Eur. Transp. Res. Rev. (2009) 1:35–45
DOI 10.1007/s12544-008-0004-z

ORIGINAL PAPER

Towards safer level crossings: existing recommendations, new applicable technologies and a proposed simulation model

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Received: 17 September 2008 / Accepted: 28 November 2008 / Published online: 13 December 2008

Abstract Every year, more than 400 people are killed in over 1,200 accidents at road-rail level crossings in the European Union. Together with tunnels and specific road black spots, level crossings have been identified as being a particular weak point in road infrastructure, seriously jeopardizing road safety. In the case of railway transport, level crossings can represent as much as 29% of all fatalities caused by railway operations. Up to now, the only effective solution appears to involve upgrading level crossing safety systems even though in more than 90% of cases the primary accident cause is inadequate or improper human behavior rather than any technical, rail-based issue. This article provides results of research done on possible technological solutions to reduce the number of accidents at level crossings and demonstrate the effectiveness of the latter. Elements of these recommendations and related research activities constitute the main focus of the research work described in this paper. It is organized as follows: In Section 2, we consider statistical data related to LX accidents in certain given European countries. These statistics as well as a European Commission Directive related to safety targets are analyzed and the main trends are drawn. The study was carried out on the basis of the classification by the European Railway Agency of active LXs and passive LXs. These results form the foundation for the work described in Section 3. Section 3 focuses on advanced technology to improve LXs safety. The main thrust of the study is to evaluate low-cost, standard technology that can contribute to a direct decrease in the number of accidents, at an affordable cost. Existing surveillance technologies already used in rail or road transport are first considered. To facilitate LX bi-modality, special emphasis is put on technical solutions which have already demonstrated high efficiency in both environments. In Section 4, the mode of operation of each potential solution is modeled and evaluated considering several operational scenarii, in order to evaluate the aggregate benefits of all the input. Setting models to describe the dynamics surrounding the LX environment will prepare a basis to support the decision making process of a joint rail and road sector strategy on how to control LXs. Finally, section 5 brings the study to a close with a list of the main areas in which to concentrate our future work.

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Keywords Level crossing · System architecture · Dynamic models · Sensors · Telecommunication · Remote Transmission

1 Introduction

Recently, the Coordination Action for the Sixth Framework Programme "Safer European Level Crossing Appraisal and Technology" (SELCAT) provided recommendations for further actions intended to improve safety at Level Crossings, noted LX in the sequel. Considering existing input from other projects as well as its own analysis, SELCAT's recommendations were developed around two major ideas: (a) the use of advanced technological solutions designed to minimise the impact of human factors as the main cause for accidents at LXs and, (b) a joint rail and road sector strategy to control and reduce risks at LXs.

Among the major high level recommendations provided by this Coordination Action, one is to encourage society to recognise the bi-modality of road/rail interface and work closely with the road and rail sectors and all relevant governmental agencies, to help reduce levels of risk from LXs.

Elements of these recommendations and related research activities constitute the main focus of the research work described in this paper. It is organized as follows: In Section 2, we consider statistical data related to LX accidents in certain given European countries. These statistics, as well as a European Commission Directive related to safety targets, are analyzed and the main trends are drawn. The study was carried out on the basis of the classification by the European Railway Agency of active LXs and passive LXs (see definitions later). These results form the foundation for the work described in Section 3. Section 3 focuses on advanced technology to improve LXs safety. The main thrust of the study is to evaluate low-cost, standard technology that can contribute to a direct decrease in the number of accidents, at an affordable cost. Existing surveillance technologies already used in rail or road transport are first considered. To facilitate LX bi-modality, special emphasis is put on technical solutions which have already demonstrated high efficiency in both environments. Information drawn from previous on-site evaluations is also provided. Advanced driver information systems are also included in this Section 3. Use of fast, reliable, wireless links to enable a seamless communication between the vehicles, the LX, and the main control centre/s are analysed in particular in the light of a recent European Commission's decision. In Section 4, the mode of operation of each potential solution is modeled and evaluated considering several operational scenarii, in order to evaluate the aggregate benefits of all the inputs. Setting models to describe the dynamics surrounding the LX environment will prepare a basis to support the decision making process of a joint rail and road sector strategy on how to control LXs. Finally Section 5 brings the study to a close with a list of the main areas in which to concentrate our future work.

2 Analysis of existing statistics

Safety at LX is only one part of a wider picture of transport safety within the whole transport system. Governments, the rail industry and road organizations have been implementing a variety of countermeasures for many years to improve railway LX safety. These actions are substantial and have resulted in a continuing decrease in the number and the severity of LX accidents. Every year, more than 400 people die in accidents involving road vehicles at road–rail LXs in the European Union [1]. Ninety percent of these fatalities are linked to errors committed by road vehicles drivers. LXs have been identified as being a particular weak point in road infrastructure, seriously jeopardizing road safety. This is a particular problem for Rail companies because they cannot control the actions of road vehicle drivers and pedestrians at LXs. The cost of railway accidents at LX is at least 110 million euro per year in the EU (almost 1.200 LX accidents per year between 2004 and 2006). LX accidents are the shared responsibility of several transportation players such as railways, road and local authorities, and land use planning entities. Good cooperation between railways and the road sector is a key point for managing LXs' safety. Table 1 shows that the majority of fatalities involve Rolling Stock (RS) in motion (67%) and LXs (29%). Therefore, RS in motion and LX encompass 96% of fatalities. This demonstrates that, for the rail sector, LXs represent the weak point in terms of accident risk. During 2004–2005, the number of fatalities in road accidents registered in EU-25 is 85.000, caused by 2.573.100 accidents, which represents a fatality rate of 0.033 (85.000/2.573.100). The comparison for this same period (2004–2005) of fatalities per accident in the railway sector at LXs shows that 842 fatalities were caused by 2,917 accidents at LXs (source Eurostat) in EU-25 [1]. The fatality rate per LX accident is 842/2,917=0.29.

