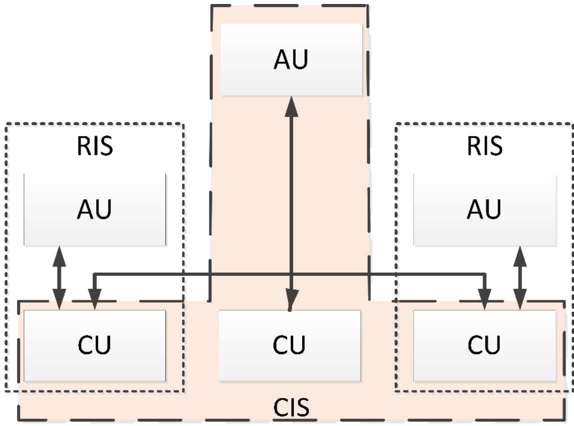

Figure 4. Architecture of the Central ITS Station (CIS), consisting of an AU and multiple CUs, and of 2 Roadside ITS Stations (RIS), consisting of a AU and single CU.

D. Cooperative application platforms

The road side applications are deployed on applications units (AU). Two versions have been implemented. The application unit of a Roadside ITS Station (RIS) runs localized applications, and in general interacts with a single CU. A Central ITS Station (CIS) runs applications on regional level across multiple CUs, see Figure 4. Typically, an AU on a RIS or CIS runs applications for a single project, such as the Basic Set of Applications, or speed optimization and shockwave damping [15]. The application platforms are developed on an OSGI platform [16]. Technically, the same platforms are used for both a types of application units, facilitating the reuse of common components.

1) Facilities on the Application Units

A central component in the facilities layer of the ITS Reference architecture is the Local Dynamic Map (LDM). The LDM is responsible for collecting all relevant, real-time information and to provide a consistent view to the applications. The so-called Dynamap is an implementation of the LDM. It collects all information available for a specific road segment, e.g. for an intersection or for the full 6 km highway. All information is combined and three consistent views are generated at a 10 Hz frequency: a road users view (vehicles, trucks, etc.), a traffic view (traffic flows and densities), and an event view (incidents like slow moving vehicle or a traffic jam tail, etc.).

Although standardization of messages is underway in ETSI and CEN, current practice is that every project has its own version of the various messages. If ASN.1 definitions of these messages are available, java based implementation can be generated easily and replaced or added in the OSGI platform. A communication provider connects to the related CUs. For every type of message that is relevant for the applications on the AU, the communication provider subscribes itself with the CU, based on the BTP port number of that specific message type. Encoding and decoding of these messages is taken care of by a so-called message manager. Different versions of the same message are handled by different message managers. However, as the interface towards other facilities (e.g. the Dynamap) and applications is the same, these can be handled transparently by the higher layers.

2) Applications on the Application Units

Applications are implemented based on the information provided by the Dynamap, In this way, the applications are independent of the underlying sensors, and functions like data fusion, data quality, and graceful degradation can be implemented at a single location, and consistency over different applications can be guaranteed as well.

Several applications have been implemented on the application platform, including traffic jam detection and mitigation, green light optimum speed advise (GLOSA) and several safety warning applications [5] [15] [6].

E. Test Management Center

All components in the sensor, communication, and application platforms can all be used as part of the system under test, or as part of the independent observation system. The validation and evaluation tests and field operational tests are all controlled from the Test Management Center (TMC). The TMC is uniquely used as part of the independent observation system. It contains functions for logging, control and monitoring, and analysis.

A visualization tool (Figure 1. above) allows for direct inspection of all information in the Dynamap. The most important sources of information are the VBM system and V2I messages transmitted by cooperative vehicles.

The logging system is completely data agnostic: any component that wants data to be logged, can define its own data structure, and provide both the data definition (once) and the actual data (periodically) to the logging facility. Three modes of operation are supported simultaneously:

- a high performance mode, typically used by the components directly connected via the fiber network;
- a high reliability mode, typically used by test vehicles connected via 2-3G, and
- an off-line mode, where data is first collected , possibly in another data format, and afterwards imported in the logging system.

