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The train communication network in the trains of FS fleet: optimisation, integration and interoperability of railway functionality

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Abstract

Here are described the activity of research, test, commissioning and conformance assessment carried out by the Italian Railway to introduce the Train Communication Network in the vehicles of the fleet. This system can be considered like a train infrastructure capable to configure itself automatically and to connect, through common interfaces, all the on board electronic equipment. The network transfers along the train a great amount of data, both in cyclical and sporadic way, and this allows to realise new applications and to improve the existing one; among the first we have the Passenger Information System and the Centralised Train Diagnostic, for the second the most important is the Remote Control for Traction which equips all new locomotives like E 402A, E 402B, E 412, E 464, the steering coaches Z1 and the TAF Electrical Multiple Units. The Remote Control is here examined in some details, mostly because FS - TRENITALIA is the unique railway operator which has put in composition and made work together vehicles from different manufacturers in such a complicated application. For this reason, FS promoted inside the international assembly (*Union International des Chemis de fer*) the developing of conformity evaluation procedures and tools, which led to have at disposal open standards and the corresponding facilities to perform the tests. TRENITALIA has one of the three existing UIC-TCN Test Beds in the world capable to assess the conformity of TCN equipment which support UIC applications (remote control, diagnostics, passenger information system, doors, etc.) and some homologation experiences, methods and results are considered. Since the beginning of year 2001, push-pull trains using Remote Control have been put into service on the north-south and west-east corridors of Italy and the results of exploitation have shown the great benefits of this technology.

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Generality

The introduction of a digital communication network on FS - TRENITALIA vehicles fleet derives from the need to provide the new electronic locomotives with a modern and high performances remote control system, suitable both to multiple traction and to push-pull trains.
The story started at the end of the '80, when the IEC (International Electrotechnical Commission) in collaboration with the UIC (Union Internationale des Chemins de fer) set up the WG22 (Working Group 22) to define a Train Communication Network (TCN) and the interfaces among train programmable equipment; in this way it would have been possible to achieve the plug-compatibility both between vehicles and between the devices aboard a given vehicle. The result has been the TCN standard (61375-1) and a complementary set of UIC leaflets which defines the applications relying upon the train bus and guarantees their interoperability. The flexibility of this system has encouraged a global train approach, equally for closed and open compositions, allowing to introduce new functions - like passenger information, seat reservation, centralised diagnostic applications, ... - together with the most traditional ones like traction and vehicle control. FS has been a pioneer in the exploitation of these techniques and faced since the beginning the problems deriving from the implementation of TCN on existing vehicles of different manufacturers: this has led to have an active role in the normative, technological and engineering fields, to arrive to have IC trains commonly running, with good operative outcomes, on the Italian network.

The Train Communication Network

The Train Communication Network (see figure number 1) is constituted by communication *gateways*, or *nodes*, put in the vehicles and interconnected by a train bus or WTB (Wire Train Bus); inside a certain vehicle, gateways interfaces themselves to a vehicle bus MVB (Multifunction Vehicle Bus) which joins the electronic equipment inside, thus allowing a coded information exchange among all the devices in the train.

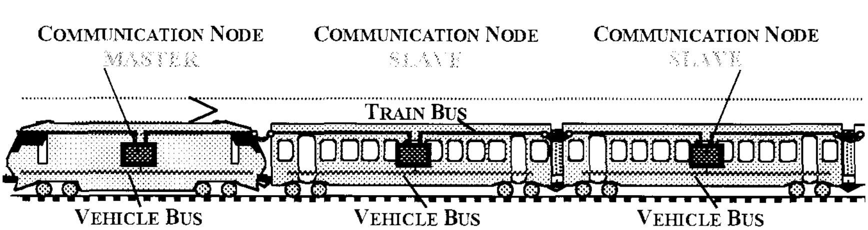

Figure 1: TCN architecture.

TCN architecture is hierarchical and offers many degrees of freedom because nodes without MVB, as well as nodes with more MVB segments may exist.

