Towards a Safer Railway Traffic Management Based on a Backup Decentralized Wireless Positioning System

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***Abstract*-Nowadays railway traffic is managed automatically using Centralized Traffic Control (CTC) systems. Despite these systems are very robust, they are not free of failures. In those situations, traffic management has to be performed manually increasing the probability of accidents due to the occurrence of human errors. Advances in wireless communication technologies and distributed systems enable the design of new intelligent transportation systems that could be used in conjunction with CTC systems. This paper identify some security weaknesses in the way in which the railway traffic is regulated in emergency situations and presents a backup decentralized traffic management system which is focused in the resolution of these deficiencies, providing additional security levels and services.**

Keywords-Railway Traffic Management; Emergency Situation; Security; Decentralized Wireless Positioning System

I. INTRODUCTION

Intelligent Transportation Systems (ITS) are becoming very valuable instruments for supporting the railway traffic management and improving its security. In fact, nowadays railway traffic is managed automatically using Centralized Traffic Control (CTC) systems [1]. These systems rely on wired communications and can handle in a centralized way the location of trains, state of the signals, status of level crossing, orientation of the needles, among other railway traffic management issues. The application and systems that handle these tasks are very robust and its reliability is close to 100%. But problems occur when these systems fail. In those situations, traffic management has to be performed manually and through voice communications between traffic operators and railway drivers. Advances in wireless communication technologies and distributed systems enable the design of new systems that could be used in conjunction with CTC systems, replacing them in case of fail or complementing them when they work, being able to provide additional security levels and services.

The work presented in this paper is the result of the work done during the last four years in collaboration with a railway operator company of the north of Spain. Firstly, how the railway traffic management is currently done using its centralized system (CTC) will be analysed. Once the security weaknesses in the traffic management are identified, the way in which the implantation of a backup decentralized system could improve the traffic management and its desired working will be described. Secondly, the technical design of the distributed positioning system for managing the railway traffic in emergency situations that has been developed will be shown. Finally, the methodology applied to validate the reliability of this backup system previously to its implantation, as well as the results obtained will be detailed.

II. SECURITY WEAKNESSES IN RAILWAY TRAFFIC MANAGEMENT

Traffic management is a fundamental activity to ensure the safety of any railway system. The main objective of the traffic management is safeguarding the integrity of people, vehicles and the railway installations; ensuring the fulfilment of transport services (of people or goods).

The main activities that involve the traffic management in the railways (as well as any regulation of vehicles) are based on the control and coordination of the regulation elements: (1) light signals, (2) needles or track change systems, and (3) barriers or protection elements (of the level crossings).

Most of the railway traffic management systems are automatic or semi-automatic and are based on electronic devices deployed both on the tracks and the regulation elements. Normally all these devices are controlled centrally from a single seat of command or control center, although in some cases (if the railways are complex) there may be several control centers. Therefore, it could be argued that the intelligence of such systems is concentrated in large systems that simultaneously receive the information from the regulation elements, as well as indications of the location of the trains (obtained from the physical contact of the wheels of trains with devices installed on the tracks).

Although railway traffic management systems are very robust, when these systems fail, traffic regulation tasks have to be done manually. In such situations, the security of the entire railway system lies on the regulation operators. They have to ensure the security of the railway system through voice communication with train drivers. Such situations of degraded operation increase the stress of people since a failure in the orders of regulation can lead to an accident. For this reason, efforts are ongoing to define new procedures and support systems to assist regulation operators in emergency situations (when the main traffic control system does not work properly). The aim is to reduce human errors caused by these situations.

Table I shows the main differences between the automatic and manual railway traffic management.

TABLE I KEY DIFFERENCES BETWEEN AUTOMATIC AND MANUAL RAILWAY TRAFFIC MANAGEMENT

Activity	Normal Situation	Downgraded Situation
Control of the light signals	Automatic	The state of the light signals ceases to be valid
Track change systems	Automatic	It is possible that the planned route changes will not be performed
Protection elements	Automatic	There is no guarantee that work
Positioning of the trains	From the devices that detect the wheels contact with the track	The driver indicates the position of the train through voice communications
Work of the regulation operator	Monitor the normal performing of the regulation system	Regulating the traffic: avoid dangerous situations, locate the trains, respect turns, try to meet schedules, etc.
Work of the train driver	Driving tasks and respect the light signals	Driving tasks, notification of the position of the train, monitoring the indications received from the control center

The occurrence of an accident in the manual traffic management is proportional to the number of trains to be regulated, and the intervals of passage of such trains. In fact, if automatic traffic management does not work properly, the probability of an accident increases significantly. For this reason in many emergency situations some trains are stopped at stations to simplify the task of traffic control. This solution minimizes the occurrence of accidents, but decreases the efficiency of the railway transportation and increases the dissatisfaction of passengers. This is one of the reasons because in recent years efforts have been focused on the development of backup systems which can help in the regulation of railway traffic in emergency situations.

