ONTOLOGY BASED APPROACH FOR AN EUROPEAN WAYSIDE TRAIN MONITORING SYSTEM

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ABSTRACT

Due to the automation and centralisation of railway operation the demand for train monitoring systems arises to guarantee operational safety in times of liberalisation of the railway market. The motivation for wayside train monitoring has it's origin in national considerations and regulations. Accordingly monitoring systems are designed for national use, but the market of railway undertakings is not limited to national borders anymore. By exchanging measured data of wayside train monitoring devices across national borders, an improvement of availability and safety in rail traffic on the European corridors seems to be achievable. Beyond different thresholds for measurements used by different infrastructure managers an ontology based method of describing fault states and their dependencies remains the same. The realisation of monitoring measures may be national specific, but the opportunity for cross border data exchange seems to be possible. Therefore a concept was developed which shall allow application of the national driven approach on the European freight corridors.

Keywords: train monitoring, interoperability, safety related fault states

INTRODUCTION

In railway systems, there are many different fault states which can occur during operation. For safety reasons, these well known fault states on trains have to be prevented. In former times railway operation was managed mainly by many station inspectors in railway stations who were also responsible for fault state monitoring of passing trains. But in the last years the operation is getting more and more centralised and so the task of fault state monitoring has to be overtaken by automated devices. This general trend in railway operation was considered by a concept for an overall train inspection system which allows integration of different stand-alone sensor systems for wayside train monitoring (hot box detection, dynamic weighing, derailment detection, etc.). Fault states may also have dependencies among each other, which are not sufficiently known yet or not used for fault state prevention.

Thus, in a first step a method has been developed for the description of dependencies. As systematic description of all relevant states and their dependencies a fault state matrix has been created.
Due to liberalized railway market this approach should not be limited by borders of national infrastructure managers. In the EU-Project “InteGRail” an ontology based approach was selected to describe overall system architecture for different applications in railway operation. Based upon the published documents it is not possible to realize a cross border data exchange due to usage of proprietary specifications. So an additional concept must be created for cross-border traffic between different infrastructure managers. Therefore three scenarios were devised which enable the classification of national-specific situations. Based on these models the necessary data exchange between different infrastructure managers can be described systematically. A key factor for implementation is given by the item of railcar identification because of the necessity to allocate measured properties to vehicles. The identification may be done by equipping the cars with onboard units (for instance with RFID-tags). But currently an European wide standardization is missing and only a low rate of cars is equipped with proprietary solutions. Thus, at present an alternative and independent identification method like the optical recognition of railcar numbers has to be preferred.

METHOD

In a railway system fault states have a lot of dependencies to each other. In general, faults state can lead to another fault state which might be worse than the one before. Thus, in an abstract approach fault states can be interpreted as causes and the resulting fault states can be interpreted as consequences (Figure 1). If there are no measures for recognition and reaction, the final consequence of many fault states is a derailment. Therefore it is necessary to prevent the long-lasting occurrence of critical fault states. Because of the movement of the train, most of the relevant fault states can not be observed directly. Thus, suitable indicators have to be measured, which can be done by onboard or wayside monitoring systems.