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WTB and MVB communication processes are managed with a master-slave philosophy through a polling extended to all the two busses participants; in any case this strategy does not imply the existence of a single point of failure because each gateway can become master on the WTB and, on the MVB, more *bus administrators* are generally available and work together using a passing token.
The TCN offers two transmission services to the applications: *variables* (Vs) and *messages* (Ms) whose main difference is that while Vs are broadcast at regular intervals by a sender to a certain number of subscribed receivers, Ms are *event driven* and are transmitted on demand with a point to (multi)point connection subject to collisions: so the delays introduced by the network for Ms are not deterministic. Vs are particularly suitable to represent *process data* associated to remote traction control (see figure number 2).

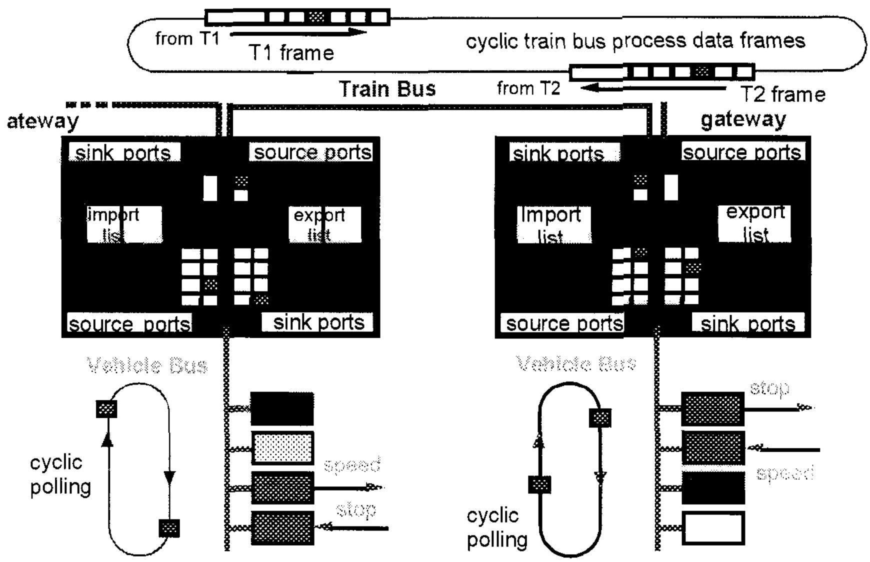

Figure 2: Variables transmission.

On the contrary, Ms are typically used to transfer, long non repetitive telegrams as the diagnostic ones (see figure number 3).

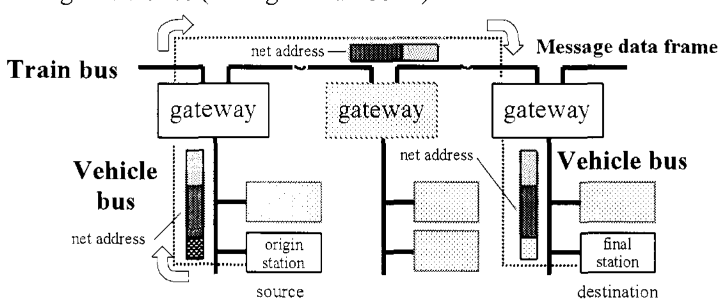

Figure 3: Messages transmission.

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The structure of the system permits an automatic configuration according to the available resources and it is particularly suitable to work on open trains. Such a facility derives from a particular start of normal operation, which is called *inauguration*. During this phase, the gateways electrically connect the various WTB cable sections in order to form a single bus segment terminated at its ends; in addiction each gateway receives a unique address which identifies its position and orientation in relation to travel direction. To ensure that all nodes share consistent information and that proper addressing of Vs and Ms data takes place, the WTB master generates the *topography* of the train which contains the number, the position and the node descriptor of each gateway; the topography is sent to the slaves and all the nodes share a copy of it. When a change in train composition occurs, the master generates the new topography and dispatches it before the start of normal operations. The node descriptors defines which kind of V *datasets* the node publishes on the busses and which are the functions it supports; in addition it identifies also the different kinds of vehicles belonging to the Railway Administration. Beyond the node descriptor, each gateway has a vehicle descriptor which includes detailed features of the vehicle; the elements of this structure are defined in UIC Leaflet 556. In the following table number 1, the main features of TCN are reported.

Table 1: Characteristics of WTB and MVB.