III. TAKING ADVANTAGES OF NEW TECHNOLOGIES TO IMPROVE THE LEVEL OF SECURITY IN EMERGENCY SITUATIONS

Taking into account the security weaknesses of traffic regulation in emergency situations, we propose a Backup Traffic Management System (henceforth BTMS), which is being deployed in a regional railway company of the north of Spain. This system arises in order to automate some tasks to be performed by the traffic regulation operators when traffic regulation is performed manually. It is based on an intensive use of new Information and Communications Technologies (ICT) and has been designed using a decentralized approach in which the trains themselves take a leading role in the traffic management.

Although the main objective of this system is to assist traffic operators when the primary system fails, it also develops other additional functionalities that improve the process of traffic regulation in normal conditions. As for example to enable digital communication between the control operators and the drivers, ensuring that regulation orders are transmitted properly; or to provide a backup wireless positioning system that allows each train to notify its position to the control center. Therefore, this system can work in two operation modes:

- *Emergency mode.* When the main system CTC fails BTMS assists to traffic operator in traffic management for this railway line tracks where the main system CTC do not work properly. In this case the backup system works in emergency mode for the line segments configured by the operator.
- *Normal mode:* When CTC works without any failure BTMS is not used for traffic management, but it offers additional functionalities that can be also performed in normal mode.

A. Additional Functional Capacities

The main functional capacities provided by the use of the new BTMS, which are able to improve the security of the traffic regulation, are:

- *Train positioning reception.* The BTMS receives and stores positioning information from trains' onboard system. This information is send using a real-time wireless 'train-to-earth' communications infrastructure.
- *CTC positioning notifications reception.* The BTMS is designed to also receive the positions of trains from CTC.
- *Synoptic representation.* Traffic situation representation for the track stretches where the main system does not provide information (Fig. 1). The new system represents the affected line stretches situation (train locations, track section occupation states, etc.) from information received from train-side systems.

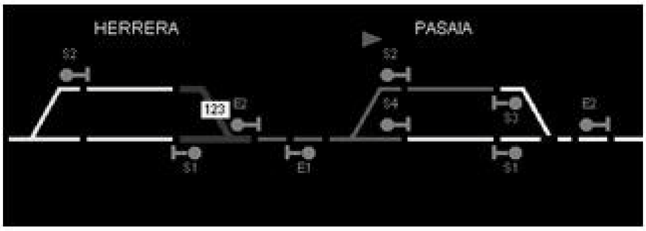

Fig. 1 Traffic situation representation

- *Control message sending from control center to trains.* This functionality will allow traffic operators to send messages to the train drivers in order to manage and control the traffic.
- *Interlocking assistance.* The BTMS assists traffic operators in train interlocking process. In addition, this process involves control message sending to train drivers.
- *Coherency evaluation.* BTMS compares and evaluates positioning information received from both train system and CTC. The porpoise is to determine the reliability of the new positioning system.
- *Statistical analysis.* Concerning with aspects related to the system performance and overall reliability.
- *Using wireless "train-to-earth" communication.* In order to enable communications between BTMS and the train system, it is necessary to integrated it with a 'train-to-earth' wireless communications architecture based on mobile and radio technologies.

TABLE II FUNCTIONAL CAPACITIES OF THE BTMS WORKING IN EMERGENCY AND NORMAL MODE

	Emergency	Normal
Train positioning reception	x	x
CTC positioning	x	x
Synoptic representation	x	
Control messages	x	x
Interlocking assistance	x	
Coherency evaluation	Log files	Real time
Statistical analysis	x	x
Train-to-earth wireless communications	x	x

Table II shows each of the additional functional capacities mentioned above, indicating which of them work in emergency or/and normal mode.

B. *Traffic Management in Emergency Situations Using BTMS*

When CTC fails the traffic management cannot be performed in an automatic way in these track segments affected by the failure. BTMS aims to resolve this problem performing traffic representation of these areas and assisting to traffic operator in traffic management.