This result demonstrates that the risk of a LX user dying is ten times higher than that of a road user. Also to be noted is that fatalities at LXs represent roughly 842/85.081=0.9% of all fatalities in the road sector and 29% of all railway accident fatalities. Hence, what is a significant risk to the

Table 1 Fatalities per class of accident in EU-25

Fatalities by type of accident (2004–2005)	Accidents caused by RS in Motion	Accident at LX	Others	Collisions	Derailments	Fires on board	Total
No of accidents	3,644	2,917	5,853	1,294	1,202	271	15,181
No of fatalities	1,976	842	68	61	8	1	2,956
Percentage	67	29	2	2	0	0	100

Table 2 2004–2005 data on the rail–road interface

Transport mode	(A) N° fatalities at LXs	(B) Total fatalities	(C) = (A)/(B) %
Road	842	85.081	0.9
Railways		2,956	29

safe operation of the rail network is in fact only a small element of the overall road safety issue (Table 2).

Up to now, the only effective solution appears to have been to upgrade LX safety systems [2] even though in over 90% of the cases, the primary accident cause seems to stem from inadequate human behavior rather than any technical, rail-based issue. Human causes from roadside include all intentional and non-intentional road vehicle driver errors; zig-zagging, warning light violation due to inattention, sun shine or perception of waiting time. The standards set by the European railway sector involve high safety requirements for LX systems which represent a substantial cost which in turn hinders the technological upgrade of existing systems. Railway standards already include a definition of safety risk. It is based on a classification of risks ranging from low to high, and according to which unacceptable levels of risk must be eliminated by the technical system. Nevertheless, the lack of an approved common safety methodology which would allow the industry to quantify the risk to be reduced still leads to the imposition of the highest safety integrity levels for technical solutions in most European countries.

In 2004, the European Commission produced Railway Safety Directive 49/2004/EC [3], in order to define Common Safety Targets (CSTs) and to improve, where possible, system safety levels. The Directive stipulates that Member States are duty-bound to conduct an independent investigation in order to improve rail safety and prevent accidents. In addition to serious accidents, the investigating body may conduct investigations into accidents and incidents which, under slightly different circumstances, could have resulted in more serious accidents, including technical failures in structural rail sub-sections or interoperability components of the trans-European high-speed or conventional rail systems. The Railway Safety Directive 49/2004/EC requires the safety of railway transport to be defined according to acceptable individual risks to LX users (Article 7, §4a) [3]. The Directive expects the development of procedures and methods for risk evaluation and assessment (Article 6, §3a). The CSTs define safety levels that must at least be reached in each Member State by different parts of the railway system and by the system as a whole. These CSTs are expressed as risk acceptance criteria for individual risks (passengers, maintenance staff including subcontractors, LX users and others, and unauthorized persons) and societal risks.

ERA (European Railway Agency) classified LXs into two groups: active LXs (group A) and passive LXs (group B) (Fig. 1).

The simplest description for passive type LXs may be all LXs equipped with any warning signs, plates, devices, or any other protection equipment, which is permanent and independent of any traffic situation. The first analysis of operational LX risk was carried out on the basis of the active and passive LX types as defined per the European Railway Agency for the purpose of defining Common