Characteristics	**Wire Train Bus**	**Multifunction Vehicle Bus**
Structure	Automatically configured bus, recognition of orientation and position of nodes at each change of composition	Fixed structure and device addresses.
Medium	Shielded, twisted pair, 120 Ω, 860 m, 32 nodes with a standard cable (22 vehicles).	ESD: twisted wire pair, biased RS485 ; (20m, 32 devices); EMD: shielded twisted wire pair isolated by transformer (200 m, 32 devices); OGF: optical glass fibre (2000 m, 2 devices - star coupler).
Physical redundancy	Duplicated physical medium.	Duplicated physical medium.
Signalling	Manchester with preamble.	Manchester with delimiter.
Signalling data rate	1 Mbit/s.	1,5 Mbit/s.
Physical address	Point to point and *broadcast*.	Point to point and *broadcast*.
Frame size	Variable: 4 - 132 bytes.	Quantified: 16, 32, 64, 128, 256 bit.
Medium allocation	By one master.	By one master.
Link layer services	***Process Data*** cyclic broadcast. ***Message Data*** sporadic point to point or broadcast. ***Supervisory Data*** sporadic and cyclic bus management data.	

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The signalling used for the train bus requires a dedicated channel constituted by a twin shielded cable, part of the UIC 18 poles cable, according to UIC Leaflet 558 (see figure number 4).

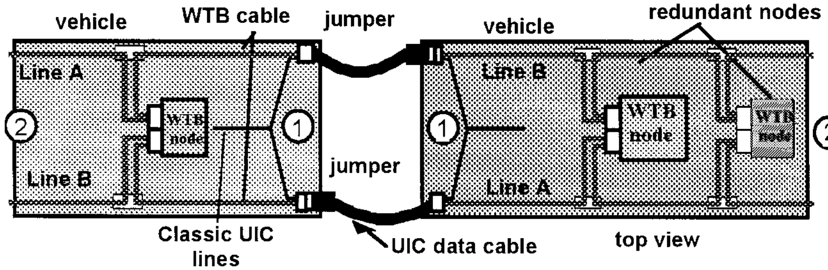

Figure 4: 18 Pole UIC cable and gateway application.

Although the new vehicles, as well as the ones to be refurbished, will be equipped with that cable, the most common available cable in FS fleet is the old UIC 13 poles. After an extensive test campaign to characterise the existing transmissive channel, it was seen that lowering WTB signalling speed from 1 Mbit/s to 500 kbit/s it is possible to use the not dedicated channel, avoiding to install the 18 pole cable, thus delaying TCN adoption. This solution, named TCN*, is fully compatible to the standard because the gateways support both modalities and no practical functional difference is perceivable by the user.

The remote control for traction

The remote traction control is a particular application which uses TCN to transfer commands, states and measures, both analogue and digital, among the connected devices to assure the remote control of the not attended traction units; the controlled devices may be totally different in nature, provided that they are compatible with reference to the interpretation of information. The train run and the remote control takes place from a vehicle with an active driver's desk: this is the *traction master* and its gateway, is the one which sends driving commands using R1 telegrams. All other gateways are connected to led vehicles which execute the setting derived from the leading vehicle and send R2 or R3 (coaches) telegrams.

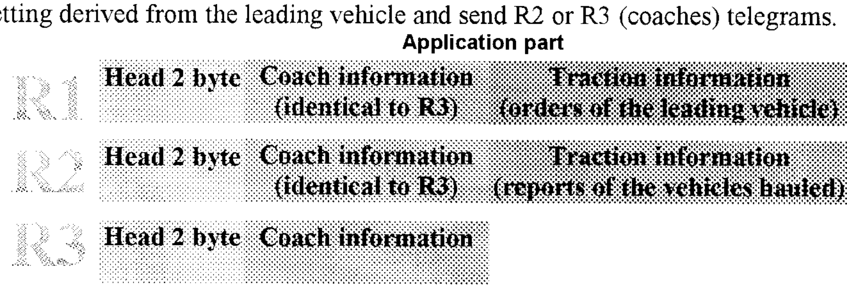

Figure 5: UIC Telegrams

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In the network, the leading vehicle is the only one to transmit R1 telegram, while the other emit R2 (or R3 for coaches) telegrams: these correspond to different formats that consent a continuous verification of the data that they transport; it is worthy to note that the network master is a node located in any vehicle, not necessary the one in the leading vehicle (i.e. a locomotive or a steering coach). The singleness of R1 emission is taken into particular account for the safety of this application and that possible conflicts due to the presence of more leading vehicles are immediately controlled and solved by the software: in this case traction is inhibited and all units bring themselves in a safety status; the driver then intervenes with the proper recovery operations. For instance, in case of electrical locomotives, any unstable situation, however created, is taken in charge by the system that forces a stable status following transition similar to those of figure number 6.