Therefore, in this emergency situation the traffic operator configures the BTMS to consider these problematic track segments as in emergency mode. BTMS generates a traffic representation in a synoptic for these areas. In addition, the BTMS assists to traffic operator in train interlocking process by interchanging control message with the train driver (through HMI). Fig. 2 included a more detailed description of the traffic management process using the BTMS.

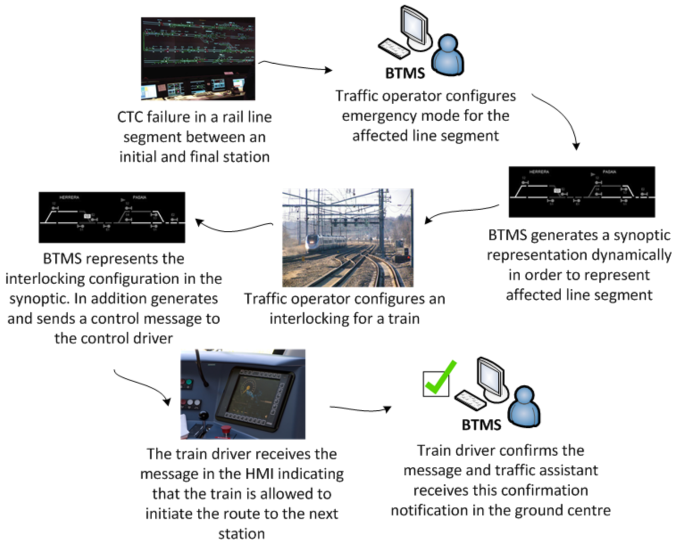

Fig. 2 Traffic management procedure using BTMS

IV. TECHNICAL DESCRIPTION OF BACKUP TRAFFIC MANAGEMENT SYSTEM

In this section, we describe the most important technical considerations about the developed system. The main aspects are related to (1) trains positioning, (2) wireless 'train-to-earth' communications and (3) traffic control message exchange service. These three issues are described below.

A. *Train Positioning System*

The BTMS permits a new way of train positioning which works independently of the main system operation. This system receives and stores positioning information generated by the hardware (accelerometers, gyroscope, odometer, etc.) and GPS modules boarded on the trains. Besides, the BTMS communicates with an external positioning information system which permits the reception of train positioning information generated by the main CTC system.

Therefore, in order to calculate new on boa rded positioning information and check its reliability, the BTMS is based on a mixed train positioning architecture:

- *Centralized architecture.* In this case, BTMS receives raw data from all the trains (generated by the primary CTC system) and calculates itself the position of each train. In this architecture on board systems don't know what their position is.

- *Distributed architecture.* In this modality, each train is responsible of calculating its position using on boarded positioning system. It makes possible to develop new on board applications based on position.

It is known that on board systems have some performance limitations due to temperature and vibration conditions inside of the train. Moving the positioning algorithms into a centralized system avoids this problem. But at the same time some important capacities are lost. For example to exchange control message related with position or the development of other on board application based on positioning. Hence, it is interesting to publish as well position information from the on board systems. Consequently it is very appropriate the adoption of a mixed architecture as the one proposed in Fig. 3, where a distributed positioning is considered.

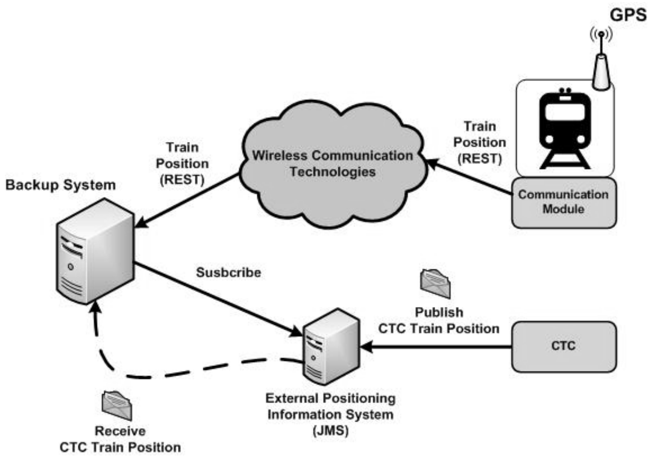

Fig. 3 Train positioning data reception in the BTMS, using a mixed distributed and centralized architecture

1) *On Board Positioning System:*

In order to enable a new way of train positioning generation and management, the presented system aims to board a new hardware/software module on each train (see Fig. 4). This system is based on GPS data and it is able to generate train positioning information applying a logical approximation algorithm for matching railway lines and GPS coordinates [2]. Then this positioning information is sent to the control center in real-time, so that the backup application can represent the train location in a synoptic.