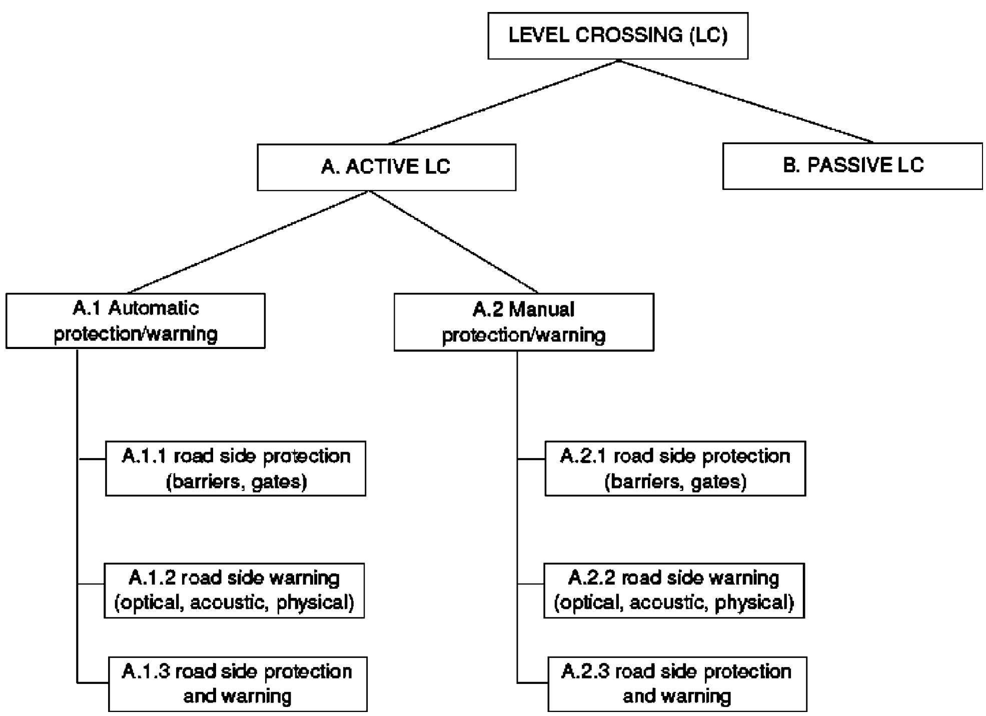

Fig. 1 LX types classified by ERA

Safety Indicators [3]. It defines an active LX as a LX where the crossing users are protected from, or warned of, the approaching train by the activation of devices when it is unsafe for the user to cross the LX. In the case of an automatic active LX (A.1 in Fig. 1), these devices are activated by the approaching train. Manual active LXs (A.2) are activated by humans when there is no railway signal interlocked with control train movements. In the case of passive LX (B in Fig. 1) there is no warning system and/or protection system showing when it is unsafe for the user to cross the LX. SELCAT project [2, 4] carried out an analysis of accident statistics by comparing operational risk according to the different LX types. As a basis for comparison, seven basic LX types as defined per ERA were taken into account. The individual risk for road LX user was compared as per the different LX types [5].

As basis for operational risk comparison, the seven level crossing types defined by ERA have been taken. However, only five of these types could be identified (the A1.1 and A2.2 were not clearly identified) when analyzing the 66 collected national level crossing types of countries involved in SELCAT project [4, 6]. Figure 2 shows this comparison whereby the height of each column corresponds to the individual risk considering the accidents (Acc), fatalities (Fat) or injuries (In) at LX of a particular type.

A comparison of LX operational risk in the EU countries analyzed using the process of normalization by vehicle interaction, is shown in Fig. 2. It is immediately clear that the operational risk of LXs in Eastern European Countries represented is significantly higher than the one in Western European Member States.

In Fig. 2, one can notice that the highest risk, for the European countries involved in SELCAT, applies to LXs with warning lights (A 1.2), followed by the automatic LX with warning lights and barriers (A 1.3) [2]. Therefore, the main conclusions drawn from the statistics analysis are as follows:

- Safety at LXs is a definite problem for rail companies as they have no control over actions of road vehicle drivers and pedestrians at LXs and as it represents 29% of total accidents in a rail system compared to the road sector which represents 0.9% of total accidents. Clearly, while LXs represent a significant risk area for the safe operation of a rail network, this is in fact only a small element of the overall road safety issue.
- The highest operational risk in Europe is attributed to automatic LXs fitted with warning lights but without barriers. The second highest risk is attributed to automatic LXs with warning lights and with barriers.
- The results of investigations into causes of LX accidents have identified inappropriate or inadequate human behaviour as the main source of the problem. Human factors play an important role for both the road and the rail. Violations of traffic regulations, disregard of warning signals, and trespassing by road vehicle drivers and pedestrians contribute to most of the fatalities. In terms of rail, staff with safety related responsibilities (i.e. manually operated LXs, warnings