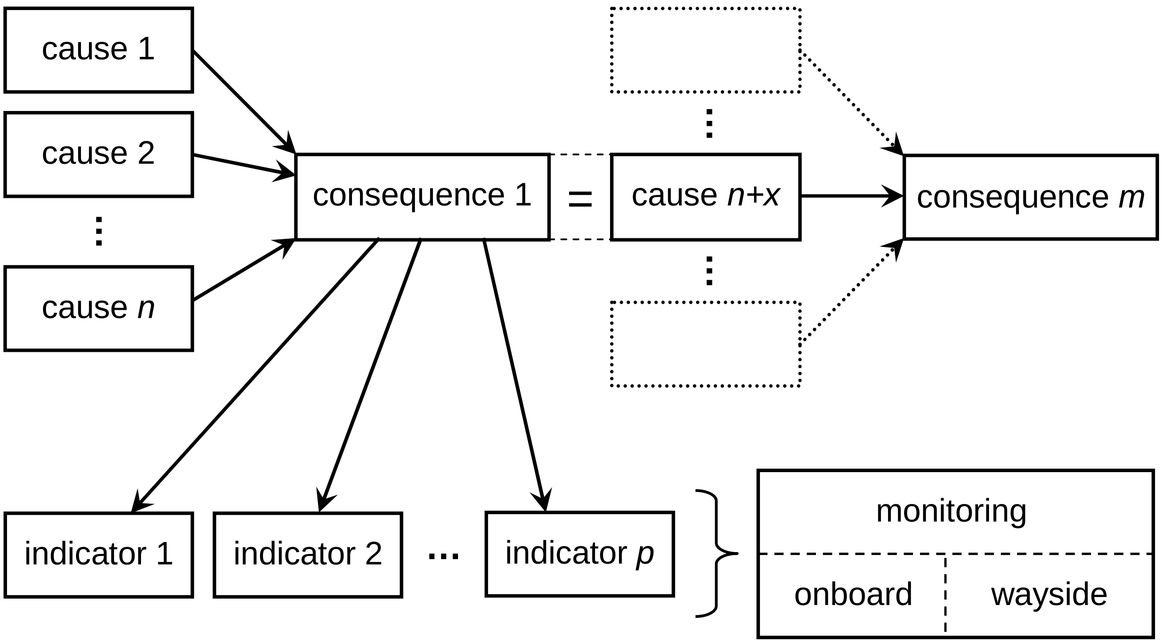

Figure 1 - Ontology based approach of causes and consequences

Fault State Matrix

Based upon the model of cause and consequences a matrix (Chloupek, A. et al. 2009) was created to point out the dependencies in a customer-friendly way (Figure 2). For each fault state a description was developed accordingly to UIC dictionary. Some examples are listed below (Maly, T. et al. 2008):

Derailment (1): A derailment of an axle or of the whole bogie often takes place in the marshalling yards. Generally such derailments are quickly detected by railway staff and the resulting damage of the infrastructure is low. But on the free line, a derailment stays often unrecognized over several kilometers, because drivers have no possibility to detect this fault state. In such cases, the consequences are an enormous damage of the superstructure and extremely high repair costs.

Hot Box (2): As the result of missing lubrication or of mechanical damage of parts of an axle bearing, the increased friction heats the bearing during the drive. Hence, a good and proven indicator for damaged bearing during the run of a train is the temperature of the box itself.

Blocked Brake or Wheel (3): Due to failures in the control value of the pneumatically driven brake system, the brake shoes or blocks of an axle may not release. Mostly, the friction is not high enough to block the whole axle. Hence, there will be a continuous heating of the brake discs (for disc brake systems) or of the wheel (for block brake systems). Moreover, the blocked brakes can cause fires in the bogie construction due to sparks. These sparks can also enkindle vegetation besides railway lines. In the residual cases of massive friction the axle won't rotate and will sliding on the rails.

	Consequence / Cause	Derailment	Hot Box	Blocked Brake or Wheel	Faulty Flash Guard	Faulty Elements of Brake System	Broken Axle	Breakage of Stub Shaft	Broken Wheel	Faulty Running Surface / Wheel Spot	Faulty Flange of Wheel	Faulty Suspension and -component	Faulty Frame	Unbalance (during vehicle´s run)	Displacement of the Load	Overload (continuous)	Violation of Clearance Gauge	Faulty Car Opening (Doors, Loading Trap, etc.)	Faulty Load Fixation and Fastener	Insufficient Lubrication of Buffers	Faulty Buffer	Overriding of Buffers	Faulty Electrical Car Equipment	Broken Pantograph	Fire on/in board	Objects within the Clearance Gauge	Enlarged Width of the Track Gauge	Track Distortion	Faulty Rail Surface	Faults inside Rail	Worn Rail	Aged Rail Material	Broken Rail	Faulty Elastic Rail Pad	Faulty Rail Fastening / Ironmongery	Aged Timber Sleeper	Cracks in Concrete Sleeper	Insufficient Track Bed
1	Derailment						1		2		3	4															5	6							7		8	
2	Hot Box							9																	10													
3	Blocked Brake or Wheel	11							12																13													
4	Faulty Flash Guard																								14													
5	Faulty Elements of Brake System			15																																		
6	Broken Axle	16																																				
7	Breakage of Stub Shaft	17																																				
8	Broken Wheel	18																																				
9	Faulty Running Surface / Wheel Spot						19		20																								21					
10	Faulty Flange of Wheel	22																																				
11	Faulty Suspension and -component	23					24							25																								
12	Faulty Frame	26					27																															
13	Unbalance (during vehicle´s run)	28																				29																
14	Displacement of the Load													30			31																					
15	Overload (continuous)						32		33	34	35	36	37									38					39											
16	Violation of Clearance Gauge	40																							41													
17	Faulty Car Opening (Doors, Loading Trap, etc.)													42			43									44												
18	Faulty Load Fixation and Fastener														45		46									47												
19	Insufficient Lubrication of Buffers																				48																	
20	Faulty Buffer	49																				50				51												
21	Overriding of Buffers	52																																				
22	Faulty Electrical Car Equipment																								53													
23	Broken Pantograph																																					
24	Fire on/in board																																					
25	Objects within the Clearance Gauge	54																																				
26	Enlarged Width of the Track Gauge	55																																				
27	Track Distortion	56																																				
28	Faulty Rail Surface									57	58																59						60		61			
29	Faults inside Rail																																62					
30	Worn Rail																										63						64					
31	Aged Rail Material																																65					
32	Broken Rail	66								67	68																											
33	Faulty Elastic Rail Pad																										69											
34	Faulty Rail Fastening / Ironmongery																										70											
35	Aged Timber Sleeper																										71											
36	Cracks in Concrete Sleeper																										72											
37	Insufficient Track Bed	73																										74										

Figure 2 - Cause consequence matrix of fault states

Broken axle (6), *Breakage of Stub Shaft* (7): There can be two types of broken axles identified. A cold axle breakage is influenced by metallurgic reasons (material defects, etc.). In contrast to the cold type, if there is a massive heat exposure, the properties of the material can be affected negatively. In combination with high mechanical stress, such a weakened axle can break (warm axle breakage). In both cases the guidance property, which is obligatory for rail-bound traffic, is lost.