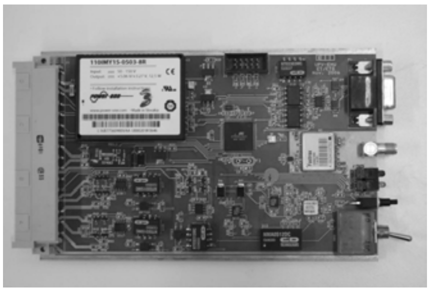

Fig. 4 On board hardware used to generate train positioning information by combining different on board positioning information sources (such as MEMS gyroscope, maps, ATP, odometer) and applying a logical approximation algorithm for matching railway lines and GPS coordinates

To generate the most accurate positioning information, this system parts from a railway lines different tabulation

ways. In this case, the tabulation is related to lines lengths (in kilometers) and the traffic signals positions. Based on this information, and the data extracted from the hardware and software modules boarded on trains (including GPS), this system translates this information to kilometric points. A kilometric point is a metric used by the railway company to tabulate the lines where its trains circulate. So, it can be said that this system is capable of translating GPS positions to kilometric points tabulated by the railway company.

For this purpose, it is necessary to implement a correct positioning algorithm to make the whole system reliable, and as it will be shown, this is not a trivial task. Nowadays, GPS is a good and low cost solution because of its reliability in railway environments [3]. But due to GPS inherent error (multipath, ionospheric propagation…), GPS only based systems have not enough accuracy. The reason is that besides the position of trains, it is also necessary to know the exact track each train takes. This is especially complex because the GPS positioning accuracy is around three meters, and the tracks are separated by less than 2 meters.

The problematic of track selection could be solved using a simple MEMS gyroscope. To improve GPS and MEMS based map matching algorithms [4, 5] it is very useful to use train information systems. Using different position information sources it is possible to add a quality parameter to the position information. This is very useful to know how reliable the calculated position is. The different position information sources used in our system are:

- *GPS coordinates.* It provides absolute position data. The GPS chip is in the on board hardware.
- *MEMS gyroscope.* It provides angular speed. It is also integrated in the on board hardware.
- *Maps.* They are organized as in [4, 5] and [2] with coordinates information. Into the rail special data switchyard information is included. This makes train's track selection based on gyroscope data possible. All the map data is stored on the on boarded equipment (HMI) to make a distributed positioning.
- *Automatic Train Protection (ATP) data.* They are an additional part of signaling systems. There are different kinds of ATPs, but all of them need beacons located in the infrastructure. These beacons provide a unique id and are used to correct possible gyroscope based track detection mistakes. Relation between track and beacon id is also stored into the rail special data.
- *Odometer.* It provides relative position data. It is a covered distance register. It has an accumulative error due to wheels wearing away and wheels slide. But it is very useful when there is no GPS coverage. In fact, for tracks without GPS coverage, distance and speed data are used to determine the exact position of the trains.

2) External Positioning Information System:

Our BTMS is continuously receiving and storing positioning information produced by the train-side systems. Furthermore, the BTMS can receive positioning information used by the primary traffic management system thanks to the existence of an External Positioning Information System that publishes the information generated by the primary positioning system (CTC). This positioning information is provided via a JMS based Message System using a publish/subscribe schema.

Consequently, the BTMS stores the information that receives from the distributed (on board) positioning system as well as from the centralized (CTC) one. This storage tasks are performed even when the primary CTC system is properly working, because the information collected will be used later for statistical purposes in order to analysis the reliability of the secondary system with respect to the primary one. For further details see Section V.

B. 'Train-to-Earth' Communications

The system presented on this paper permits a real-time train traffic management, so it is necessary to enable a wireless communication channel between the BTMS installed on the control centre and the trains. For this reason, the system that we propose in this paper uses a 'train-to-earth' wireless communications architecture based on mobile and radio technologies [6]. Fig. 5 shows the basic protocols and technologies applied in the communications architecture.

