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RAILWAY DRIVER ADVISORY SYSTEMS: EVALUATION OF METHODS, TOOLS AND SYSTEMS

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ABSTRACT

This paper adopts a two-stage assessment procedure. First, a wide range of existing on-board algorithms and existing, real-world, DAS applications is identified, using a basis of scientific literature, input from a specifically designed survey and professional experience. Next, the reviewed systems are evaluated using a set of criteria, like: distribution of intelligence, processing unit integration, driver interface, positioning system and communication requirements. The above provides a clear structure for the comparison of DAS. Using it, combined with a professional judgment to take account, for example, of the possibility of using just some components of individual systems, allows a provisional assessment to be made of which systems should be investigated in more detail as potential components of real-world applications. The results highlight major differences in the way that algorithmic intelligence and processing capabilities are distributed between the control centre and the train. They also highlight different approaches to the integration of driver interface, train positioning systems and communication technologies that facilitate the exchange of information between the track-side and the train. The decision to embark on one of the various approaches depends not only on algorithmic issues but also on human factors considerations and the limits of technology and the costs of upgrading it. Practical aspects such as technical and spatial characteristics of the driver's cabin, context and format of the advisory information are also of importance.

Keywords: driver advice system, advisory information, railway driver-machine interface

INTRODUCTION

This paper builds on the research project ONTIME "Optimal Networks for Train Integration Management across Europe", and more particularly on the research for Driver Advice

Systems (DAS). The objective of this research is to develop and assess an integrated engineering and operational approach to improve railway traffic management, using advisory information to reduce energy consumption and increase network capacity without reducing the service quality. The research has been undertaken with support from a stakeholder group representing European Infrastructure Managers, DBNetz (Germany), ProRail (Netherlands), RFF-DCF (France), SBB (Switzerland), RFI (Italy), Trafikverket (Sweden) and Network Rail (UK).

This paper covers the basic methodological steps followed to assess the state-of-art of railway driver advice systems and highlights the basic findings of this research. Work includes: survey of existing driver advisory information systems, discussions with stakeholders, review of the driving needs and characteristics, including technical and human factor issues, hazard analysis, assessment of options for system architecture, train installation and driver interface and finally, formulation of recommendations for further study.

The basic conclusions from the research suggest that the implementation of a driver advisory information system is technically and operationally feasible on European railway networks; performance and capacity benefits are expected in some locations but these are difficult to quantify; the safety impact is expected to be neutral or positive.

Preferred options have been proposed for system architecture, train fitment and driver interface, but it is recognised that, unless the key Traffic Control Centre (TCC) to train interface is defined, there may be a range of solutions for different types of rolling stock and train services.

UNDERSTANDING ADVISORY SYSTEMS

The analysis below defines the context in which a railway driver advice system should operate. This context is delineated by a series of determinants which need to be clearly understood before analysing current practices and technologies. The most important determinants which are tackled by this paper include: driver needs and characteristics, driver-train interaction, and technology compliance.

Driver Needs and Characteristics

While driving the train, the driver's primary goals are to [RSSB, 2002a; 2002b]:

- Ensure safety (this duty takes priority over all other duties);
- Maintain the schedule of the service (as far as possible), and if the above are covered,
- Improve energy efficiency of service delivery, while respecting standard operating procedures (set by the RU).

To meet these objectives the driver must drive the train in a safe and efficient manner, which means:

- Selection of the appropriate train speed, i.e. adopting a speed that does not exceed the various speed restrictions (or otherwise compromise safety), and is sufficient to achieve the service timetable (or minimise delay).
- Monitoring the speed of the train by collecting information from the speedometer and various sources (visual perception of speed, cab noise, and motion).
- Comparing the appropriate speed with the train speed. When the train speed does not match the required one the driver identifies the difference, usually represented as a time or speed gap.
- Using the difference between the required and the actual speed to control the train speed by changing the settings of the power or brake controller.

Managing the service in this way requires the driver to continuously monitor the progress of the train against a series of passing marks and scheduled stops. Without driving advisory/support, the drivers have no guide about progress within the schedule, and only route knowledge and experience allow the driver to judge if the service is running early or late between two timing points. Any temporary speed restrictions within a route, while reflected in the timetable, make the driver's judgements about progress and recovery time more difficult.

Driver-Train Interaction

Integration of the train driver into the DAS design is a multi-stage activity [Dekker, 2008]. This paper will define the framework and the principles for the application of human factors methods in order to help the designers to consider the requirements, capabilities and preferences of the human operator and therefore, to facilitate (or remove obstructions to) his integration. This application framework has the following dimensions:

- The context of operations: how it's to be used, the capabilities and constraints of the system, and the reactions that these cause to the drivers.
- Integration of human operator: how the DAS design should make use of the particular characteristics and support the constraints common to all drivers from their human psychology and physiology, and any additional consideration that must be given to the user preferences and requirements.
- Impact of human operator on systems and processes: the relationship of the human factor with issues like safety and interaction with other systems such as legacy TMS, TMS, etc.

The Context of Operations

By integrating a wide range of data, performing complex analysis and reviewing past performance, the DAS can help the train driver avoid particular biases common to the psychology of all human operators (e.g. selective attention, persisting with an incorrect view of the system or over-confidence), that might otherwise reduce task performance [Wickens and Hollands, 2000]. However, some common problems associated with the use of advisory systems may still occur (not an exhaustive list):

- Ignoring the advice provided: perhaps stemming from low trust, poor understanding or insufficient training of drivers in the use of the system.
- Misinterpretation: the driver fails to use the information provided in the appropriate way, so that the desired performance improvement is not achieved.
- Misuse: the driver uses the system for purposes other than that for which it was intended (for example, the driver may find opportunities to temporarily isolate the system or change set points so that it appears that compliance with the system is good, while no real performance improvement has been made).
- Distraction: the driver attempts to act on advice from the system when other considerations may be more important (for example, by incorrectly prioritising energy consumption over other responsibilities such as maintaining timetable).

Integration of Human Operator

The driver's activities in relation to the human-machine interface permit an understanding of the demands upon the drivers and the requirements for the design. It also provides a way of summarising the various steps required for the integration of human operator needs and constraints into the DAS design:

- Receiving information from the system: The ability of a driver to receive information from the advisory system requires an understanding of human perceptual abilities.
- Understanding the received information: The driver must resolve the information presented through the DAS interface with information from other sources, and his own understanding of the current status of the system. In other words, the driver must interpret the information presented on the DAS in the context of the driving operation.
- Deciding on the most suitable response: Drivers use the information to adjust their driving behaviour. In modern railways the driver has a responsibility to drive safely, meeting the service targets, in an energy efficient manner.
- Applying the decision on the controls: The driver implements the decided response through the train controls.