Faulty Running surface / Wheel spot (9): The term defects describe many different irregularities, which can occur on the running surface of a wheel. For instance, flat spots are flattenings of the round wheel, whereas reweldings are similar to little metal bumps. Beside there are out-of-roundnesses, and material eruptions. All lead to short force peaks with increased amplitudes during the run of the train and effect additional stress in the rail and in the wheel. Thus, such wheels can damage the rail and should therefore be rejected.

Violation of Clearance Gauge (16): The risky situation of clearance profile exceedings can be divided into three categories: if the exceeding is on the outer side, a collision with pylons for overhead contact wire is possible. If the exceeding is on the inner side on a double track section, there is a higher risk of crashing with other trains or with signal posts. If the exceeding is above, flashovers from contact wire may take place.

For the conceptual design of the inspection system it is important to know, what kind of elements will be expected to exceed the clearance profile. Besides massive exceedings done by displaced cargo or by derailed wagons, which do not require fast or sensitive measuring, also loose fastener of cargo can exceed the clearance gauge. Another low-loader wagon specific problem of clearance gauge violation concerns truck antennas. In detail, low-loader wagons offer the transportation of trucks on railways. A well-known operational problem of low-loader wagons are modern radios in the trucks. To gain good reception, radio antennas are extending autonomously during the transportation on the low-loader wagons. Due to the fact, that in tunnels the contact wires are lowered, the possibility of flashovers is rising significantly. For detection of such small exceedings, appropriate measurement principles and sensors have to be used.

For analysis and the validation of the supposed connections between different safety related fault states in the railways, a network of technical train monitoring components must exist. The data acquisition can be done on the vehicle-side, wayside or both together. The key issue by the observations is the evaluation of the proper correlation of the collected data (allocation of fault state to vehicle number). If this practical problem can be solved, a huge database of monitored parameters and therefore of particular detailed information about important fault states and their changes will be available.

PRACTICAL APPLICATION

Checkpoints (Sünder et al. 2006) can be defined as trackside locations containing an accumulation of technical systems, which are required to enable the substitution of the traditional train supervision. Prototypes of this kind of an overall train inspection are developed in some European countries (e.g. Austria, Switzerland, Italy). Each sensor system is used for the supervision of one or several train conditions. This approach of an overall train observation enables following advantages:

- increasing of reliability of results due to data conjunction,
- cost saving due to optimized use of sensors,
- easy system extension and information forwarding due to uniform interfaces,
- low maintenance effort due to centralized function check.

The founded projects ended with an installation of a prototype and extensive tests of its functionality on the Eastern Line (between Himberg and Gramatneusiedl) of Austrian Railways in 2005. Until now, the prototype was continuously extended and is still in operation. The research and development projects were done by Thales Rail Signalling Solutions, Austrian Railways (ÖBB) and Vienna University of Technology.

Stand alone sensor systems

In the last years several sensor systems were developed to detect fault states (Buurman, G. 2005, Eisenbrand, E. 2001, Müller-Boruttau, F. et al. 2009, Rottensteiner, U. 2003, Schöbel,

A. et al. 2006, Stadlbauer, R. et al. 2007). The development state of train monitoring systems can be divided into three categories:

> Cat. A: Well engineered systems are available on the market for a while. Mostly, they have a high degree of industrialization and the manufacturer has a lot of experience concerning the practical and long-term use. Real measurements exist under different conditions (e.g. high passing speeds, environmental influences), which allows a well-founded estimation of the sensor systems capabilities.
>
> Cat. B: Newly developed systems or prototypes are often using very promising approaches of measuring methods and thus they offer high chances of a successful detection of specific train fault states. But the verification of their reliability, especially under extreme conditions doesn't exist, which makes a comprehensive testing needful.
>
> Cat. C: For some types of irregularities there are either systems just under development or there are still no detection systems available on the market.

All of the detection systems are completely stand alone systems. In case of a detected conspicuity, they are only able to inform human personnel but are incapable to set actions by themselves. Thus, the personnel have to decide according to well-defined process instructions what to do. But human decisions always imply a preventable risk of errors. Furthermore, most of the systems do not provide interfaces to other systems respectively have only customer-specific interfaces. So if these systems shall be integrated into a higher-level system, new interfaces have to be designed.