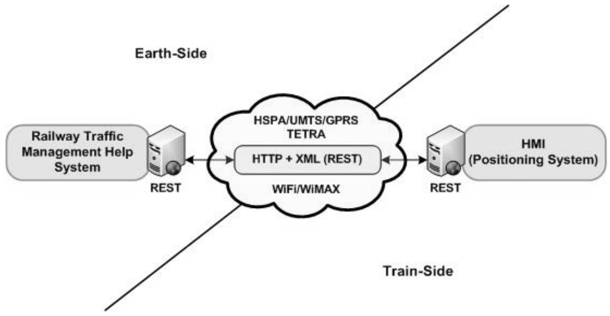

Fig. 5 'Train-to-Earth' communications architecture

To make this communications possible, the trains have been equipped with the necessary connectivity hardware and software system. Furthermore, taking into account mobile communications coverage aspects, to enhance trains GPRS connectivity, the communication system boarded on trains allow GPRS communications within two different telephony providers, working one of them as main provider, and the second one as the secondary when the first one is not operative. In this case mobile technologies such as GPRS/UMTS/HSPA are used for real time communications. These technologies do not offer either a great bandwidth or 100% coverage, and they have a cost associated to the information transmission. Despite this, these technologies are a good choice for the delivery of high-priority and small sized information.

On the other hand, this system can use WiFi radio technology to realize communications between the trains and the railway infrastructure points equipped with WiFi connectivity (a private net of access points is needed). This technology allows the transmission of large volumes of information and does not have any costs associate to the transmission (for example log information stored on trains, or train services information that is uploaded on train periodically).

According to the transmission characteristics (volume of information to be transmitted by BTMS, its high priority, real-time communications needs, coverage and communications costs) the communication technology used is the mobile one. However, as the application layer protocols are standard, other radio technologies such as TETRA or WiMAX could easily substitute the ones selected now. These technologies can achieve a 100% coverage and neither one has a transmission cost. However, there are certain limitations such

as the cost of deploying a private TETRA network, and the cost and the stage of maturity of the WiMAX technology [7].

Regarding the communication protocols, the interaction between the terrestrial and the on-board system is based on REST (REpresentational State Transfer) technology. This communication technology uses the HTTP (HyperText Transfer Protocol) protocol and XML formatted messages. This solution is similar to traditional XML Web Services but with the benefit of a low overload and computational resources consumption [8]. Although the information interchanged between the Terrestrial and the On-Board Communication Managers is encrypted, using the HTTP protocol allows the easy migration to HTTPS (HyperText Transfer Protocol Secure) that offers encryption and secure identification.

C. Traffic Control Message Exchange Service

This service allows the procedural alarms transmission to the train-side systems. These kinds of alarms indicate anomalous situations to the train drivers: primary system failure, signal exceeds authorization to a c ertain point as a consequence of a f ailure of any electro-mechanical track component, etc.

Moreover, taking into account the different circumstances that can occur, and notifications given to engine drivers, there are two types of messages:

- *Messages generated by the traffic operator.* The traffic operator in the terrestrial control centre can select and send messages manually to a train driver. These messages must be confirmed immediately by the driver when they read them on the on boarded equipment.

- *Temporal speed limitations.* These messages are predefined by a circulation inspector and they have greater priority than the others. Once the message is created, it is sent to all the trains immediately.

V. COHERENCY EVALUATION METHODOLOGY

The BTMS include a coherence evaluation tool to analyse its reliability compared to the information generated by the CTC. As argued before, it is needed to determine backup system applicability and permits to identify aspects for system improvement.

The BTMS is designed to work independently of the main system operation. It receives and stores positioning information generated by the hardware (accelerometers, gyroscope, odometer, etc.) and GPS modules boarded on the trains. Besides, in order to make the coherency analysis, the system communicates with an external positioning information system which permits the reception of train positioning information generated by the CTC system.

Thus, the coherency methodology defines two different evaluation types:

- *Real time.* When system receives positioning information from train at the moment of its generation.

- *Deferred.* When system loads train positioning information from log files stored in train system.

A. Information

The coherency tool compares positioning information generated by two different systems: CTC and the train boarded system. The first one indicates track sections occupied/released by train. The second one generates positioning information based on GPS (*kilometric points*).

In order to compare information generated by these two systems, the BTMS is able to traduce kilometric point (KP) generated by trains into track section (TS) corresponding to this positioning information.

So, the BTMS has information about all track sections of the railway lines specified by the CTC of the company, as well as their order and sequence relations. Furthermore, these tracks sections are determined by an initial and final kilometric point and other parameters that permit to BTMS to relate train positioning based on ki lometric points with track segments defined by the CTC system.