STABLE STATUS	DESCRIPTION
1	m. sw opened & panto down
2	m. sw opened & panto up
3	m. sw closed & panto up
4	Ready for (remote) control
5	Torque positive

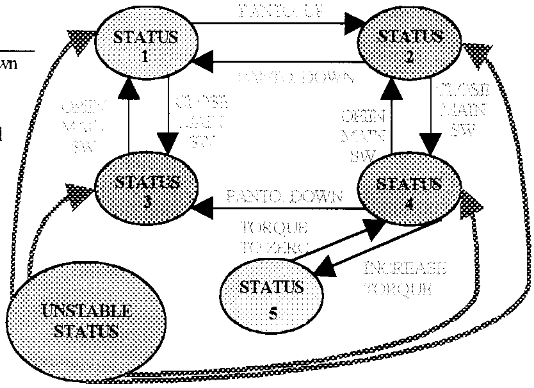

Figure 6: Transition between unstable and stable states.

Many are the independent tools used to verify the correctness of the transmission, but principally to the supervision and the protection of each operation performed by the remote control. Some basic characteristics of the system are synthetically reported in table number 2.

Table 2: Remote control general characteristics.

1	The vehicles in the composition are not subject to any limitation in their direction: side 1 (or 2) of a vehicle may be arbitrary coupled with side 1 (or 2) of another vehicle.
2	Each vehicle equipped with an active gateway fixes its position in the train composition during the inauguration and is automatically addressed by a number.
3	TCN forecasts automatic directional recognition for full vehicle orientation.
4	The leading vehicle knows the last led vehicle in the composition.
5	The nodes notify the leading vehicle their permanent and dynamic properties.
6	Wrong and missing commands or TCN faults do not cause danger conditions.
7	Each node can be removed from the composition without loss of continuity.
8	In case of remote control failure, each vehicle reaches a stable status.

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The presence of more traction vehicles in a train originates new and delicate management problems - let's think for example to the command of pantographs in multiple-voltage vehicles - but big efforts to induce the most logical and simple automatic driver's behaviour have been made. The various remote control function have been collected and described in detail into the UIC leaflet 647, initially implemented by TRENITALIA, where the reference to a *functional model* (see figure number 7) greatly helps in the standardisation and interoperability task.

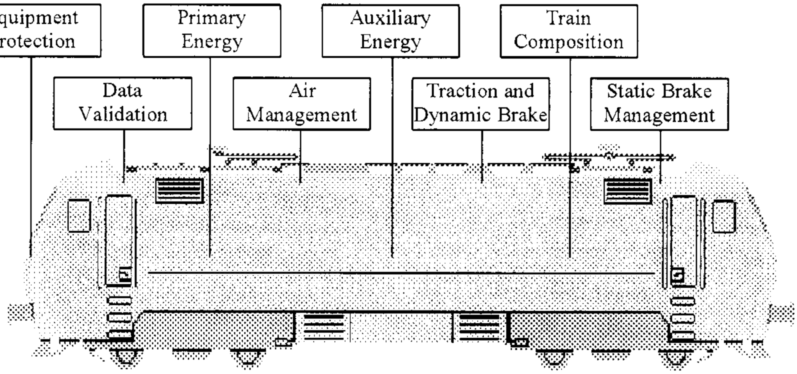

Figure 7: Locomotive functional model.

As example of the concept for traction, electrical braking and speed control, a model (figure number 8) used for MVB and WTB signals is reported hereafter.