Layered structure of the networked concept

Based upon this situation a national project was founded to create a concept for an overall system (Maly, T. et al. 2004, Maly, T. et al. 2005). One essential design criteria was the ability to integrate different existing sensor systems for monitoring all kind of potential fault states on a moving train.

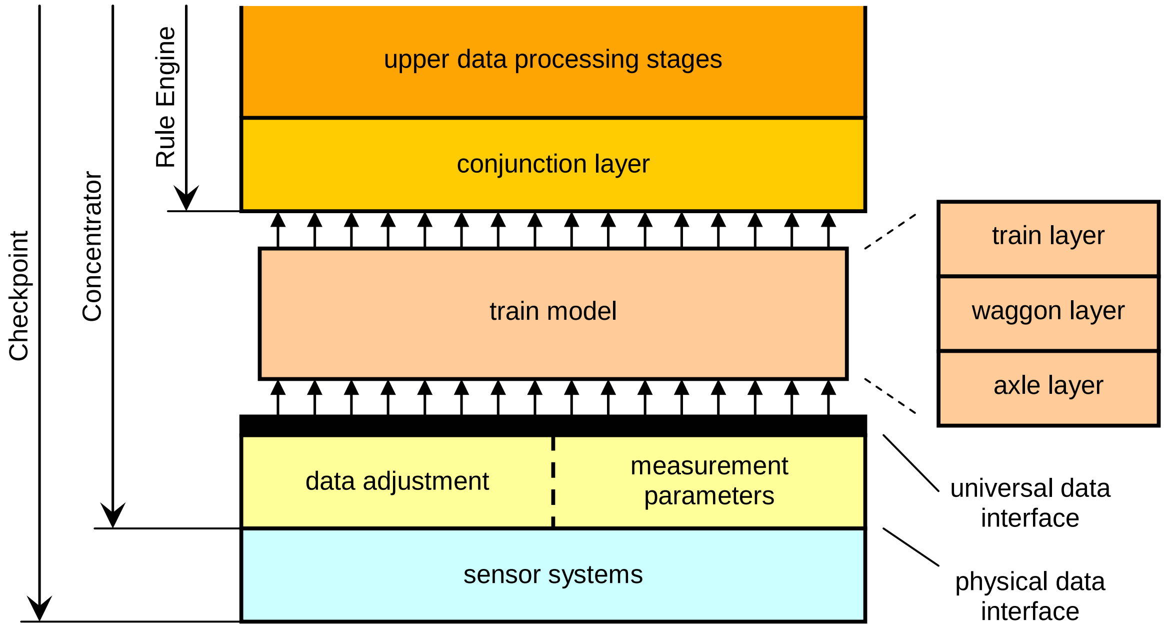

Figure 3 - Layer model for standardization, data storage and data provisioning

From a physical point of view, the idea of a Checkpoint system can roughly be split into the sensor systems (lowest layer) and in the Checkpoint concentrator, which is a Checkpoint-wide common data processing unit (Fig. 3). The sensor system layer is responsible for data acquisition. The gathered data are transmitted via the physical sensor interfaces to the concentrator. On top of this, the adjustment layer is situated, whose major task is to standardize the sensor data to well-defined data types. Moreover, the layer provides the train model with its standardized data via a universal data interface. Because of its sensor dependency, the adjustment layer has no generic character. This means, that the concrete realization of the adjustment units has to be adapted to the underlying installed sensor systems. To keep the implementation effort for each adaption unit within limits, a generic interface was designed to allow communication with different types of sensors. The specification of this interface can be used by any manufacture of sensor systems to forward measured data to the Checkpoint. Beyond, the adjustment layer supplies additional information about the sensor systems, environmental conditions and measuring methods by adding measurement parameters. These parameters allow improving the data interpretation.
The train model (Fig. 4) is based on the universal data interface. It links measured objects (also called “characteristics”) according to their reference range “train”, “wagon” or “axis”. New data are included in chained lists of the appropriate reference range corresponding to their measurement location on the train. The train model allows the upper layers to use sensor data with different measurement ranges referenced by their train position. Furthermore, the Train Model enables a simple position declaration for the occurred alarms during the action generation.