B. Scenarios

There are different scenarios concerning to the reception of train positioning information and its subsequent comparison with the position received and stored from CTC. So, the coherence evaluation defines three general scenarios.

1) Train in A Single Track Section:

The train is situated completely in a single track section. So, in this case the KP indicated by train should correspond to the TS_A track section notified by CTC to determine that there is positioning coherence between them.

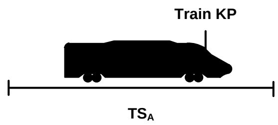

Fig. 6 Train in a single track section

Fig. 6 shows the following situation:

- *The last occupation information from the CTC:* TS_A

- *The last train position:* a KP between the initial and final KP of the TS_A track section.

- *Coherency:* $TS_{ini}\ CV_A \leq$ Train KP $\leq TS_{fin}\ CV_A$ ✓

So, when BTMS receives train positioning information, if this KP corresponds to TS_A track section, the system determines that there is coherency in this train position.

2) Train in Two Track Sections:

This scenario describes the situation in which the train is in two track sections simultaneously. In this situation is important to take into account that the train positioning (KP) is related to the drivers terminal of the train, and it is compared with the last track section occupation notified by the CTC that is previous of the train KP generation time.

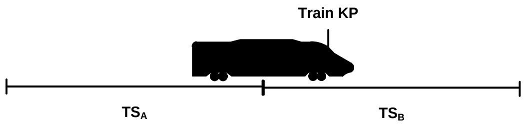

Fig. 7 Train in two track sections

The Fig. 7 shows the following situation:

- *The last occupation information from the CTC:*TS_B

- *The last train position: a KP between the initial and final PK of the* TS_B *track section.*

- *Coherency: TSini* $TS_B \leq$ *Train KP* $\leq$ *TSfin* TS_B ✓

In this case, the KP position generated by train system corresponds to the TS_B track section that has been indicated in the last occupation notification message by the CTC. So, in this case the system would determine that there is consistency of data between both systems.

3) Train Entering in A New Track Section:

The following figure (Fig. 8) shows a situation where the train begins to occupy a new track section while is almost entirely positioned in the above track section (except the train terminal, corresponding the KP position to the beginning of the train). Therefore, in this situation is possible that the train position corresponds to the next track section that is beginning to occupy the train.

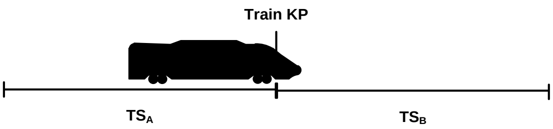

Fig. 8 Train entering in a new track section

Thus, although the received KP corresponds to the next track section (TS_B), it is possible that the BTMS has not received the occupancy of the track section from the CTC yet.

So, Fig. 8 represents the following situation:

- *The last occupation information from the CTC:* TS_A
- *The last train position:* a KP between the initial and final PK of the TS_B track section.
- *No coherency: TSini* $TS_B \leq$ *Train KP* $\leq$ *TSfin* TS_B ✗

In this case, although really the positioning generated by train determines the actual position where the train is, this position points to the TS_B, and the last CTC message occupancy corresponds to TS_A. So, in this case the system would determine incoherency between train and CTC positions. Thus, it is necessary to implement a mechanism to determine coherency in such situations (safety margin). This mechanism will be described in the following sections.

C. Influence of Communication Delay

The transmission of train positions to the terrestrial control centre depends on t he communication availability. There could also be coverage problems along the railway line. To solve this problem, all positions generated by the boarded system are stored locally on the trains in log files. These log files will work as a registry that permits to know what positions were not sent due to communication and coverage problems. Furthermore, the information contained by these logs can be integrated offline with the BTMS in order to guarantee system reliability.

In addition, due to coverage lost and communication failures, train positions may be received with some delay. Therefore, both train positioning information and CTC positioning information indicates what the date and time of this information generation is. So, when the BTMS receives train positioning information, compares it w ith the CTC positioning information corresponding to the last CTC positioning notification message stored in the database that is immediately prior to the message received from the train.

D. Security Margin Consideration

There are cases in which train position and CTC position do not point to the same TS, but two positions are correct (for example in case of contiguous track sections).