Impact of Human Operator on Systems and Processes

Key requirement for the design of the format and content of the advice to the train driver is the consideration of the possible hazards that might be introduced by the advisory system. This will allow the identification of safety requirements to guide the DAS definition and interface specifications.

It can reasonably be stated that the main safety hazard associated with the use of the DAS is mishandling of the train, due to equipment malfunctioning or confusion in the driver's mind caused by the messages passed to him. This mishandling may lead to SPAD (Signal Passed At Danger) or over-speed incidents, possibly resulting in collision or derailment [RSSB, 2008a; 2008b; 2008c]. On the other hand, it is claimed that DAS would be capable of reducing the risk of SPADs, due to the net reduction in the number of signals approached at red. Risk of dewirement due to over-speed can be considered to be negligible .

Technology Compliance

A driver advice system aims to provide advice to drivers to optimize traffic flow and/or energy efficient driving [Wardale, 2008]. To achieve this objective there must be technological compliance between the system which monitors progress of the train against the targeted timetable and provides advice to the driver and the various track-side ICT; particularly those in the TCC, which would inform the on-board system when the planned arrival time at station or junction has to be adjusted to avoid conflict with another train [DeltaRail, 2008a; 2008b].

The compliance of the DAS with the following components is of critical importance for the effective design of a driver advice system. They are studied here in very generic terms.

- Traffic Management System (TMS)
- Train positioning
- ERTMS/ETCS

Traffic Management System

When a driver advisory system is implemented, the number of train conflicts that have to be resolved by TMS will reduce, but there are a number of detailed issues that need to be considered:

- TMS predictions of train running are usually based on full speed running, so a train which has been advised to run a reduced speed or coast will run later than expected by TMS.
- TMS calculation of train delays at conflicts take account of starting and stopping of trains; less delay will result if a train is advised to reduce speed and avoid having to stop.

It should be possible to use the same data sources and algorithms for conflict detection in a driver advisory system and in TMS. This could be based on updated TMS algorithms enhanced with additional sources of information, such as temporary speed restriction data and more precise knowledge of train location and speed.

Train Positioning

Signalling detection

Signalling train detection is the established technology used today by signal operators and automatic route setting systems to predict and manage conflicts between trains. Advantages of this positioning technology are: position information is available for all trains, without depending on any equipment installed on the train; information is available in real-time at the TCC for the area in which the train is running, and nationally in other TCCs within a few seconds; coverage is continuous on fitted routes.

Disadvantages of this technology include: train location is reported only when a train passes onto a new signal berth (every km or so on main lines, but much more widely spaced on secondary routes). There is no reporting at intermediate points, and no reporting of position of stationary trains; train speed is unknown, except by inference from the time between successive reporting points; train location is not directly available onboard; train location is not available on secondary routes using absolute block or token working.

Satellite Navigation

Advantages of the GNSS train positioning technology include: standard GPS is relatively cheap to install and maintain (equipment only has to be fitted on the train, and many trains are already fitted with one or more GNSS systems); speed and location data is available on the train with sufficient accuracy to provide real-time advice to the driver over a high proportion of the rail network.

Disadvantages of the GNSS technology are: until Galileo and GLONASS come online there is only a single supplier of the data; rail environment will block all GNSS signals at some locations, requiring other data inputs (e.g. inertial navigation or odometry) to improve coverage; a communication channel is required if the information is to be used in the TCC as well as on the train; mapping from GNSS co-ordinates to a position on the railway network is required if the information is to be used for conflict prediction in a TCC.

ERTMS/ETCS

There are two significant obstacles to using ERTMS/ETCS as an element of a driver advisory system:

- The benefits from a driver advice system would only be realised on those parts of the network fitted with ERTMS/ETCS.
- As ERTMS/ETCS is a standardised and safety critical system; making modifications to it to incorporate driver advice functionality will be very expensive.

TECHNOLOGY STATE-OF-ART

A review has been undertaken in this paper to identify existing systems that provide advice to drivers on optimising rail traffic flow or energy efficient driving. To do so data was collected form various sources, including:

1. Literature and web sources
2. Advice from Infrastructure Managers (IM) and Railway Undertakings (RU)
3. In-house experience and know-how

Information from IMs and RUs partners was collected using personal interviews. The identified DAS with their most featured characteristics are presented below.

Table 1 – Existing systems and key characteristics

System	Description	Comments
CATO	Objectives:	Good trial of

System	Description	Comments
Transrail, Sweden	▪ Achieve improved energy efficiency and optimised capacity on the network ▪ Ensure no train stops at a signal on its planned route Key functions: ▪ Two-part system, CATO-Train and Control Centre. ▪ Provide optimized target date to drivers ▪ Calculate the most efficient driving pattern	integration of traffic control and driver advisory. Without a closed feedback control loop.
RouteLint Prorail, Netherlands	Objectives: ▪ Improve communications between drivers and dispatchers to acquire energy-efficient driving and improve punctuality. Key functions: ▪ High speed data link between trains and control centres ▪ Speed adjusting (acceleration, braking, coasting) according to real time train traffic information	Provide route setting information ahead to the drivers.
Automatik Function Systransis/ Thales BLS, Switzerland	Objectives: ▪ Avoid stops in the tunnel ▪ Gain time in cases of conflict ▪ Achieve a smooth traffic pattern in the tunnel Key functions: ▪ Provide a recommended order for trains through the tunnel's single-track section. ▪ Provide "advisory speed" to drivers approaching the single-track section.	Successful application of simple driving advisory integrated with ETCS-2 on a single track line with junctions.
FreeFloat DB, Germany	Objectives: ▪ Guide trains in real time to avoid conflicts so as to reduce delays and energy consumption Key functions: ▪ The system has two control loops: inner control loop and outer control loop. ▪ Generate updated rescheduling decisions for the drivers with the consideration of traffic control.	Good trials on driver advisory taking traffic control into consideration.
GEKKO DSB Denmark	Objectives: ▪ Indicate drivers to be on correct pathway. Key functions: ▪ Implemented with a PDA device ▪ Request timetable and infrastructure information to calculate optimal speed profiles for the drivers.	Demonstration of onboard PDA linked to the central server.
FreightMiser TTG Australia	Objectives: ▪ Improve energy consumption / punctuality of freight rail Key functions: ▪ Calculate optimal speed with different journey time ▪ Calculate optimal coasting points during the journey and provide the information to the drivers	Specific driver advisory system for freight trains.
LEADER Knorr-Bremse	Objectives: ▪ Reduce energy consumption ▪ Reduce the in-train forces ▪ Provide optimal driving advisory strategies Key functions: ▪ Calculate train behaviours on the basis of rolling stock and infrastructure data ▪ Calculate energy efficient driving strategies for the train drivers	Good trials to include function of reducing in-train forces in driver advisory system.
AVV AZD, Czech Republic	Objectives: ▪ Achieve automatic train operation (ATO) ▪ Save energy using advanced train control Key functions: ▪ Reduces train speed or stops the train in accordance	Claimed achieved Energy savings up to 30%. Not only purely driving advisory,