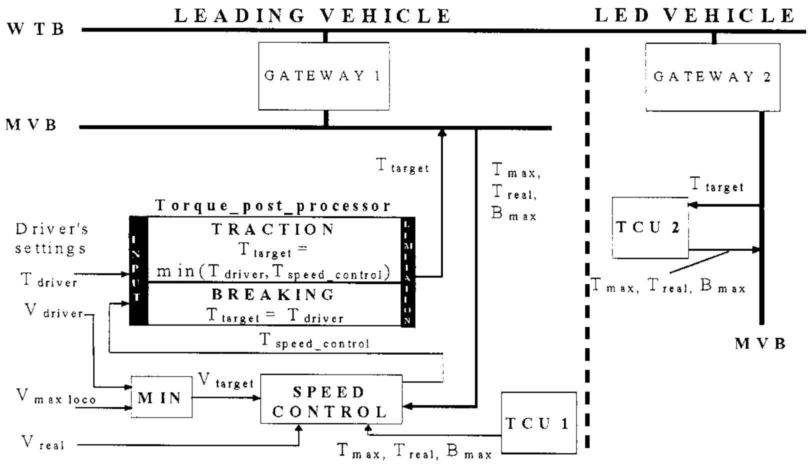

Figure 8: Remote control. Speed controller on the leading vehicle.

Traction torque is given in percentage for each traction unit: the leading vehicle sets a percent value and applies to all the vehicles in the train. Thus, each traction

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unit develops a different absolute torque but the single relative exploitation is the same. In the leading vehicle the driver fixes the values of the desired torque and speed T_{driver} - V_{driver}; the *Torque_post_processor* produces T_{target}, on the basis of the speed *controller output* $T_{speed\_control}$ and of T_{driver}, depending on traction or breaking command. All these values are expressed in %: positive value means traction torque, while negative value means dynamic brake; T_{target} is the value transmitted to all vehicles. To control traction at the receiving side, the T_{target} value in % is translated into an absolute target value in kN according to the characteristic diagram of the given traction unit. In the most general case, each *traction control unit* TCU feeds-back T_{max} and B_{max} (respectively maximum traction and breaking torque that the vehicle can perform at that speed) plus T_{real} (real - traction or breaking - torque performed by the vehicle at that speed) to allow more sophisticated speed controller implementation. To this rationale, a set of WTB signals correspond in the UIC 647 leaflet and their adoption consent to get this working independently by the effective internal vehicle architecture.
This simplified description covers the fundamental control type which must be owned by all vehicles to reach the interoperability, but more complex control types exist and these permits to solve the various and specific traction modalities, like the case in which a speed controller is not available on the leading vehicle.

The homologation of gateways and applications

On the basis of the elements given, it is clear that, to have real working and interoperable applications relying upon TCN, it is necessary establish the conformity of the gateways and of the software stack which equips them. The type_approval of the train bus nodes, for the vehicles that run in international traffic, is set by the UIC Steering Group 5R and it checks the external behaviour of a gateway, to decide if it is compliant with train bus UIC leaflets. This is accomplished testing the conformity of the inauguration mechanism, of the data traffic (Vs and Ms) and of the implementation of the UIC *mapping server*, that is the software module which maps the UIC train bus functions into the real vehicle configuration. To this purpose a *UIC test bed*, that is an equipment to be attached to the node under test which stimulates the execution of test cases and/or the record of the results, is used. The logical architecture of the test bed is depicted in figure number 9, while the real FS TRENITALIA facility is shown in figure number 10.

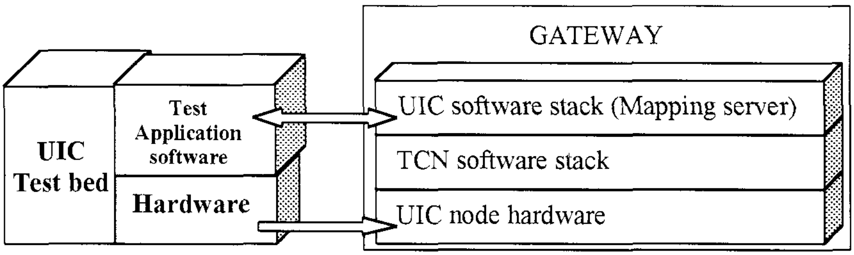

Figure 9: Logical architecture of the UIC test bed

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The main elements of the *test bed* are: 1. Personal Computer with MVB interface and I/O card (50 pin ribbon cable interface); 2. WTB line monitor to measure inauguration duration (connected to the MVB interface); 3. Test rack containing equipment to manipulate gateway connections, to generate power on/off commands, to control MVB, to host the reference gateways used to get data from the WTB. (The devices under test may be put inside or outside the rack and shall be equipped with their own power supply); 4. Power control of maximum six devices under test outside the rack which can be manipulated independently of each other.