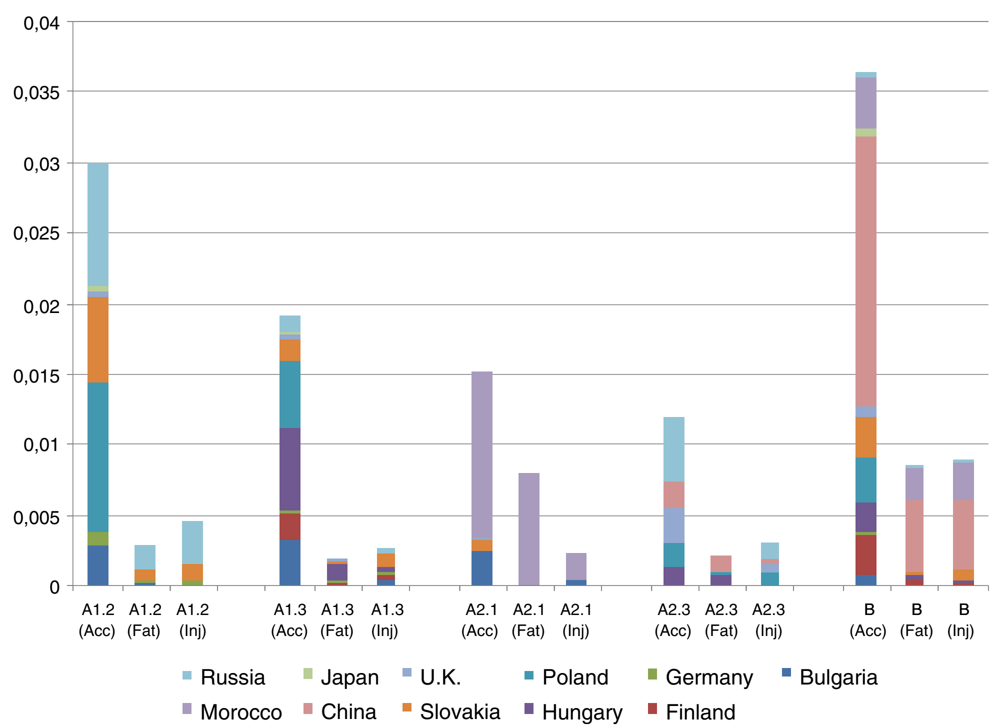

Fig. 2 Comparison of accident statistics normalized by simplified vehicle interaction (Accidents/Rail network.km/Mio. Train km * Road network.km/Mio. Road passenger.km/Number of LXs) by LX type [6]

given by train drivers, supervision, and fall back operations) are particularly vulnerable to human errors. Therefore, design of new technological solutions intended to minimise the impact of human behaviour ought to be based on an analysis of human factors in the context of limiting safety risks at LXs. Such an approach is expected to produce a twofold benefit: it will help increase people's awareness of risk at LXs and it will minimise the impact of intentional and unintentional hazardous human behaviour. The solution suggested at the end of this article will consider the highest operational risk at automatic LXs with warning devices and half barriers. This solution can be applied to other LX types.

3 Possible solutions using advanced technology to improve LX safety

The main focus of this section is to suggest solutions applicable to the following areas:

– technological improvements of the LX safety infrastructure, such as deployment of various types of sensors (audio, video, radar, laser) for timely detection of potentially hazardous situations;
– use of fast, reliable, wireless links to enable seamless communication between train, car drivers, LX and a main control center.

3.1 Current technologies used for object detection

Most LXs are fitted with high performing equipment such as red lights, automatic full/half barriers, notices. However, such equipments are unable to prevent or to detect dangerous behaviors. Nowadays, most collisions occurring at road–rail interfaces are due to vehicle drivers not seeing a train coming or believing that they still have enough time to cross. That is why clearly identifying whether or not vehicles/pedestrians are trapped on the tracks and inside the barriers and efficiently using this information may reduce the risk of collisions between trains and vehicles/pedestrians. Obstacle detection systems appear as a breakthrough solution to improve LX safety and lower the number of fatalities.

3.1.1 Current technologies used for object detection

The detection of vehicles, pedestrians or other obstacles approaching a LX requires the setting up of detectors. Several technologies provide this, such as optical or sonic sensors, inductive loops, radars and video imaging.

The choice of the appropriate detector depends strongly on external factors, e.g. environmental conditions or the size of the object to detect.

A study was led by RSSB [7], the Rail Safety and Standard Board—a UK company which aims at providing knowledge, analysis and a substantial level of technical expertise, and powerful information and risk management tools—researching into obstacle detection at LXs. On the basis of this study, obstacle detectors can be divided into two major categories: conventional and advanced.

Conventional obstacle detection has been used to prevent crashes between trains and vehicles (optical beam, sonic detection, inductive loop) [8, 9]. Obstacle detection systems using advanced methods are constituted by Radar Method [8, 9] and video imaging [10, 11].

3.1.2 Detection with video imaging

This section is mainly concerned with the timely detection of events that could jeopardize personal safety of individuals, groups, cars, as well as other related incidents that could adversely impact upon the quality of service for LXs. All operators, passenger groups and staff representatives have in-depth knowledge of such events and where they are likely to occur. The main purpose of the tools is, clearly, to detect such untimely events *when* they are happening. For illustration purposes, a non-exhaustive list of possible events to detect includes: Car parked on the tracks, objects left on the tracks, trespassing, pedestrians crossing the LX.

The main aim of the use of video imaging is to develop cost-effective and integrated technical solutions that can sustain the deployment of pro-active monitoring procedures on a railway network. For this purpose, an in situ experimentation was carried out at a LX. Several scenarii representing events of interest were played by actors; they created mainly potentially dangerous situations at LXs. The scenarii played by these actors stemmed from real situations which had occurred and had lead to accidents. The system developed and tested on this occasion was able to detect in real-time each element interfering in the operation of a LX: trains, cars, motorcycles, bicycles, pedestrians, and any other object. For this first experimentation, an architecture composed of two cameras was set up, one for the detection of the on-coming train and the other for the monitoring of the LX's central section. CCTV (Close Circuit Television) at LXs could indeed be used in the following methods:

– Off-line use: the primary function of a perception system using optical sensors consists in the observation. The passive LX analysis leads to the production of statistics related to the use of the LX, road user behavior in terms of speed, inter-distances, by automatically detecting and identifying abnormal behaviors thanks to indexing on to the video. This also allows the various entities supervising the LX to have quick access to a video sequence which helps to have a better understanding of behaviors leading to dangerous situations. This method allows access to information made available by these systems.