Control and monitoring is responsible for the management of experiments executed on the test site: test vehicles are instructed and software is configured for specific tests. The monitoring serves multiple purposes: safety during the execution of experiments, proper operation of all components, and direct observation of the performance and quality of the experiments being executed.

The analysis process is to some extend standardized over several projects. The first step is in the analysis is data cleaning: erroneous data or other useless or irrelevant data is removed. The flexibility of the agnostic logging system, requires that in this step data is converted to a consistent format, e.g. with consistent naming and consistent use of units. Especially for cooperative systems, multiple logging data streams have to be analyzed simultaneously, as the interaction between different systems is crucial. To facilitate

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this, all data is synchronized on fixed timestamps in a second step. Synchronization is required to e.g. extract vehicle distances. In a third step, relevant events like heavy breaking or the transmission and/or reception of a specific cooperative message are determined, and performance indicators are calculated. These performance indicators can be further used for e.g. an impact assessment for e.g. safety, environmental, or traffic flow impact. [17].

IV. Open innovation

The system described above has been developed and operated by partners of DITCM like TNO, TomTom, Peek. The purpose of the DITCM test site is to stimulate open innovation. Therefore, many components have been included from many partners and projects. Open innovations are supported for the objectives of section II. Several examples are given in the following sections.

A. *Innovating cooperative systems*

In the Spits project, field tests were held in 2011 in which the road side infrastructure cooperated with a low percentage of vehicles equipped with a Cooperative Advanced Cruise Control (CACC) or an advisory system [15]. The road side units continuously monitored all vehicles and communicated traffic information to the equipped vehicles. When the road side detected a shockwave, speed advice messages were sent to the equipped vehicles to damp the shockwaves as quickly as possible. shows the tracks of all vehicles in one of the experiments and the response of equipped vehicles to the speed advices. Figure 5. Shows the tracks of all vehicles during one of the tests, where twice a shockwave was induced. These tests demonstrated that, even with a low penetration of equipped vehicles of 10%, cooperative systems can improve traffic throughput.

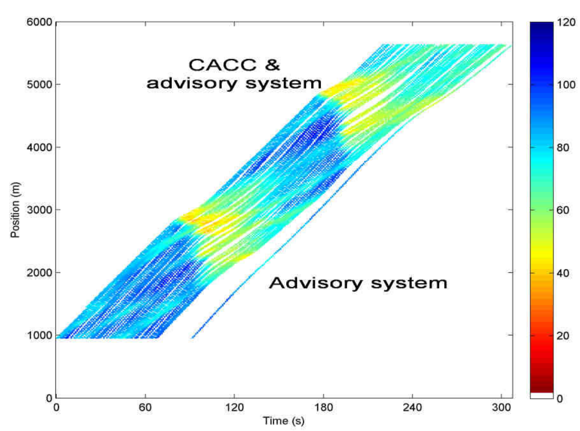

Figure 5. Vehicle trajectories of equipped and unequipped vehicles in the SPITS shockwave damping experiments.

B. *Technical evaluation of cooperative systems*

In the DRIVE C2X project, the project partners have visited the test site several times for a week to test the performance of the DRIVE C2X reference system and applications [18]. Additional components from partners have been installed to provide the roadside applications and communication , including several CUs and a complete RIS (AU + CU). Part of the system under test has been implemented in the test site facilities. Basic technologies like timing accuracy, communication distance and packet loss, and localization quality has been evaluated. See Also the performance of several safety related and traffic management related applications has been evaluated.

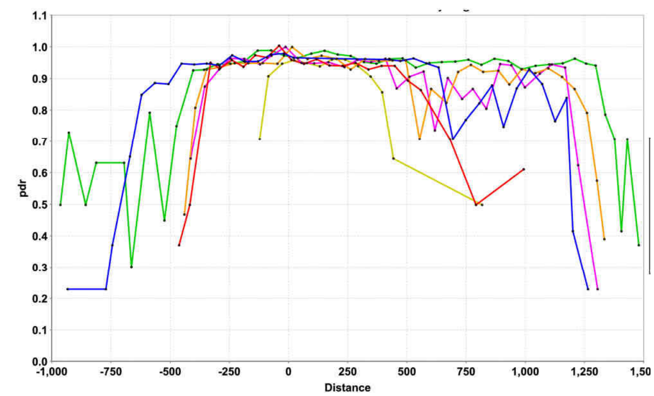

Figure 6. Packet delivery ratio as a function of communication distance for six independent vehicles, as measured during the DRIVE C2X technical testing.