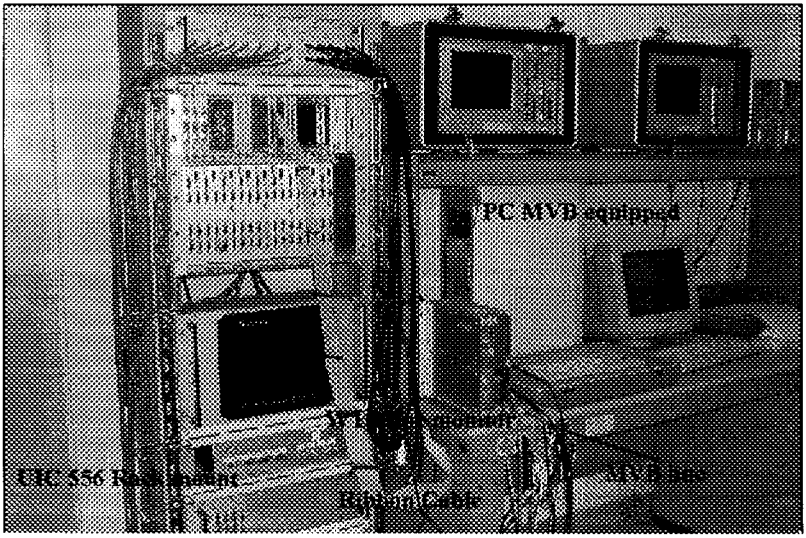


Figure 10: FS-TRENITALIA homologating *test bed*

In the test bed runs a *UIC testing application*, which consists of many hundreds of different steps, repeated in many *Test Train Configurations*: a sample of the test sequence is reported in figure number 11.

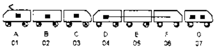
Step	action	expected result	checks	expected configuration
1	power up of A - G	TCN/UIC inauguration with A - G: ordering according to rule "c"	• unconf. NADI (8 entries) • no leading vehicle	
2	confirm ordering	UIC inauguration with A - G: ordering according to rule "c"	• inauguration data (A - G: "UIC address set") • conf. NADI (8 entries) • no leading vehicle	see above
3	set leading request on G_2 in dir1	UIC inauguration with A - G: ordering according to rule "a"	• inauguration data (A - G: "conf. configuration", info on conf. configuration; G_2: requests leading in dir1) • conf. NADI (8 entries) • leading vehicle G_2 = 01	

Figure 11: The start of the UIC test in Test Train Configurations number 1.

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To have *legal value* for international traffic, all these tests shall be carried out in suitably equipped and approved laboratory; at the moment only three exist: two by German manufacturers and one at the Technical Direction of TRENITALIA, the only at disposal of a railway operator.

The InterCity train service in FS network

All these activities have naturally led to the commercial exploitation of push-pull Intercity trains on the Italian network. The compositions normally forecast an E 402A locomotive, some coaches - Z1, Eurofima, *Gran Confort* (up to 14, typically 11) and a steering coach SPZ1.

Figure 12: E402 A in Milan - first FS loco used for in TCN push-pull trains.

The service develops on 18 different turn days, that means that 18 complete set of rolling stock runs together: it results that something like 50 trains a day runs using these techniques from Milan to Reggio Calabria and from Milan to Venice. After a first period of natural tuning both of the system and of the whole process (setting up the trains, maintenance, training, hidden faults elimination, etc.) the obtained outcomes are positive because the average utilisation increase of the traction unit is about 20% and the need of personnel reduces of a similar amount, but above all the stop time due to shunting in head stations has a strong cut. These tempting figures constitutes only the beginning of a diffusion to other kind of locomotives like the E 402B, that already support remote control.
In conclusion the benefits which derive from TCN are many because the network is designed to host a lot of different, efficient, modern and powerful application more and more suitable to improve the intrinsic quality of the railway transport, thanks to the integration in a system view of all train functions.