– Online use: here, the objective is to use the perception system tools in the surroundings of the LX to recognize potentially dangerous situations such as the presence or approach of objects (pedestrians, motor-cycles, vehicles or other obstacles) which could get in the way. The objective of this method consists in detecting and anticipating a critical situation.

Online use allows real-time detection of all components involved at the LX, and an analysis of their interaction. In addition, it becomes possible to classify such elements with reference to their nature and behavior, in conjunction with the functional model of the LX [12, 13].

The experimentation lasted several days so that we could simulate some one hundred scenarii. They were inspired from scenarii drawn from real accident analyses. The accuracy of the algorithm was tested and compared findings collected in situ. Accuracy of tested events was around 99.3% with a processing time of 25 frames per second.

We observe here that we are able to detect with good accuracy a classic example of potentially dangerous situations which often lead to serious accidents. These situations must be communicated and shared with the other actors involved around the LX (Train driver, control centre, car drivers). A specifically adapted communication tool is necessary to ensure the correct type of transmission of information. This point is developed in the next section.

3.2 LX advanced information system

Communications are vital for seamless and safe railway operations. They are also becoming vital on the road side with many different concerned users. To illustrate the problem, at Britain's level crossings, between January and September 2008 there were nearly 900 incidents involving a vehicle. Pedestrians too are running the risk with over 200 near misses this year. Thus, pedestrians, cyclists and vehicles can most likely beneficiate of an infrastructure-based advanced information system improving the existing warning lights. These figures show also that vehicle drivers are very much concerned and that an advanced driver information system delivering warning information inside the vehicles can most likely increase safety at LX. This section will now concentrate on this category of road users. The goal of this section is to compare current situations regarding wireless communications in railway and road operations, i.e. Communication Based Train Control (CBTC) and Car to Infrastructure (C2I) communications. As far as railways are concerned, CBTC Systems, also known as Positive Train Control (PTC) systems, provide positive train separation, speed enforcement, and road worker protection utilizing wireless communications to exchange control information. As far as roads are concerned, based on WLAN communications, VANETs—the Vehicular Ad-hoc NETworks could provide a broadcasting facility between vehicles within radio line of sight, to broadcast real time information on traffic, and road conditions and hazards. At rail–road crossings, these wireless communication systems could therefore be used to reduce road–rail intersection collisions by transmitting train movement information to road users.

3.2.1 Train wireless communication system

The railway wireless communication systems resort more and more to the use of existing off the shelf products designed by the telecom industry, upgraded if necessary. By using such an approach, the railway industry can take full advantage of the R&D investments of the telecom industry. The railway industry would also benefit from any evolutions in telecommunication standards.

Table 3 lists some different wireless technologies used or tested for railway communications.

In Table 3, the two first lines consider WLAN (Wireless Local Area Network) and WMAN (Wireless Metropolitan Area Network) systems. In line 1, IEEE 802.11 represents the WLAN (Wireless Fidelity Wi-Fi). Wi-Fi systems are now rolled out on board many trains to support wireless passenger services. They are also a CBTC solution widely used for train to wayside communication in subway systems. IEEE is performing a standardization work on CBTC, and IEEE RTVISC-1473 considers the different train-wayside communication solutions provided by train control suppliers. WLAN communications are among these existing technologies [14, 15]. The satellite communications which have been included here since railway operators are now considering them [16–18]. Satellite communications are also now commercially used for providing Internet up to trains, with data relayed inside the trains, using Wi-Fi [18]. Finally, Table 3 mentions the GSM-R, the "Global System for Mobile Communication for Railways", the digital cellular system standardized in order to harmonize train to ground radio systems for control/command on board trans-European trains. GSM-R is typical of a telecommunication industry development upgraded to fulfill the railway CBTC requirements [19].

So, if we consider a train passing through a LX at a maximum speed of 160 kph, a conventional train with 15 wagons would need approximately 900 m to stop. Then, starting from this 1 km communication range order of

Table 3 CBTC–PTC wireless telecommunication technologies

Standard	Family	Radio tech	Downlink/uplink	Reliability/implementation	Mobility	Broadcast range	Notes
IEEE 802.11	WLAN	OFDM	Up to 54 Mbps	Already implemented on board some trains	Operational for subway CBTC	Base station needed every 500 m for continuous subway CBTC	Useful CBTC rate: 6–7 Mbps
IEEE 802.16	WMAN WiMAX	OFDMA	70 Mbps	QoS/Easy	High	<20 km	Useful rate: 10 Mbps at 10 km range.
Satellite	Broadcast	Satellite Digital Radio	Broadcast satellite to train 16 kbps	High		>1,000 km	Satellite visibility requested
GSM-R	GSM	CDMA	9.6 hbps/9.6 kbps	High/Easy	High	Base stations needed every 3–4 km	EU railway dedicated spectrum

magnitude and using the information in Table 3, we can select the best candidates to support an effective LX track-to-train advanced information system. Loading a continuous coverage communication system with the only locally LX significant information would be ineffective. Thus, GSM-R and satellite communication are not feasible. WiMAX would provide more range than necessary. WLAN with two or three consecutive repeaters and corresponding hops would provide the necessary communication range. For our LX application, in addition to train communication, a reliable, safe and high data communication link for car-to-car (C2C) and C2I is also required. Therefore, in this section we will also evaluate the potential of this WLAN technology for road applications. The recent European Commission decision providing a single EU-wide 30 MHz frequency band that can be used for road safety applications will be presented and analyzed as well as results from simulations for a short range radio C2C communication system. This recent Commission Decision paves the way for a possible mandatory C2C and C2I wireless communication system to be installed in all road vehicles circulating in Europe, in several years.