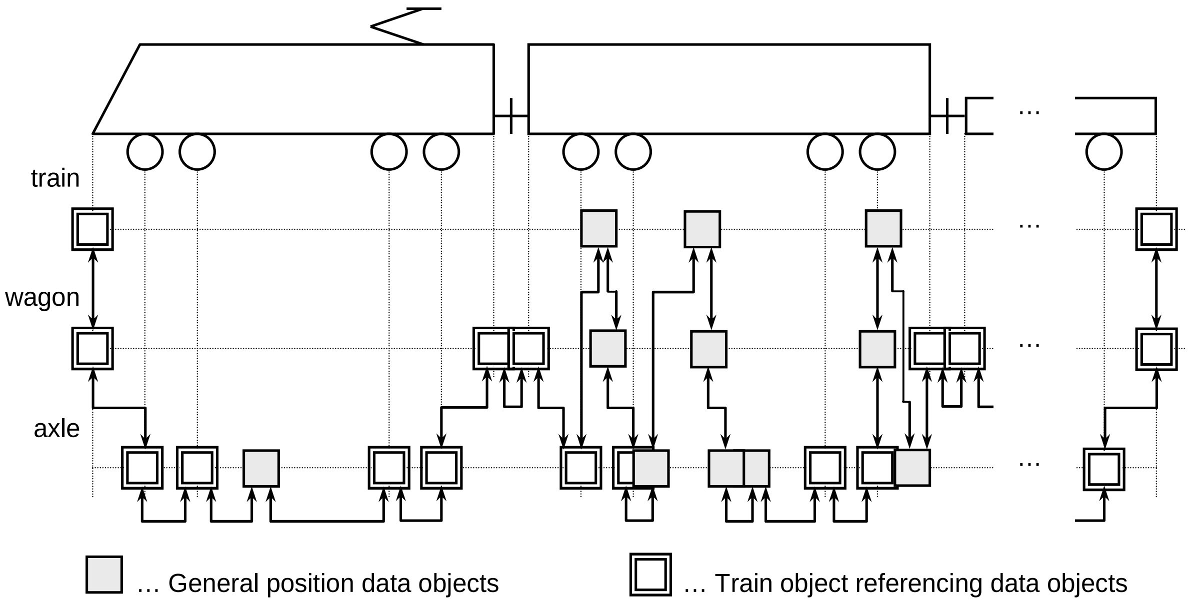

Figure 4 - Train Model

The first layer beyond the train model, the conjunction layer, allows combining sensor data in a flexible way. This is performed by executing user-defined rules which are also used to generate adequate actions (alarm messages dispatched, interlocking system informed, etc.). The set of defined rules is executed autonomously by a rule engine.

SCENARIOS OF INTEROPERABILITY

For the network of Austrian Railways the installation of a Checkpoint network until 2013 is planned. This network consists of Checkpoint concentrators along the tracks and a so called Checkpoint Master Node which is the centre of all wayside systems. This situation is the base for all subsequent considerations.
For an evaluation of possible interaction with the Checkpoint system, the situations and future trends of neighbouring countries have to be determined. In detail, following information of neighbouring networks has to be ascertained and compared with the situation in Austria:

- Existence / number of train monitoring systems
- List of fault states, detected by these systems
- Documentation of thresholds for different fault state recognition defined by national infrastructure managers
- Analysis of information chain (who gets when which information and which interfaces are used thereby)
- Verification of networking functionality (central data storage, trend analysis, etc.)
- Interfaces of an existing centre where all monitoring results are available and check of functionality of this centre

These tasks can be fulfilled by bilateral workshops. Independently, even without these detailed information, a general valid categorisation of installed monitoring systems can be done. Three developed scenarios consider the options of cross-border communication the different kinds of sensor solutions of neighbouring countries. Based on this categorisation, the further evaluation and implementation process can be described systematically. In the following the scenarios and the resulting advantages of data exchanges are explained in detail.

Scenario 1 – stand alone sensor systems

Figure 5 shows scenario 1 which illustrates an early stage of automated train monitoring in the neighbouring country. In this situation the observation tasks are done by stand-alone systems (e.g. hot box detectors). The measured data are not forwarded to any other system. Such systems process, evaluate and store the measurements without alarm notifications to other systems.