System	Description	Comments
	with absolute speed limits, signal indications and timetabled station stops ▪ Automatically set the vehicle to coast	but also automatic coasting execution.
Dresden S-bahn TU Dresden, Germany	Objectives: ▪ help an S-Bahn driver operate his train efficiently with respect to energy consumption and downstream conflicts Key functions: ▪ Inform the drivers of the time to departure ▪ Offer drivers three driving strategies including cruising and coasting	Stand alone system with COTS products. Energy savings of between 7 and 12 percent have been reported.
ESF - EbuLa DB, Germany	Objectives: ▪ Reduce CO2 emissions ▪ Reduce energy cost Key functions: ▪ Calculate the optimal time to shut off traction power ▪ Display train driving advisory information for drivers	Deutsche Bahn saved €32 million by energy-efficient driving between 2002 and 2005.
Driving Style Manager (DSM) Bombardier	Objectives: ▪ Advise drivers about speed, acceleration and deceleration to minimise the energy consumption Key functions: ▪ produces an energy-optimised driving style (EODS) with the consideration of temporary or dynamic speed indications and signaling information	Integrated with ETCS DMI. Trials to provide unified operational system for different countries worldwide.
FARE SBB, Switzerland	Objectives: ▪ To maintain the connectivity of service pairs Key functions: ▪ Train rescheduling to maintain the OD pairs ▪ Provide drivers train advisory information to implement train rescheduling decisions	The system aims to maintain railway connections with integration of train rescheduling and control.
Fassi/ EcoTrainBook Erzgebirgbahn, Germany	Objectives: ▪ Reduce energy consumption by train driving advisory Key functions: ▪ Show the drivers different energy consumption with different driving styles ▪ Provide driving recommendations	The system provides a kind of decision making assistant for drivers on driving strategies.
Trip Optimizer GE Transport USA	Objectives: ▪ Energy saving driving with close loop speed regulation Key functions: ▪ Calculate optimal cruising speed and display in the cab for train drivers.	Installed in GE locomotives. Optimal cruising speed is displayed lineside at stations.
Energy Efficient Timetabling, France	Objectives: ▪ Save electricity energy consumption ▪ Save investment of power infrastructure using lower peak load Key functions: ▪ Calculate start and end of each coasting zone (CZ) and speed within each recommended speed zone (RSZ) ▪ Provide static printed CZs and RSZs to drivers	Static driver advisory to provide CZs and RSZs. The project experience shows that CZs and RSZs are stable for train paths.
TCAS Research/BR, UK	Objectives: ▪ Make good use of train coasting to reduce energy consumption and braking maintain cost Key functions: ▪ Monitoring train running against timetable ▪ Calculate train coasting points for drivers	Initial trial for train driving advisory with simple but efficient functions.
MetroMiser Siemens, Germany	Objectives: ▪ Provide energy efficient driving with energy optimized timetables.	DAS for light-rail, metro and suburban systems,

System	Description	Comments
	Key functions: ▪ Timetable optimizer for calculation of energy optimized timetables ▪ On-board unit to calculate and provide optimal driving advisory information	Provision of optimised timetables and optimised driving profiles.

Following the revision of existing advice systems it is important that they are classified so as to draw firm and structured conclusions regarding the desired characteristics of the suggested DAS. There are two dimensions to consider when categorizing driver advice systems. One is the type of information presented to the driver that determines his/her degree of freedom to decide on the best-suited driving strategy. The other one is related to the interactivity of the DAS (static or dynamic exchange of information) with the track-side systems.

As regards to the information presented to the driver, we have identified three main classes of information that are provided in practice, sometimes in isolation and sometimes in combination with one another.

- Explicit driving instructions: a current speed target or a speed profile over time, or advice to speed up, slow down, or coast.
- Temporal information: telling the driver whether the train is running early or late with regard to the optimum speed profile to realise the timetable.
- Decision-support information: such as gradient profile, energy usage, or position of other trains.

As concerns the scope and interactivity of the DAS the systems presented above fall into three main categories:

- Fully static: Simple systems that provide the driver with (predefined) timetable information and other generic advice on paper or on a screen. The French paper-based system and the German and Swiss electronic timetables are typical examples. They are also the only systems that are in widespread use today.

- Semi-dynamic: Systems that aim to provide the driver of a train with dynamic advice on how to drive the train in an energy-efficient manner to a pre-defined (static) timetable. Examples of this are LEADER, FREIGHTMISER, and GEKKO. Several examples of such systems appear to be well developed, but with take-up by only a few heavy freight operators.

- Fully dynamic: Systems that aim to optimise traffic flow for the railway network as a whole, by dynamic re-planning the timetable to avoid conflicts, and providing advice to drive the trains in accordance with the new plan. These systems are still at the concept stage, with significant research projects under way in Switzerland and Germany.

Within this “territory” the following sections discuss the available options for the implementation of a DAS.

POTENTIAL SOLUTION ALTERNATIVES

In this section, possible alternatives are considered for implementation of a driver advice system. They relate mainly to the technological-mix and the driver integration options that need to be included in the design of DAS.

Technology mix

The technology mix required for the development of the DAS corresponds to five different layers: system architecture, processing unit integration, driver interface, train positioning and communications. For each layer, the main alternatives are examined and the advantages and disadvantages of each alternative are described. Some initial conclusions on the appropriateness of certain alternatives are drawn, and recommendations are given for possible action during the system's design stage.

Layer I: System Architecture

i. DAS Intelligence entirely at the TCC (alt.I-1)

Under this alternative all the intelligence of the driver advice system is deployed in the control centre, and the onboard system only displays information to the driver. The architecture requires that the following functionality is provided by the TCC: tracking of train movements; prediction of future train movements; conflict detection and resolution; calculation of new target train timings to avoid conflicts; calculation of energy efficient speed profile for each train; and calculation of driver advice information to achieve target timings.

The TCC data requirements include static and non-static (or quasi-static) data. Static data corresponds to the network geography and timing point locations; gradients; permissible speeds and train characteristics. The non-static data refers to the temporary speed restrictions, timetable and train composition.