The train system generates positions based on GPS which point generally to train driver terminal. On the other hand, the CTC generates positioning information based on track sections occupancy/release indications. However, in order to perform coherency analysis and identify the track section which points the position generated by train, BTMS defines a *security margin*. The objective is to check if the train location is related to one or more track sections. So, it has been defined the security margins value taking into account the half of the length of the train (more or less 35 meters). Thus, the system consider as coherent all these track sections that are into the kilometer points range generated by applying security margin to the kilometric point of the position indicated by the train.

Therefore, the system considers that is coherence between CTC and BTMS positions in the following cases:

- *The CTC and train points to the same track section:* see Fig. 9.

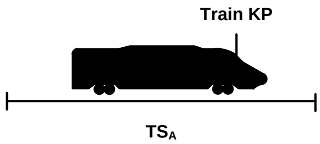

Fig. 9 The CTC and train points to the same track section

- *The CTC and train positions points to contiguous track sections (security margin):* see Fig. 10.

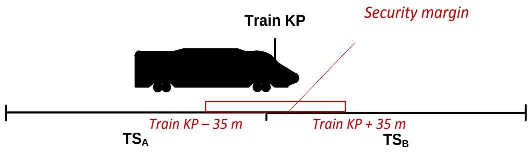

Fig. 10 The CTC and train positions points to contiguous track sections (security margin)

Thus, in the example of the previous picture, the train position would have two coherent track sections (TS_A and TS_B).

E. Coherency Evaluation Mechanism

Fig. 11 shows a diagram with the logic of coherency evaluation mechanism.

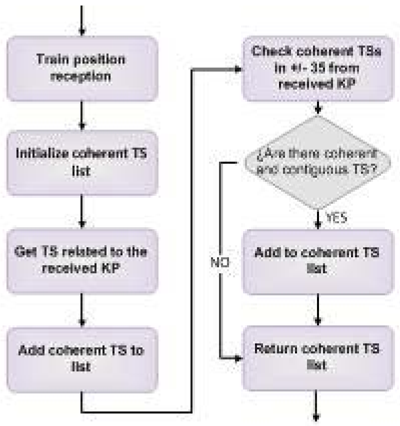

Fig. 11 Coherency evaluations mechanism

F. Evaluation Algorithm

As it was explained before, the BTMS performs the coherency evaluation in two different modes: real time and deferred.

1) Real Time:

When BTMS receives a train position in real time, the system evaluates if this position is coherent comparing it with the notified CTC position. Fig. 12 shows how this comparison is done.

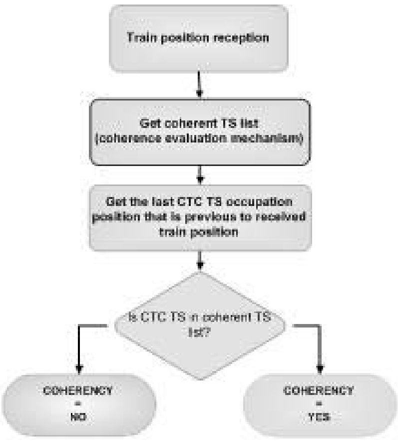

Fig. 12 Real time coherency evaluation mechanism

2) Deferred:

This mode of coherency evaluation is defined to check the coherency of positions stored on logs in train system. Thus, these logs can be checked by the system to determine if the positions stored there are coherent with respect to previously received and stored CTC positioning information. Fig. 13 shows how this comparison is done.

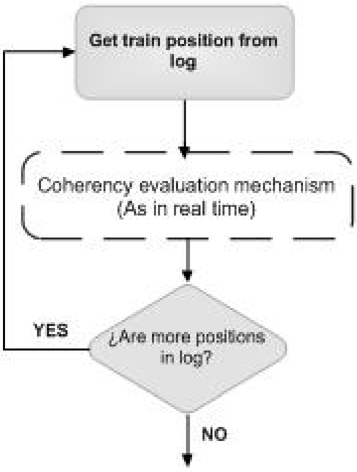

Fig. 13 Deferred coherency evaluation mechanism

G. Test Results

In order to evaluate the BTMS reliability, the system was tested firstly in a real scenario corresponding with the route of a specific train service. So, in order to perform these tests it was necessary to meet these requirements:

- A train equipped with software and hardware that allows receiving train positions through wireless "train-to-earth" communications in ground centre.
- BTMS connected with the external positioning information system receiving and storing positioning information generated by CTC system.
- Train system generating and storing train positioning information in log files.