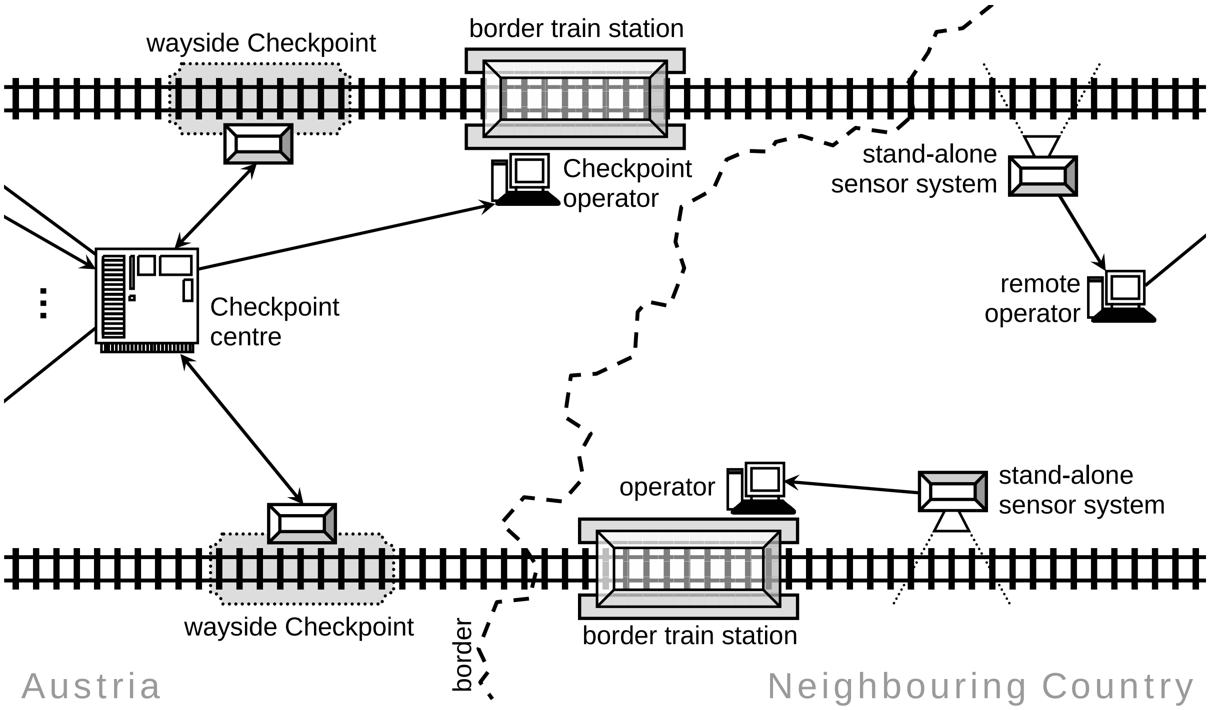

Figure 5 - System architecture at the border in Scenario 1

Information are only provided to a local user who is responsible for setting tasks already defined before going into operation. Therefore an automated data processing is not possible. In case of an alarm the operational handling has to be done by some personal. Sensor systems near to the border enable the reduction of sensor systems, if both infrastructure managers are able to use the measurement data from the systems of the neighboured country. From the Austrian point of view, this means, that data from foreign stand-alone systems must be imported to the Austrian Checkpoint network. Whereas the foreign network must be able to import data provided by the Austrian Checkpoint network. Therefore a generic solution must be developed, to enable the usage of information for all adjacent countries. Moreover today's operational handling of neighbouring infrastructure manages must be analysed to find out differences and necessary changes in operational rules and standards. Also national thresholds which are not regulated by TSI or which are given by national authorities have to be collected and the applicability to the foreign stand-alone systems has to be checked. This means, for usage of national specific thresholds, systems must provide raw measurement data for external evaluation or the systems must allow easy configuration of different thresholds.

Scenario 2 – networked sensor system(s)