- Advantages: the system can be implemented using an existing driver interface, avoiding any additional equipment on the train; no requirement for the RU to manage onboard static and dynamic data.
- Disadvantages: the TCC needs information about train characteristics to calculate minimum energy speed profile; content of information display to driver is limited to what can be calculated in the control centre; dynamic update of compensatory feedback to driver is limited by latency in communications and train position monitoring at TCC, which might result in a sub-optimal speed profile.

Alternative I-1 seems to offer a practical and economic solution for possible DAS roll out, provided that there has been an agreement between IM and RUs on commonly accepted energy-saving strategies. Once the TCC advice components are in place it could be implemented on a widespread basis for trains with a suitable existing driver interface, and there will be minimal investment and data management costs for the RUs. However, the limitations of using an existing interface and making all the computation at the TCC will constrain the type and format of information to the driver.

ii. DAS Intelligence distributed between TCC and onboard (alt.I-2)

Under this alternative the intelligence is distributed between the TCC and the train in the following manner: (a) the onboard component calculates an energy-efficient speed profile to achieve the pre- planned or dynamically updated train timings, and generates detailed driver advice to follow the profile and achieve the timings; (b) the TCC is responsible for conflict detection and calculation of new target train timings to avoid conflicts.

The architecture requires that the following functionality is provided by the TCC: tracking of train movements; prediction of future train movements; conflict detection and resolution; and calculation of new target train timings to avoid conflicts. The TCC data requirements include static and non-static data. The static data corresponds to the network geography and timing point locations. The non-static data refers to the temporary speed restrictions and timetable. Similarly, the onboard component functionality would include: update of onboard timetable with new target train timings; real time train location; calculation of driver advice information to achieve target timings; and display of driver advice information. Onboard data requirements include static data which corresponds to gradients, permissible speeds and train characteristics; and non-static data which refers to the temporary speed restrictions, timetable and train composition.

- Advantages: this solution minimises the need to exchange information between TCC and onboard in real-time because the functions are allocated to the system that already has access to the required data (data is processed where it actually lives); information display to the driver can be tailored to the type of train operation and rolling stock characteristics; the onboard driver advice can work to a pre-planned timetable if communication with the TCC is not implemented, or as a migration step for future upgrading.

- Disadvantages: RU has to manage provision and update of route and timetable information to the onboard system.

This is clearly an attractive alternative, as it puts the intelligence where it is easiest to access the required data, and allows for optimum interfacing with the driver and with other relevant TCC systems. The architecture achieves optimisation of running to a pre-defined timetable using the onboard system, independently of the TCC.

iii. DAS intelligence entirely onboard (alt.I-3)

Under this alternative all the intelligence of the DAS is concentrated on the train. The TCC is capable of (existing) manual and automatic route-setting, but does not provide centrally any traffic management information. This implies that, if detection and resolution of conflicts between trains is to be achieved, each train must be able to predict when it will be in conflict with another train and adjust its target timings accordingly. As a result each train needs access to information about the planned and actual running of other trains.

The architecture requires that the only functionality provided by the TCC is tracking of train movements. Real time communication between TCC and onboard system includes regular updates on the movements of other trains in the area. The TCC data requirements are minimal under this option. Similarly, the onboard system functionality includes: prediction of future train movements; conflict detection and resolution; calculation of new target train timings to avoid conflicts; update of onboard timetable with new target train timings; real-time train positioning; calculation of driver advice information to achieve target timings; and display of driver advice information. The onboard component data requirements include static and non-static data. The static data corresponds to the network topology and timing point locations, gradients, permissible speeds and train characteristics. The non-static data refers to the temporary speed restrictions, timetable and train composition.

- Advantages: the system can be implemented without a TCC based component (except for disseminating existing train running information to DASs on trains).

- Disadvantages: conflict resolution is being carried autonomously by each train and by automatic route setting systems in the TCC – this may result in non-optimal or conflicting solutions with no provision for a manual override by TCC staff; large amount of data need to be transmitted to each train in real-time; RU has to manage provision and update of route and timetable information to the onboard system, and a much more inclusive database is needed including also timetable information for other RUs' trains.

This alternative is sub-optimal as the onboard system is being expected to undertake tasks that would be better performed once by a TCC based component. The only reason to select this option would be where an IM is unwilling to invest in the control centre part of a DAS.

Layer II: Processing Unit

The second set of technological options to be considered relates to where the algorithmic intelligence is located and, therefore, where data processing is taking place. Six alternatives have been identified, including: data processing undertaken only at the TCC; data processing in a stand-alone system; data processing integrated with DMI; data processing integrated with third-party application requiring communications and/or position services; data processing integrated with ERTMS/ETCS; and data processing integrated with TMS.

i. Data processing only at the TCC (alt.II-1)

This alternative is only possible when architecture alternative I-1 is chosen, i.e. all the processing takes place in the TCC, so that the onboard component of the DAS is only the means of receiving communications and displaying it to the driver.

- Advantages: Minimum equipment on the train.
- Disadvantages: See disadvantages of architecture alternative I-1.

ii. Onboard stand-alone system (alt.II-2)

The most straightforward option for the architecture alternatives requiring significant data processing on the train is to provide a dedicated processor unit installed in a suitable location with convenient access for maintenance, and linked by cable of wireless connections to the DMI and any other interacting systems.

- Advantages: Installed with minimum interaction with cab and other onboard systems.
- Disadvantages: Requires a dedicated space and connections to other equipment.

iii. Integrated with DMI (alt.II-3)

As the DMI is an essential element of DAS, a logical approach is to integrate the data processing into the DMI. The obvious example is when the complete onboard system is a portable device like a road vehicle SatNav, but it could also be applied to a permanently installed DMI.

- Advantages: Reduces the number of modules to be installed.
- Disadvantages: Maintenance access may be more difficult for a processor installed in the driver's desk and might lead to the replacement of the full unit in case of partial failure of a component.

iv. Integrated with other application(s) (alt.II-4)

Alternatives IV-3 and V-3 (see below) describe DAS use of a position system and/or communication capability shared with other applications on the train. It is already common practice for the position and communication functions to be integrated into a single package. Suppliers of these systems often provide a modular architecture that allows other functionalities to be integrated.

- Advantages: DAS shares enclosure, power supply etc with other systems; Exploits shared services with minimum train wiring.
- Disadvantages: Limits choice of suppliers for DAS and full-unit-replacement maintenance policy as described above.

v. Integrated with ERTMS/ETCS (alt.II-5)

As identified in alternatives III-3, IV-4, V-5 (see below), an onboard ERTMS/ETCS system can provide DMI, positioning and communications facilities for a DAS. A logical conclusion of this would be to integrate DAS functionality with the European Vital Computer (EVC), which provides the onboard data processing for an ERTMS/ETCS fitted train.