Thus, in order to perform the tests, BTMS system was connected with a trial train while it is doing its service. System was recording positioning information (CTC positioning information in BTMS and train positioning information in log files on train) related to 18 km train round trip involving 6 stations. Once train finished the route selected to perform the tests, we obtained log files generated in train system. Then this logs where loaded in BTMS in order to perform coherency evaluation mechanism.

During the tests, BTMS received 142 pos itioning information notifications from CTC involving 43 t rack sections. On the other hand, 1.425 positions where stored in train systems log files. Tests results showed 93.82% coherency between positioning information generated by two systems. This value varies with margin error adjustment. So we are working to assign it an optimal value. Furthermore, the train route selected to perform the test involves a train station where train positioning system did not work properly because of the stations track sections relation complexity. This problem is being improved. Therefore, once these issues are fixed coherency index will be even better than presented here.

VI. CONCLUSIONS

In this paper we have presented the work done during the last four years in collaboration with a railway transportation company of Spain. After analyzing the traffic management method used by this company when the principal traffic regulation systems do not work properly, we can conclude that it has some security weaknesses to be resolved. In these situations the probability of accidents increases significantly due to the occurrence of human errors. The main objective of this work is to improve the way in which railway traffic is managed in emergency situations through the use of a Backup Traffic Management System (BTMS).

The most innovative issue of this system is that it is based on a decentralized positioning system in which each train is responsible of calculating its position using an on boa rd hardware/software positioning system. This system is based on wireless positioning technologies (GPS) and it is able to generate train positioning information by combining different on board positioning information sources (such as MEMS gyroscope, maps, ATP, odometer) and applying a logical approximation algorithm for matching railway lines and GPS coordinates. The result is a solution which enables on boa rd systems to know what their position is without the assistance of the primary centralized systems of positioning. Moreover, a set of technological services and procedures to assist the traffic operator and train driver in the traffic regulation are arisen with the aim to provide additional security levels.

The BTMS is part of the technological innovation plan for the control center of the mentioned Spanish railway company. Currently, it is being deployed and tested. A critical issue to be tackled is the validation of positioning coherence between centralized positioning system (CTC) and the decentralized one, due to factors such as lost of communications or GPS coverage, among others. The analysis of the consistency of the position of the trains is one of the key elements of the new ecosystem of applications since the position of the trains will be used by ot her applications such as the incident management system, a system for providing context and position based information, the train status diagnostic system, or the system which notifies timetables at stations, among others. Some methods to validate this coherence and the results obtained have been presented in this paper.

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REFERENCES

[1] A.L.A.T.D. Ambegoda, W.T.S. De Silva, K.T. Hemachandra, T.N. Samarasinghe, A.T.L.K. Samarasinghe, “Centralized Traffic Controlling System for Sri Lanka Railways,” in Proc. of 4th International Conference on Information and Automation for Sustainability (ICIAFS 2008), Colombo, Sri Lanka, pp. 145-149, December 2008.

[2] W. Shang-Guan, B-G. Cai, J. Wang, J. Liu, “Research of Train Control System Special Database and Position Matching Algorithm,” in Proc. of IEEE Intelligent Vehicles Symposium, Xian, China, pp. 1039-1044, June 2009.

[3] E. Bertran, J. A. Delgado-Penin, “On the use of GPS receivers in railway environments,” IEEE Transactions on vehicular technology, vol. 53, no.5, September 2004.

[4] S. S. Saab, “A map mathing approach for train positioning part I: Development and analysis,” IEEE Transactions on Vehicular Technology, vol.49, No 2, pp. 467-475, March 2000.

[5] S. S. Saab, “A map mathing approach for train positioning part II: Application and experimentation,” IEEE Transactions on Vehicular Technology, vol.49, No 2, pp. 476-484, March 2000.

[6] M. Aguado, et al, “Railway signaling systems and new trends in wireless data communication,” in IEEE Vehicular Technology Conference, pp. 1333–1336, September 2005.

[7] C. Pautasso, O. Zimmermann, F. Leymann, “RESTful Web Services vs. Big Web Services: Making the Right Architectural Decision,” in Proc. of 17th International World Wide Web Conference (WWW2008), Beijing, China, 2008.

[8] M. Aguado, O. Onandi, P. S. Agustin, M. Higuero, E. J. Taquet, “WiMax on Rails,” in IEEE Vehicular Technology Magazine, Vol. 3, Issue 3, ISSN: 1556-6072, pp. 47-56, Sept. 2008.

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