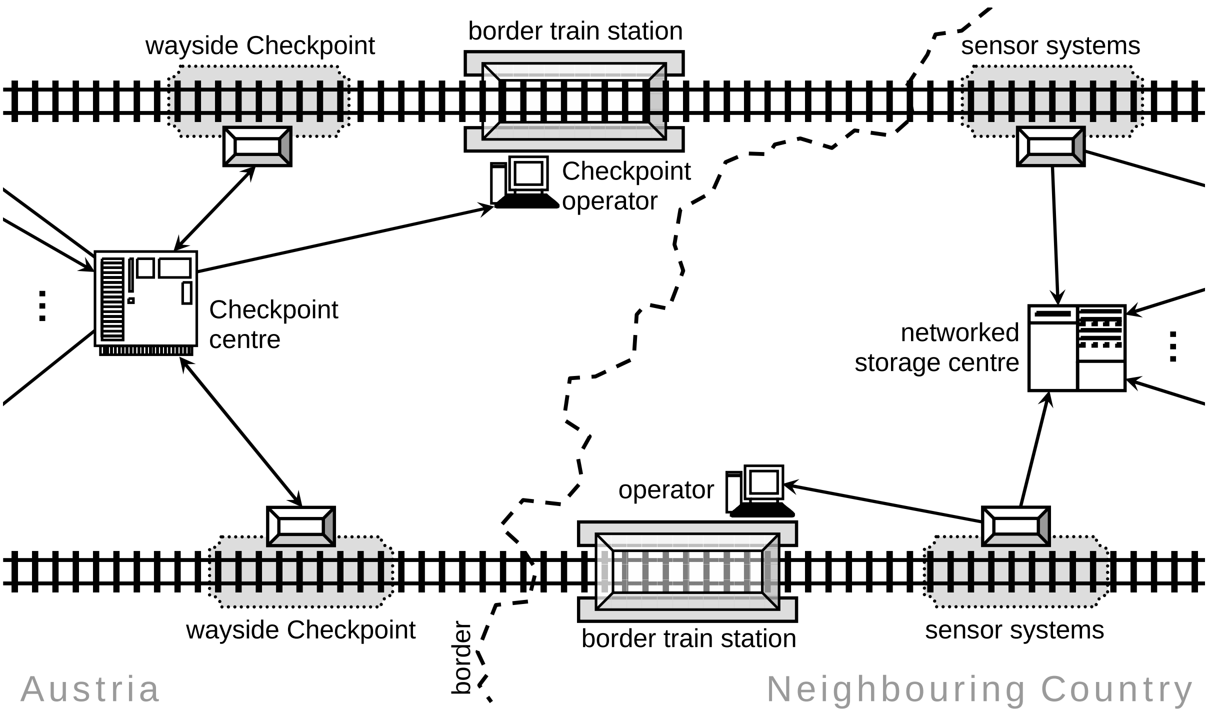

Figure 6 - System architecture at the border in Scenario 2

Figure 6 shows the situation for a neighbouring infrastructure manager which already has sensors for train monitoring and a centre for storing. The components are connected to a centralised network. Gathered data from wayside systems are forwarded to the centre where it is stored. The whole data treatment of wayside systems as well as of the centre is sensor is system specific and proprietary. Further interfaces for online data processing are not available.

In this scenario it must be analysed how the data model of a train is designed to check the ability for importing and exporting data. Moreover it must be carefully examined, whether sensors are able to provide measured data beyond evaluated qualitative results (to the centre and/or to third party systems). As already in scenario 1 mentioned, this is a basic requirement to deal with national threshold definitions. In principle, the data exchange can be done with wayside monitoring systems near the border or with the foreign data centre. Based on the component's data providing abilities and the necessary efforts for extension, the communication concept has to be developed.

Scenario 3 – Checkpoint like system

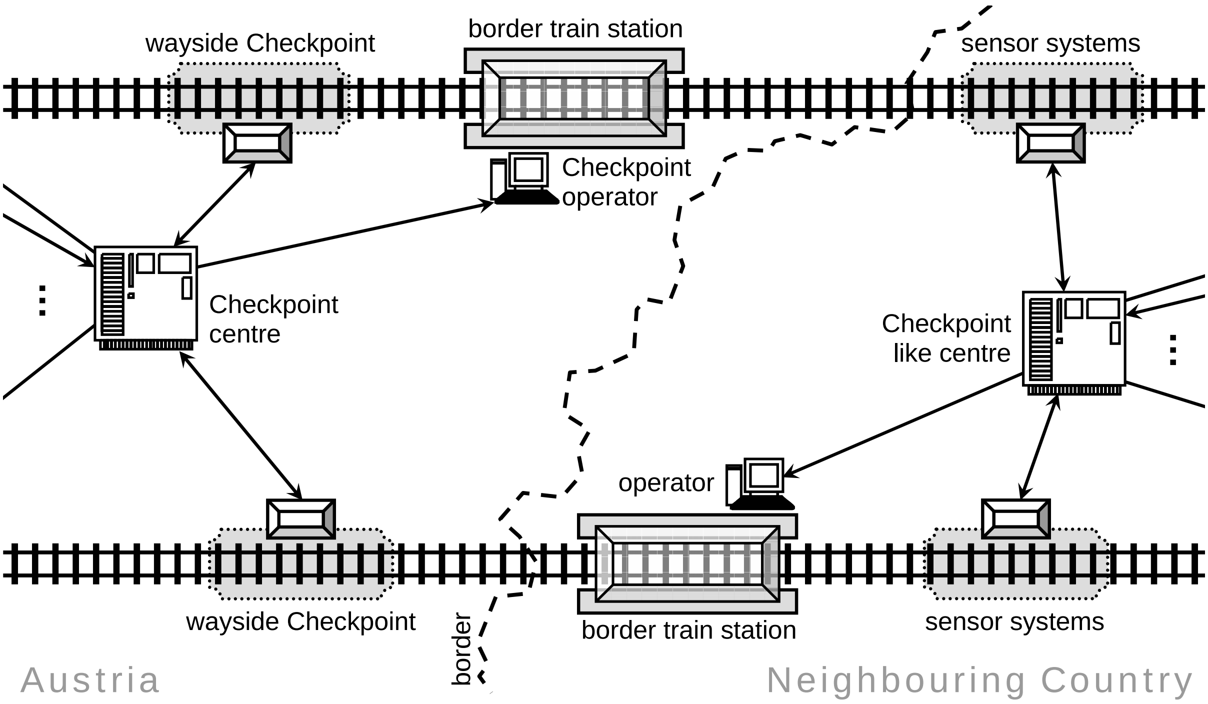

Figure 7 - System architecture at the border in Scenario 3

Figure 7 shows the scenario with an almost comparable neighbouring train monitoring network (f.e. Nietlispach, U. 2009). Similar to the Checkpoint concept, the processing of train data is highly abstracted from the underlying measurement systems and thus very suitable for exchange with other networks. Interfaces for other users and systems are implemented. Due to generic interface definition an extension for cross-border data exchange can easily be realised.