- Advantages: access to ETCS DMI, positioning and communications without external connections; avoids duplicate transmission and storage of route and train information that is relevant to both ERTMS/ETCS and DAS (e.g. temporary speed restrictions); implementation of DAS on a high integrity platform will minimise the risk of system errors that could mislead or distract the driver.
- Disadvantages: development of DAS software to signalling standards of safety and integrity could be very expensive; ERTMS/ETCS is a standardised European system and suppliers will be reluctant to adapt their products to provide DAS, unless there is a mandatory European standard.

vi. Integrated with Train Management System (alt.II-6)

Modern trains are fitted with a train management system that provides positioning and communications functionality, together with a dedicated diagnostic display in the cab. Driver advice functionality could be provided as an additional TMS function without any additional hardware, on new trains or as an upgrade to existing trains with TMS functionality.

- Advantages: driver advice system can be implemented with minor hardware modifications; static and non-static data (e.g. timetables, train formation) can be shared with other TMS functions.
- Disadvantages: can only be procured from the existing TMS supplier; modification to existing TMS may be expensive to develop and validate; the DAS is constrained to positioning, communications and DMI capability of the existing system.

Layer III: Driver Interface

A key element of a DAS is the driver interface also known as Driver-Machine Interface (DAS-DMI). As the driver needs to be able to observe it regularly whilst the train is in motion, it has to be positioned in his field of vision on or around the cab desk [RSSB, 1995]. Five options have been identified: portable device on the cab desk, dedicated DAS-DMI permanently fitted, integrated with ERTMS/ETCS DMI, integrated with TMS DMI, integrated with GSM-R DMI.

i. PDA in cab (alt.III-1)

With this option, the DMI system is implemented in a portable device carried by the driver. If the complete system is implemented in the portable device, this is equivalent to a road vehicle SatNav device. Alternatively, the portable device could be linked via a wired or wireless connection to other parts of the system installed permanently on the train.

- Advantages: minimum hardware cost; easy replacement of faulty unit; cab installation limited to providing a holder; static and non-static data can be loaded into portable device away from the train and carried on to the train by the driver.
- Disadvantages: portable device vulnerable to mismanagement, loss or damage.

ii. Exclusive DAS-DMI (alt.III-2)

A possible option for the driver interface is to permanently modify the dashboard to accept a dedicated display screen for the DAS. As with the portable device, this could either be a complete system in one box, such as a tablet PC, or simply a display screen connected to other systems installed elsewhere on the train.

- Advantages: screen size and information display can be optimised for the application.
- Disadvantages: difficult to find space in existing cabs and expensive to install.

iii. Built-in ERTMS/ETCS DMI (alt.III-3)

The majority of new trains and some long-life existing trains will be fitted with ERTMS/ETCS, and the ETCS DMI will become the primary display device in the train cab, providing the speedometer function even when the train is operating under conventional signalling. From an ergonomic and installation viewpoint, the ETCS DMI will be the optimum place to display driver advice information.

- Advantages: driver advice well integrated with other information used by driver for primary speed control tasks; driver advice system can be installed without cab modifications.
- Disadvantages: depends on vehicle being fitted with ERTMS/ETCS; depends on ETCS DMI software/hardware being capable of integrating display data from another source.

iv. Built-in TMS DMI (alt.III-4)

New trains are fitted with a Train Management System (TMS) with a dedicated diagnostic display in the cab. This could be used to display also DAS information to the driver, especially if the TMS supplier provides the DAS functionality.

- Advantages: driver advice system can be implemented without cab modifications.
- Disadvantages: TMS DMI provided for diagnostic purposes may be in a location that is difficult for driver to read while driving the train; DAS can only be procured from the existing TMS supplier; modification to existing TMS may be expensive to develop and validate.

v. Built-in GSM-R DMI (alt.III-5)

The GSM-R cab radios to be fitted to the majority of European train fleets over the next few years will provide a text message display in a position in the cab that is easily read by the driver. To use this facility for DAS, the information to the driver would be sent via a SMS message to the cab radio. This DMI option is well matched to architecture alternative I-1 in which the advice to the driver is generated in the TCC.

- Advantages: driver advice system can be implemented without cab modifications.
- Disadvantages: format for advice is limited to text; frequency of update of DMI is limited by capacity and latency of GSM-R text messaging infrastructure and TCC processing component - frequency of update is also severely limited by the driver's cognitive limitations and other human-factor considerations.

Layer IV: Train Positioning

All of the DAS architectures require a means of determining train location (and also train speed, as a matter of fact) in real time to allow comparison with an energy efficient speed profile that will achieve the target arrival at timing points and junctions. Five options have been identified: dedicated GNSS positioning system with or without integrated antenna, shared GNSS positioning system on the train, ERTMS/ETCS positioning system, and train positioning with information available from TCC.

i. GNSS with built-in antenna (alt.IV-1)

This alternative requires a dedicated GNSS positioning system. It is particularly appropriate in conjunction with DMI alternative III-1, where all the functionality for the DAS is embedded in a portable device like a road vehicle SatNav.

- Advantages: no external connections required.

- Disadvantages: location of the equipment in the train cab means that satellite communications will be obscured for longer as compared to a GNSS with external antenna; lack of interface to other train systems limits opportunity to improve coverage by augmentation from other data sources such as odometry.

ii. GNSS with external antenna (alt.IV-2)

Where the DAS is permanently installed on the train, the performance of a dedicated GNSS location system can be enhanced by connection to an antenna on the train roof.

- Advantages: reduced obscuration of satellite signals compared with option IV-1.
- Disadvantages: installation of additional antenna on train roof and cable to the DAS; GNSS signal obscurity zones compared with options IV-4 and IV-5.

iii. Shared GNSS (alt.IV-3)

Unlike the previous options, this one requires the existence of a shared GNSS positioning system on each train, providing accurate time and position information to all the functions that require it.

- Advantages: avoids multiple antennae installation on train roof and associated wiring; cost of integrating augmentation technology such as inertial measurements and odometry is shared between multiple applications; can be combined efficiently with a shared communications gateway (alternative V-3).
- Disadvantages: if not already installed, will add cost compared to a GNSS system dedicated to DAS.

iv. ERTMS/ETCS positioning (alt.IV-4)

A train fitted with ERTMS/ETCS maintains a record of train location and speed using track mounted position reference balises and odometry. This function operates continuously irrespective of the ETCS mode and level of operation, so it would be available for an ERTMS/ETCS fitted train running on a conventionally signalled route, provided ERTMS/ETCS fixed balises are installed in the track.