3.2.2 Car wireless driver information system

As stated before, in a CBTC system, the railway Local Control Centre and the Main control Centre are interconnected by bi-directional data communication links which may be wired or wireless. This is not the usual situation yet on road sides where only lateral visual signaling exists, and there is no distant repetition of the LX signaling information inside road vehicles. This situation could evolve in a near future. In fact, improving traffic efficiency, reducing congestion on roads and reducing accidents as well as damage cost are challenging tasks in most regions of the World. To put the problem into context, annual damage cost caused by accidents in the EU alone is approximately 100 Billion euro. This can be potentially minimized by using new information and communication technologies. Among these technologies, C2C and C2I communications are good candidates to improve the current situation. In this way, connecting vehicles to each other or to infrastructure by a wireless radio link opens the way for a new range of applications and upgrades of existing applications [20, 21]. Moreover, the C2I communications can send data to distant additional signaling panels for other road users (pedestrians, cyclists,...). Recently, new spectrum requirements, corresponding to new C2C and C2I communication requirements have been discussed within several European agencies. The European Conference of Postal and Telecommunications Administrations (CEPT) approved the spectrum requirements for road safety and traffic efficient

Intelligent Transport System (ITS) applications as articulated by the industry. On August 5th, 2008, the Commission published a Decision providing a single EU-wide 30 MHz frequency band to be used for immediate and reliable C2C, and C2I [22]. Figure 3 presents such a typical C2I–C2C communication scenario of the propagation of an alerting message.

As mentioned before, in over 90% of cases, the primary cause of accident at LXs appears to be inadequate or improper human behavior rather than any technical, rail based issue. Thus, any advanced driver information system such as the Vehicular ad-hoc Network (VANET) offers the potential to reduce road–rail intersection collisions by communicating information on train movements to road vehicles.

C2I communications on a centimeter-wave length are expected to be using unidirectional and semi directional antennae broadcasting on a horizontal plane and concentrating energy at low angles over the road surface. Vehicles use relatively low, close to the ground, antennae and a typical antenna height above the surface of the road is approx. 1.7 m. In Europe, a constant 23 dBm/MHz Equivalent Isotropic Radiated Power (EIRP) over the whole bandwidth, is currently envisaged to provide an expected useful range of several hundred meters. To simulate transmission from a LX to a vehicle, a propagation model was used. The model considered signals reflecting off the ground [23, 24]. The LX communication system antenna height was set at 5 m and the receiving antenna height was set to 1.7 m. Using a 10 MHz band channel, transmitter power was set to 33 dBm. To achieve the requested C2C C2I 6–7 Mbps bit rate, considered sufficient for vehicle to infrastructure communication [22], a −72 dBm reference input power level was considered as a receiving threshold. Figure 4 represents the simulation results obtained using these parameters and this −72 dBm reference input power.

Considering the results in Fig. 4, we obtain a communication range in excess of 500 m. Fading heavily affects communication over the first 100 m. Received signals drop several times below the −72 dBm selected reference level.

3.2.3 Conclusion

The type of LX to vehicle wireless communication described above could therefore provide vehicles with the duplication of the LX status information across a significant transmission range. This would mean that the driver of a vehicle driving at an average speed of 60 kph would receive warning information 30 s before arriving at the LX. This definitely broadens the warning triangle obtained from direct visual information, which is often situated 150 m ahead of the LX in a rural environment and 50 m ahead in an urban environment. For other road users (pedestrians, cyclists, etc), several warning techniques can be used in order to provide the same signalling information. Moreover, wireless communication also offers better flexibility in terms of the content of the information sent to drivers. As seen in Fig. 4, LX information status can be relayed by intermediary vehicles to increase this 500 m communication range further. However other studies still have to be done in order to determine which advance delay time proves most effective when conveying this information to drivers.

4 Static and dynamic specification of the proposed system

4.1 Architecture

What we propose here is a static point of view of the system. UML[1] diagrams will be used to illustrate the different points of view. The deployment diagram presented in Fig. 5 gives a description of the architecture while indicating the physical position of the system's components and their distribution. In this diagram, the communication links between the "modules" are also shown. All of the transmission means are not shown in this diagram and we use module links to represent communications. For instance, the train detection system may alert the LX local protection system through a connection which could be either wired or wireless as in the system proposed in [25]. For the sake of clarity, we have included in our model certain external entities which interact with our system. In Fig. 5, these entities correspond to what is outside the dotted line.

