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.

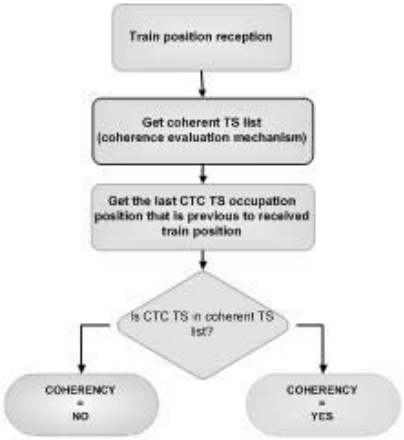

Fig. 12 Real time coherency evaluation mechanism

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.

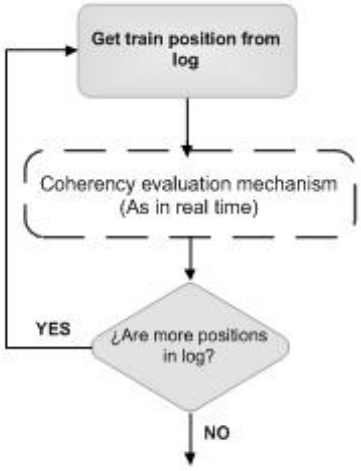

Fig. 13 Deferred coherency evaluation mechanism

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 positioning information notifications from CTC involving 43 track 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 board 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 board 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 other 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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