- Advantages: train positioning is not affected by features which obscure satellite signal reception on the train.
- Disadvantages: location information is only available where there are balises installed in the track; the ERTMS/ETCS onboard computer has to provide a data interface to make the location information available to the DAS.

v. Train positioning with information available from TCC (alt.IV-5)

An alternative to train based positioning is the use of train location information from the TCC. With current technology this is based on signalling train detection, which only provides location information when the train passes fixed locations on the track. This positioning option is most appropriate for use with architecture alternative I-1, and when the driver advice is based on time targets rather than speed.

- Advantages: no train installation required.

- Disadvantages: train positioning is inaccurate, based on fixed signal berth locations; instantaneous speed measurement is not possible; position information is not available on secondary lines using absolute block or token working.

Layer V: Communications

For driver advice systems, communication between track-side and train-side is very important to transfer data onto trains and backwards. Seven options have been identified: 3G/GPRS data communications network, with or without integral antenna, 3G/GPRS data to a communications gateway on the train, GSM-R text messaging, ERTMS/ETCS data communications, data transfer to the train by a local system at depot, data transfer to the train via a portable device.

i. 3G/ GPRS to DAS with built-in antenna (alt.V-1)

Data communications to moving trains is easily provided via the public mobile radio providers. This solution uses mainly GPRS (over GSM) and 3G, but WiFi or WiMax may also be available in some locations. The simplest installation option is to mount the data terminal within the DAS equipment on the train with an integral aerial.

- Advantages: no external connections required to DAS equipment.
- Disadvantages: communications coverage may be poor in some area; potential electromagnetic compatibility problems (EMC) from interaction between the antenna and other cab equipment.

ii. 3G/ GPRS to DAS with external antenna (alt.V-2)

Where a DAS with integral data terminal is permanently installed on a train, the communications and EMC performance can be enhanced by use of an external antenna on the roof of the train.

- Advantages: the only external connection required is the antenna.
- Disadvantages: installation of additional antennae on train roof and associated wiring.

iii. 3G/ GPRS to a communications gateway onboard (alt.V-3)

It requires the existence of a shared communications server on each train, providing high capacity digital data communications for a range of onboard applications.

- Advantages: avoids multiple antennae installation on train roof and associated wiring; can be combined efficiently with a shared positioning system (alternative IV-3)
- Disadvantages: If not already installed, will add cost compared to a communications system dedicated to DAS.

iv. SMS via GSM-R (alt.V-4)

In principle, alternatives V-1 to V-3 could make use of the dedicated railway GSM-R network in addition to public networks, but many IMs' policy is to reserve the limited capacity of GSM-R for operational voice communications and ERTMS/ETCS. Although several European GSM-R networks have not yet been enabled for GPRS data communications, GSM-R provides a text message service which would be an appropriate channel for small packets of information, e.g. SMS to be presented to the driver, or new target arrival times. This option would be particularly appropriate for use with architecture alternative I-1 and DMI option III-5.

- Advantages: no communications charges from public wireless network operator; better coverage of railway routes than public mobile radio services.
- Disadvantages: limited data capacity.

v. Data communications via ERTMS/ETCS (alt.V-5)

ERTMS/ETCS level 2 requires continuous data communications channel between the TCC and the train. This is implemented using the EuroRadio protocol over a GSM-R circuit to a dedicated data radio on the train. The ERTMS/ETCS standards allow text messages to be sent to the train for display on the ERTMS/ETCS DMI, and this is the facility used in the DAS that has been implemented for the Lötschberg tunnel in Switzerland.

- Advantages: no communications charges from public wireless network operator; where available, provides a highly dependable and secure communications channel.
- Disadvantages: only available for an ERTMS/ETCS fitted train on a Level 2 fitted route; any functionality beyond text message display on ETCS DMI will require modification to safety critical ERTMS/ETCS equipment to provide the required functions and interfaces.

vi. Manual data transfer at depot (alt.V-6)

Where driver advice is being provided by an onboard system using the pre-defined timetable only, there is no need for real time communications with the TCC. However, there is still a need for some form of data communications to provide the onboard system with the static and non-static data required, such as route information and timetables. The non-static data requires to be updated at regular intervals, at least weekly and possibly daily. This is most easily achieved in a depot which the train regularly visits for servicing, either by a wired connection (e.g. download from a laptop) or via a local wireless link.

- Advantages: no communications charges from public wireless network operator.
- Disadvantages: physical link requires manual effort, wireless link requires infrastructure in depot; DAS cannot respond to real time updates from TCC; risk of onboard data becoming outdated if depot visit missed.

vii. Manual data transfer via a portable device (alt.V-7)

If the DAS is installed on a portable device that is carried onto the train by the driver, then the static and non-static data can be pre-loaded into the device at the location where the driver starts a turn of duty. This can usefully be combined with re-charging of the batteries of the portable device. Similar functionality could be provided for a fixed system on the train, using a memory device such as a smart-card.

- Advantages: no communications facility required on train; portable device can be used to record driver preferences and monitor performance.
- Disadvantages: portable device vulnerable to mismanagement, loss or damage; DAS cannot respond to real time updates from TCC.

Technology-mix Preliminary Evaluation

As discussed above there is a wide range of alternative solutions that could be used for the development of the DAS. A preliminary assessment of the solutions that appear most promising for further investigation is given below.