The global architecture of the system shows three main modules. The first one is the « Train sensing system » which serves to detect train arrivals and departures respectively toward/from the LX. This module is responsible for triggering the local protection system composed of automatic half barriers and signalling lights. The second module is also linked to a monitoring system (third module) composed of cameras, a processing unit responsible for the analysis of image sequences sent by the cameras—and possibly for storing them in a dedicated database—. The unit also recognises potentially dangerous situations and alerts the Local Control Centre (LCC) of the LX zone. The LCC is able to communicate with the approaching train in order for example to issue a braking order. The LCC is also linked to a Main remote Control Centre (MCC) which manages the traffic on a larger scale. Following a disruption occurring on at a LX, a MCC may decide to divert some trains to other routes. Note that train detection devices have to be situated far enough away from the LX crossing zone, so that when obstacles are

[1] UML: Unified Modeling Language

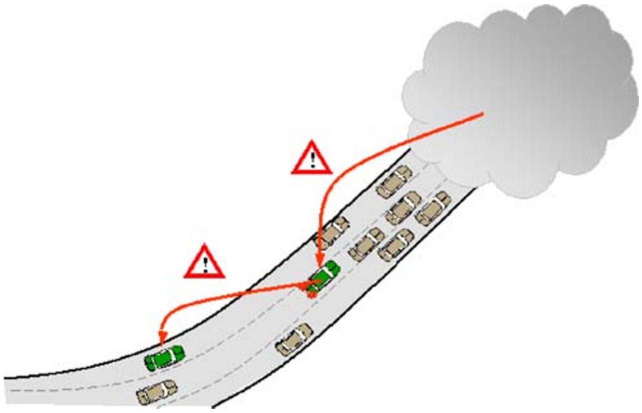

Fig. 3 Typical advanced driver information scenario (European Telecommunication Scientific Institute (ETSI))

detected within this zone, there still is enough time for the monitoring module to take anticipatory measures.

4.2 Example of operational scenario

In this section, we focus on the dynamic point of view. We will show some operational scenarios [26, 27] of the system using UML dynamic diagrams. Here a sequence diagram is elaborated (cf. Fig. 6) in such a way as to bring out the interaction between the system modules.

In Fig. 6, the following sequence of events is presented:

- Cameras send image sequences to the obstacle detection module (ODM)
- ODM checks situation while processing sequences sent by cameras
- a potentially dangerous situation is diagnosed
- alert is sent to LCC which assesses situation at the LX and alerts approaching train, which in turn starts braking
- LCC gives order to ODM to close LX to traffic
- ODM sends a closing order to local protection system (PS) which starts closing cycle
- ODM alerts to cars in the neighbourhood
- according to type of disruption, LCC can alert main control centre, which then takes the suitable decision in terms of traffic management.

The scenario presented above demonstrates the capacity for anticipation of the system; in this case, closing the LX early and alerting all approaching cars avoids compounding complications at the LX.

In the system presented above, image processing techniques are used in order to detect potentially dangerous situations at the LX. Let us note that the system will be enriched by other devices able to enhance global efficiency. This is one of the main aims of the PANsafer research project that the INRETS institute will lead with some other industrial and institutional partners. In a more complex system, several kinds of information will be generated. All this information has to be gathered, interpreted before the decision making process. A global model which depicts data handling and describes the operation of this new system in various situations will be drawn up.

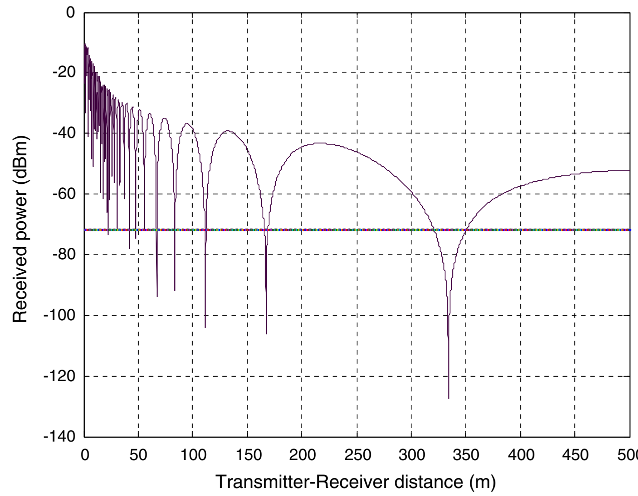

Fig. 4 Received power at 5.9 GHz, along the LX to vehicle radio link

5 Conclusion

The work described in this paper has addressed possible technological solutions to improve level crossing safety. A new generation of level crossing fitted with equipment was described, made up of three main parts: sensing, communication and LX modeling. A case study was presented with the aim to explore the potential of automatic detection technologies using intelligent cameras in level crossing safety applications. The conclusion has been that the detection of stopped vehicles provides part of the solution to the problem of safety at level crossings. However, further tests of and improvements to the video system are needed. These include: testing on a larger video data set, increasing robustness in terms of shadow and headlight detection in order to limit the number of false detection incidents, improving the reliability of the system in adverse weather conditions.

In addition, a transmission system is provided in order to transmit the status of the system as well as updates to the relevant decision making centres. It also provides triggers and signals for alarms in potentially dangerous situations, or in case of a system failure. With respect to the case study presented earlier, the transmission system presented in this paper is needed to deal with video sequences which generally require high transmission bandwidth.