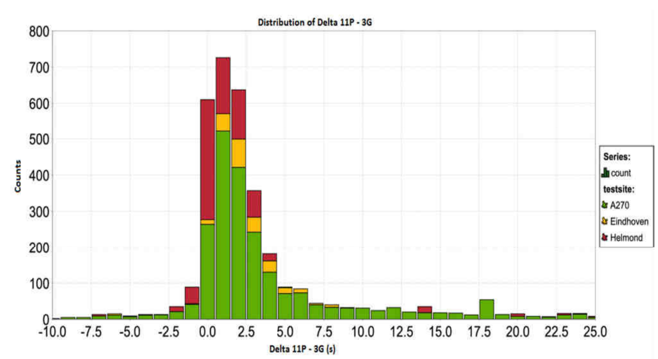

Figure 7. Distribution of the transmission time difference in the G5 and 3G communication channel, measured during the FOT of the Contrast project.

C. *Impact Evaluation*

In the Contrast project a Field Operational Test (FOT) has been designed, implemented and executed in which participants were given in-car speed advice. The aim of the FOT was to determine the impact of in-car speed advice on traffic flow and environmental impact of the mobility system. The test site has been used to detect the traffic state, determine a speed advise, and provide this advice to the vehicles via ITS G5. The TCC has been used to exchange information between test sites in Eindhoven, on the A270/N270, and in Helmond, and to exchange information with TomTom as a service provider. This made it possible to distribute the speed advise on these test sites via a 3G connection to cooperative navigation units as well, see Figure 7. The FOT has been executed in a three-month period, showing a positive effect on the driving behavior of the test persons and their environmental impact.

D. *Monitoring live traffic*

Since the DITCM test site is placed along a currently in-use public road, it allows for live monitoring of traffic using the equipped VBM system. This unique trait allows testing all facets of the system under real life conditions in contrast to controlled experiment conditions. The traffic monitoring system has been demonstrated to be able to track vehicles along the entire test site, giving information about each vehicle as they travel along the five kilometers of highway where the cameras are placed, 100 meters apart from each other. An overview of what these trajectories might look like can be seen in Figure 8. At this level of detail some lane changes can be seen as the lines connecting the two lanes, as well as a very distinct of- and on-ramp around 3000 and 4000 meters respectively.

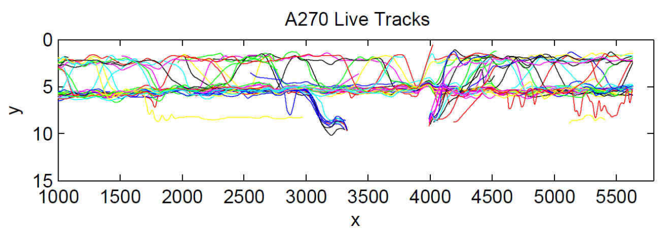

Figure 8. Lateral position of live tracks as registered on the A270. The left and right lane are located at y=3 m and y=6m, respectively. The trajectories around x=3000m and x=4000m show vehicles on the off-ramp and on-ramp.

The continuous stream of traffic information also allows for real-time identification of events that are of interest for traffic operators that are difficult to detect otherwise. Some examples of such events are vehicles driving on hard shoulder or vehicles that have stopped completely. An example of such an event can be seen in the trajectory in Figure 9. as a small horizontal line (no change in distance, over a short period of time) with a still image from the corresponding video.

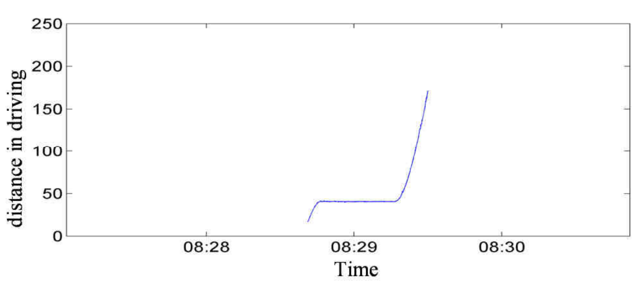

Figure 9. Longitudinal position of a trajectory of a vehicle stopping and accelerating again.