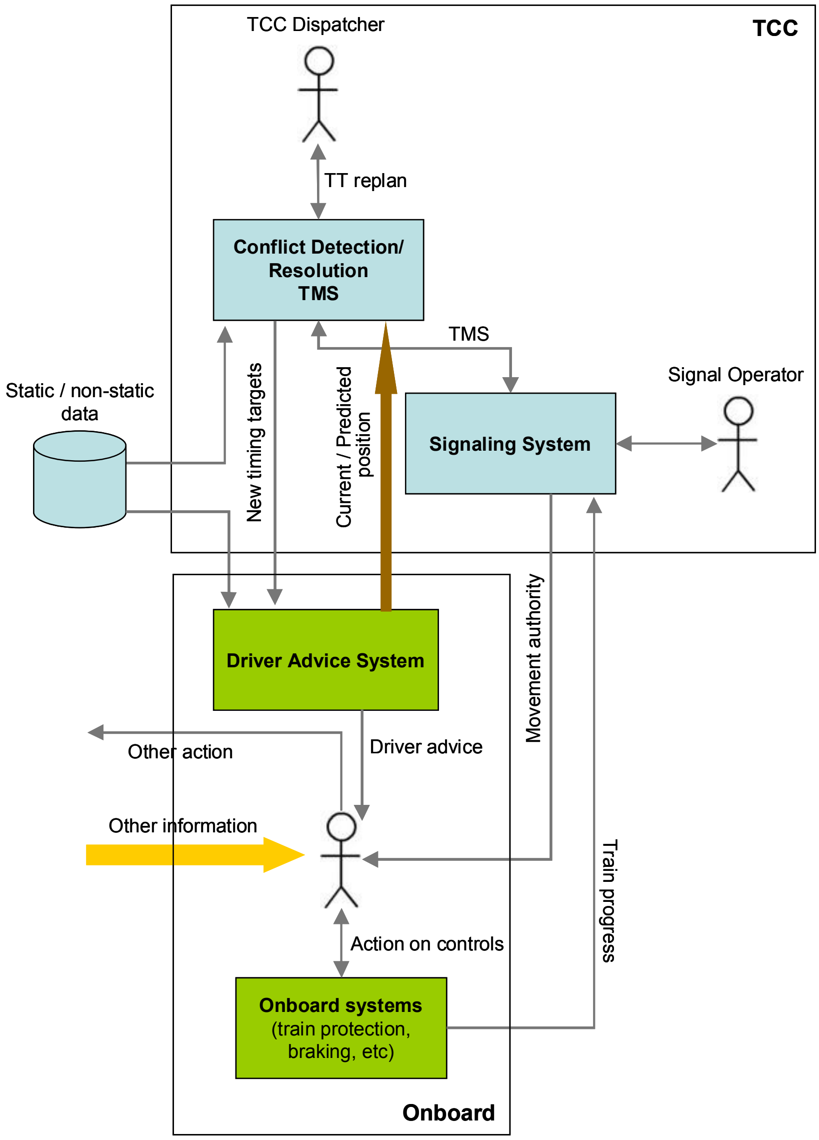

Figure 1 – Alternative I-2 general architecture

Architecture alternative I-2 seems to be the most attractive relative to the needs of modern railways. Following work should include an outline specification for the interface between the TCC and the onboard components of the DAS, in the context of a “Network-Dynamic” system type as defined above.

Alternative I-1 could be possibly considered as a fall-back solution. It is potentially an attractive option for train fleets where retro-fit of an onboard DAS is undesirable. Alternative I-3 it is recommended to be dropped and not studied further.

Driver Integration

Following the analysis of the possible technological options for the development of a driver advisory system, this section deals with basic factors influencing the integration of the human operator to the DAS design. This paper considers three such factors which are mainly related to the information presented to the driver by the DAS:

- Alternative context of advice (what information is important to the driver).
- Alternative forms of advice (how the information is transformed to advice).

These alternatives are described in more detail below and their advantages and disadvantages are assessed.

Context of Advice

According to Wickens and Hollands [2000], advisory systems present instructions to the operator in either a “follow-me” or “trade-off” fashion. Follow-me type of systems make more frequent incremental changes in the target which the operator must constantly track, while trade-off (or compensatory) systems make single discrete changes in the target that the operator must attempt to achieve, minimising the difference. Follow-me systems will require more attention as they require the operator to make many small changes in his controls over a period, but have the advantage of providing accurate control.

Based on these principles, the following alternatives are presented to demonstrate a possible way that the DAS could guide the driver. Clearly, energy efficient advice for real operations may be more complex, and will be specific to the train, its composition and the route over which it is running.

i. Static target (alt.VI-1)

Under this solution the DAS presents the driver with target times at the various waypoints in a journey. These targets could be presented as a timetable, or in a countdown format. Such information would support energy efficient driving by aiming to reduce deviation from the target timetable.

- Advantages: the static target only changes once the next target is applicable; the static target requires little computer processing, i.e. the DAS is operating as a database, storing and presenting discrete values; as monitoring the train’s positions is a direct responsibility of the driver, this solution would require little additional training or formal changes to the driver role.
- Disadvantages: benefits achievable by this system are limited to those available from reducing the variance in departure, passing and arrival times.

ii. Dynamically updated target (alt.VI-2)

With this solution, the advice system is able to receive new target times, so that the service schedule can be altered during the journey. This information would be provided by a traffic management facility external to the train. In its simplest form, such a system would only provide the driver with the revised target times during the journey, requiring the driver to adjust his driving strategy to account for the new information.

- Advantages: this solution offers the benefits of reducing the variance in departure, passing and arrival times. The ability to receive revised schedule information offers the additional benefit of controlling trains approaching congested areas, reducing unnecessary braking and acceleration.
- Disadvantages: if this solution is implemented, it would require additional communication infrastructure to transmit the revised schedule to the train. It would also require a traffic management facility capable of issuing revised schedule instructions. The latter may present some technical and organisational challenges to the existing railway operation.

iii. Contextual advice (without target setting - alt.VI-3)

This solution presents no specific driving target to the driver. Instead it gives contextual information regarding the permanent or dynamic characteristics of the track, route, train and traffic. These characteristics might include: the distance of the train in advance, the current and approaching permanent speed restrictions, the location and status of key infrastructure features (e.g. signals), the gradient profile of the route, etc. The contextual information is provided with no instruction on how the driver should respond (no explicit driving advice), but rather provides background information for the driver to decide how to use it.

- Advantages: the track characteristics may be simply collected from the infrastructure database and the signalling system.
- Disadvantages: the driver is responsible for discovering the most efficient way of driving between two landmarks on the track, under the conditions indicated by the DAS. With no clear means for finding optimum profiles, and no mechanism to assess the drivers' behaviour efficiency, the benefits of such a system are limited to those solutions (see predefined speed profile solutions below) that the driver can find through experience (only drivers with good route knowledge would achieve satisfactory results).

iv. Predefined speed profile (alt.VI-4)

This solution presents the driver with the scheduled target times but also uses an optimum profile for driving between the waypoints such that energy consumption, for instance, is minimised. This optimum profile could either be based on past (best-practice) performance and be stored in a database or could be calculated by an algorithm, allowing for the consideration of variable operating factors such as train length, load, temporary speed restrictions, etc. As the driver proceeds through the route, the DAS provides feedback about the progress of the train relative to the optimum profile, and indicates if the train is achieving the optimum profile, i.e. is running too fast or too slow.

- Advantages: as the driving advice is changing in response to the driver's performance, the trade-off or compensatory advice increases as the train departs from the optimum profile. This would allow the driver to incrementally adjust his driving strategy to maintain the optimum profile; this system offers the benefits of reducing the variance of departure, passing and arrival times, and of maintaining a more efficient driving profile between waypoints.

- Disadvantages: when for some reason there are changes in the speed required by the optimum profile, the DAS would have to indicate this to the driver to allow him to prepare for the speed change, and minimise the deviation from the optimum profile at the speed change point.

v. Dynamically updated speed profile (alt.VI-5)

Under this option, in addition to the scheduled departure and arrival times, the DAS generates the most energy efficient profile at frequent intervals, reflecting the train's recent progress. The first profile at the start of a journey represents the optimum solution (saving the most energy, for instance), and as the driver deviates from that solution, the DAS performs calculations to provide the best profile for the remainder of the journey. This differs from the predefined speed profile system of alternative VI-4, as the DAS advice does not encourage the driver to return to the fixed optimum profile, but uses an algorithm to recalculate the best performance that can be achieved as the journey is progressing.