The functional models developed for the assessment of technological change are elaborated with information on

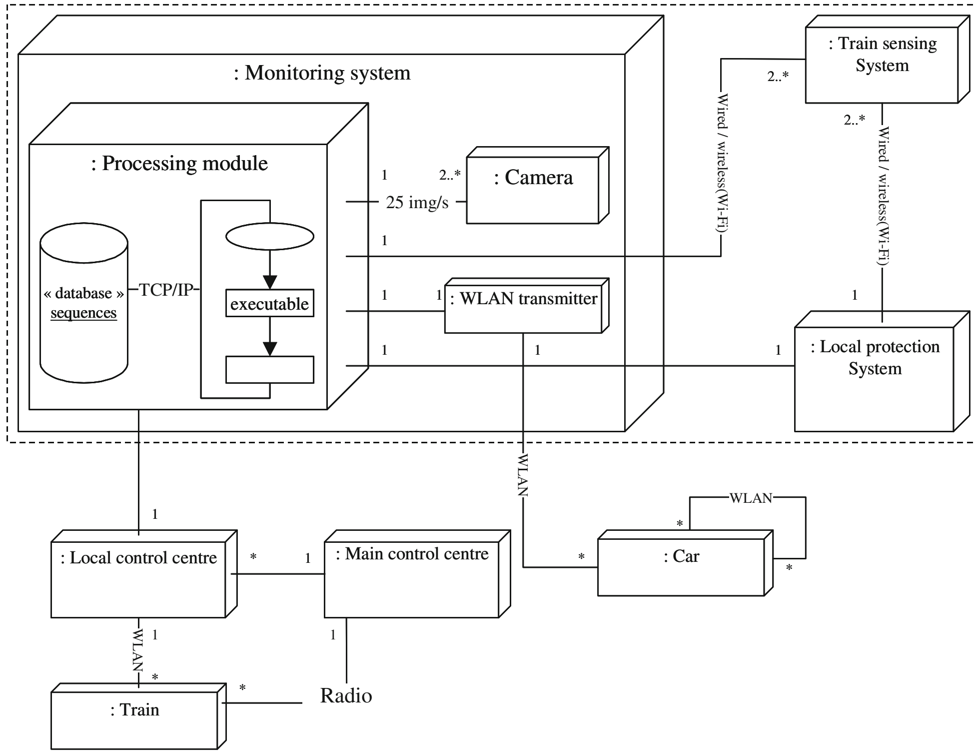

Fig. 5 Diagram showing the deployment of the proposed system

timing in order to understand the interaction between the different functions. Next, the modelling carried out has to address dependability, safety, reliability and availability of the components of the level crossing, and the effects on these parameters when new technology is introduced. In order to calculate the risks of failure and therefore the impact on failure risk when new technology is introduced, it is necessary to carry out a comprehensive physical decomposition of the system under analysis.

Further work is planned for the near future. Some of them will be developed within the framework of PANsafer Project, a French national work-programme. Among the goals of this project, we can list:

analysis of user behaviour and the behaviour linked to the infrastructure and its mode of operation, sensing and detecting automatically and faultlessly all potentially dangerous situations at level crossings, exploring new technologies and mastering evaluation techniques in order to optimise communication around the level crossing, integration and validation on a full scale test site of all the concepts developed.

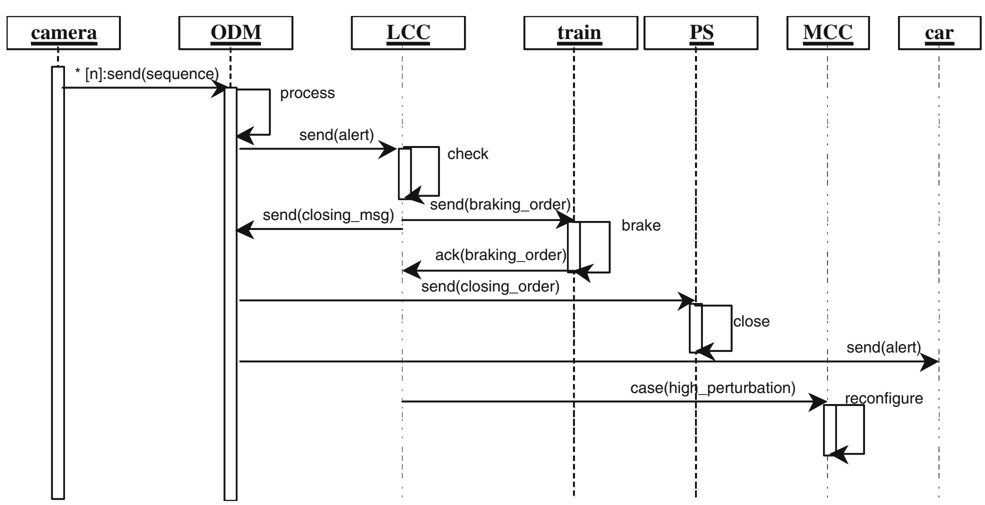

Fig. 6 Diagram showing the sequence of events of the considered scenario

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