Figure 10. Still image from video associated with Figure 9. Note, that this measurement has been performed on another Dutch highway.

E. *Driver Behavior Modeling [19]*

For simulation of future experiments it is vital to have realistic driver models that accurately characterize human driving behavior for the intended application. To simulate shockwave damping in [15] for example, the models should represent the hysteresis of braking actions while driving into moving jams, and in subsequent jams in stop & go traffic, and include different models of anticipation to predecessors' behavior. Other applications require the modeling and prediction of lane-change maneuvers [19]. The vehicles trajectories logged in normal traffic and in experiments on the DITCM test site provide ample data to develop realistic driver behavior models.

Figure 11. shows simulation results of models trained for shockwave damping in the Spits project [15]. Note that each line of an individual vehicle has a slightly different model that responds slightly different when entering the first and second moving jam. Consequently, larger gaps emerge and dissolve, and the jam front is not progressing monotonously, similar to the recorded field experiments of [20].

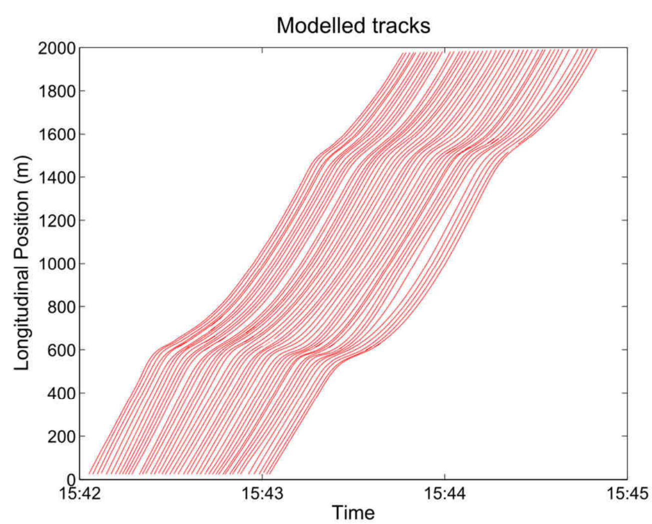

Figure 11. Simulated trajectories

V. Discussion

The DITCM test site has been developed over recent years into an extensive test site for cooperative systems in Europe, in cooperation with many partners and projects. The test site provides facilities for technical and functional evaluation and validation of cooperative systems in controlled tests as well as naturalistic driving tests, on the public motorway and urban roads. Other test sites around Europe, like the testsite from simTD (Frankfurt) [19], Score@f (Yveline) [22], SISCOGA (Vigo) [23], ITS Platform (North Denmark Region) [24], and Testfeld Telematik [25] have a larger geographical extend and larger fleets, and are suitable for functional testing of more cooperative applications. However, the fast density of sensors, communication equipment and application platforms, the flexibility to adapt to specific project requirements, and the possibility to use the same test site for open track and closed track tests, make the DITCM test site more suitable for rapid and flexible technical validation testing.

The test site infrastructure is highly configurable. Third party components, such as road side units, communication units, or cooperative vehicles, can easily be integrated. The road side infrastructure can be applied as part of the cooperative systems under test, or as an independent objective evaluation environment, or a combination thereof. Multiple projects can run simultaneously, each with their own versions of message sets, communication or application units or hardware.

The test management systems continuously monitor and log road side and vehicle data, and provide near real-time data analysis and evaluation for immediate feedback on test results and test control.

The road side systems continuously monitor the communication of all ITS stations and accurately track the movements of all traffic in real time, including normal and equipped vehicles. Driver behavior, safety margins and measures, and distances to events are monitored continuously for both normal and equipped vehicles. From this information, road side units can also generate and broadcast CAM and DENM messages for normal vehicles to emulate any penetration rate of cooperative vehicles of up to 100% on the public roads.

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