- Advantages: this solution offers the benefits of reducing the variance of departure, passing and arrival times, and of maintaining a more energy efficient driving profile between different locations.
- Disadvantages: requires a considerably more sophisticated algorithm, onboard data collection and advanced data processing capabilities; as the recommended profile and the returned advice keeps changing during the journey progress, it makes the information presented to the driver more difficult to follow - the more frequently the recalculation is performed, the more distracted the driver will be; although this solution offers benefits in terms of timekeeping, it is not clear that the speed recalculation would offer the opportunity to save much more energy than a simple fixed speed profile.

Form of Advice

This section considers the alternative solutions for the form of the information to be presented to the driver in the cab. The suggested form should make the advice readily recognisable and easily resolved alongside the other driving information presented to the driver. Possible forms of information to be presented to the driver include:

i. Timekeeping (alt.VII-1)

For example, difference in the actual time at a particular point in the route and the target time, current target departure/arrival time, etc.

- Advantages: is a reasonable way to indicate changes in schedule information when the DAS can receive revised service information, offers clear, recognisable instructions.
- Disadvantages: assumes that the timetable is feasible and optimised for the service.

ii. Suggested speed (alt.VII-2)

For example, difference in current speed and target speed, current target speed and duration, target advisory speed, etc.

- Advantages: speed information is an effective way to specify schedule targets; it offers clear, recognisable instructions.
- Disadvantages: there is a risk of over-reliance to the system advices, which may make even more necessary to couple DAS with automatic train protection against overspeed.

iii. Energy savings (alt.VII-3)

For example, difference between current and target rate of consumption, or simply current and target rate of consumption.

- Advantages: besides timekeeping, energy efficiency is generally the most important performance parameter that the DAS seeks to optimise.
- Disadvantages: this solution provides no information about the schedule targets or performance of the service against the timetable; energy consumption is not evenly distributed through the journey, but would have peak consumption at acceleration points and minima during cruising or braking – this would make difficult to provide useful advice to the driver; this solution requires trains to be fitted with energy metering equipment.

iv. Action on Controls (alt.VII-4)

For example: coast instruction, tractive power, brake pressure, etc.

- Advantages: clear, recognisable instructions.
- Disadvantages: may be difficult to describe the output of the energy efficiency algorithm in terms of train control settings; this kind of information may be regarded as patronising to a trained, skilled driver.

Preliminary Evaluation of Driver Integration Options

As concerns the advice context, it is recommended that solution VI-4, fixed speed profile, is retained as the preferred option for further consideration for a DAS design.

Alternative solutions VI-3, contextual advice and VI-5, dynamically updated speed profile, while offering some benefits, do not seem to be as promising as solution VI-4. Alternative VI-3 requires considerable specific route data or train communication infrastructure, and does not give direct advice to the driver. Alternative VI-5 seems to offer little energy-reduction benefits over solution VI-4 but is more technically demanding to implement and may present the driver with a less transparent system and more demanding tracking task. Alternative solution VI-1, static time target, may offer some of the benefits of advisory information but makes less demand in new information collection, algorithm specification, computer processing and offers a simple addition to the driver's task. It is recommended that this option is retained as a fall-back solution, but further study is required to collect more information about the deviation from scheduled arrival, passing and departure times at journey waypoints in day-to-day rail operations.

Regarding the advice form, it is recommended that a combination of solutions VII-1 timekeeping, and VII-2 speed format, is retained as the preferred option for a DAS design.

Solution VII-1 seems to be more appropriate for experienced drivers who have better ability to choose an energy-efficient driving strategy when target timings change. This option supports the drivers existing responsibility for monitoring train progress against the timetable. Solution VII-2 on the other hand provides better assistance to the inexperienced drivers in energy-saving driving. But this solution is more susceptible to confusion with safety critical speed or signalling information and will be most affected by possible latency in the system. The problems of solution VII-1 may be soluble with solution VII-3, energy savings, but this alternative is regarded as more problematic than solution VII-2. Alternative solution VII-4, action on controls, will not be further considered.

SUMMARY AND RECOMMENDATIONS

There is a clearly preferred option for system architecture in which the intelligence is distributed between the control centre and the train.

- The onboard system calculates an energy efficient speed profile to achieve the pre-planned or dynamically updated train timings, and generates detailed driver advice to follow the profile and achieve the timings.
- The TCC is responsible for conflict detection and calculation of new target train timings to avoid conflicts.

As concerns the technology-mix that could be used to implement a DAS, there is a wide range of options. These options differ according to the type of train, and whether the trains are new or retro-fit is required to the existing fleet.

For new trains, a solution could be to integrate the DAS interface into the ERTMS/ETCS DMI, which is located in an optimally in front of the driver. Train positioning data should be obtained from a shared locator unit, which uses GNSS positioning supplemented by other data sources to provide the required level of coverage over the railway network (ERTMS/ETCS location using balises is an alternative for trains which operate on restricted routes). In terms of data communications, a 3G/GPRS facility could be used for downloading the static and non-static route and timetable information, and also real-time train timing updates from the TCC.

For existing trains that are not programmed for ERTMS/ETCS fitment in the foreseeable future, one of the following alternative options may be preferable: (a) use of a portable device to provide the driver interface. This could be totally self contained with its own GPS and communications capability, or linked (via wired or wireless network) to a locator unit and communications gateway elsewhere on the train; (b) use of GSM-R text messaging as the means of advising the driver, and hence avoid the need for any additional equipment on the train (assuming a GSM-R cab radio is already fitted).

Regarding the context of advice, the recommended approach to design of the driver interface is as follows:

- The driver advisory system should operate on the basis of a fixed speed profile with feedback as the journey progresses. This implies that when the train passes a timing point, the system will calculate an energy efficient speed-time-distance profile to achieve precise on-time arrival at the next timing point. The system will then monitor deviations from the profile and advise the driver. The speed profile will only be updated if a new target arrival time is requested from the control centre.

- The driver interface should be able to display both timetable information and speed advice to the driver in the form of: (a) target times at particular waypoints through the journey, and (b) speed increments and decrements when deviating from the optimal speed profile. This would encourage punctual departure and arrival in service and would help maximize energy saving.

- The driver interface should provide information through a combination of visual and aural information – with detailed information presented in the visual display, constantly available for reference, and the significant changes in the status of the advisory information indicated to the driver through aural warnings (and, possible, spoken advice), reducing the need to constantly monitor the visual interface and minimising the visual workload.

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