Because of the cost-intensive process of installation such a network, any changes are also cost-intensive. First step of analysis are dedicated to existing interfaces of this network and their capability for data exchange with the Austrian network. The simplest solution is related to an adaption of an existing communication protocol. Only if this is too complicated a local communication solution between neighbouring Checkpoints should be designed. For saving costs it would be interesting to check the possibility to share a Checkpoint at the border. Also in this scenario it must be possible to set national threshold definitions regarding to national regulations.

CONCLUSIONS

The improvement of cross-border railway traffic is one of the most important tasks to be done in the new member states of the European Union. Thereby the quality of service on corridors should be increased by enhancing the quality of service and shortening the average dwell time at border stations.

Independently from the level of installed components for monitoring and because of the absence of fault state information of entering trains at border crossing, at present manual inspection is done at border stations by examiners. Thus, presented approach allows saving

further costs for operation as a result a reduction of staff for such inspections. Due to the loss of human inspections, the efficiency of operational handling of trains will increase, because without dwell times a higher operational capacity can be achieved. Moreover, with an interoperable train monitoring system, wagons with fault states can be identified before arriving border stations. Thus the detachment of such wagons can be better prepared and the resulting delay can be reduced further.
In summery, a realisation of introduced approach enables a more efficient fault state monitoring of cross-border railway traffic by shared use of data. This results in a reduction of costs due to lowered efforts for stuff, system installation and system maintenance.

REFERENCES

Buurman, G. (2005). A vital instrument in asset management. In: European Railway Review. Issue 3, p. 80 – 85.

Chloupek, A., M. Lange, N. Ostermann, A. Schöbel, T. Maly, D. Schratt, M. Antova, M. Hofer, and F. Auer (2009). Sicherheitsrelevante Überwachungs-Parameter im System Bahn (fahrwegseitige vs. -zeugseitige), Report for FFG, 2009, 77 pages.

Eisenbrand, E. (2001) PHOENIX MB: Die neue Dimension in der Heißläuferortung. Signal + Draht 93.

Maly, T., M. Rumpler and H. Schweinzer (2004). Joining sensor systems for railway vehicle inspection. Presentation: 3rd IEEE Conference on Sensors (IEEE Sensors 2004), Wien, Österreich; 24.10.2004 - 27.10.2004. In: "IEEE Sensors 2004", (2004), ISBN: 0-7803-8693-0, 12-15.

Maly, T., M. Rumpler, H. Schweinzer and A. Schöbel (2005). New development of an overall train inspection system for increased operational safety. Presentation: International IEEE Conference on Intelligent Transportation Systems, Wien, Österreich, 13.09.2005 - 16.09.2005. In: "Proceedings of the 8th International IEEE Conference on Intelligent Transportation Systems", ISBN: 0-7803-9216-7, 269-274.

Maly, T., M. Antova and A. Schöbel (2008). Functional Chain Analysis for Monitoring Train Fault States. Presentation: Forms / Format 2008, Budapest, 09.10.2008 - 10.10.2008. In Formal Methods for Automation and Safety in Railway and Automotive Systems, G. Tarnai, E. Schnieder, ISBN: 978-963-236-138-3, 197-203.

Müller-Boruttau, F., N. Breitsamter, S. Pieper (2009). Measuring the effects that flat spots have on the dynamic wheel load and on rail pad forces. In: European Rail Technology Review. Issue 1, 24-29.

Nietlispach, U. (2009) Zugkontrolleinrichtungen bei den SBB. In: Signal + Draht 101. Issue 1, 25-28.

Rottensteiner, U. (2003) VAE-HOA 400 DS – Heißläuferortungsanlagen für finnische Hochgeschwindigkeitsstrecken. Signal + Draht 95, 6-10.

Schöbel, A.. M. Pisek and J. Karner (2006). Hot box detection systems as a part of automated train observation in Austria. Presentation: EURNEX - ZEL 2006, Zilina, 30.05.2006 - 31.05.2006. In: Towards the competitive rail systems in europe, ISBN: 8080705518; 157-161.

Stadlbauer, R., A. Schöbel and J. Karner (2007). Wayside Derailment Detection And Its Integration In The Operation Management. Presentation: EURNEX - Zel 2007, Zilina.

30.05.2007 - 31.05.2007; in: "Towards more competetitive European rail system", Zilinska Univerzita, ISBN: 9788080706791; p. 228 - 234.

Stadlbauer, R.; Schöbel, A.; Pisek, M. (2008). CheckPoint: Solutions for Automatic Supervision with Coupling to Automatic Train Protection Systems. Presentation: 2nd International Railway Symposium / Railway Trade Exhibition, Istanbul; 15.10.2008 - 17.10.2008; in: "Proceedings", ISBN: 978-605-4073-03-0; p. 1035 - 1044.

Sünder, M.; Knoll, B.; Maly, T.; Schöbel, A. (2006). Checkpoint systems and their integration into solid state interlockings for automatic train supervision. IRSE - The Institution of Railway Signal Engineers, ASPECT 2006, London; 15.03.2006 - 17.03.2006.