COST EFFECTIVE SYSTEM FOR RAILWAY LEVEL CROSSING PROTECTION

By

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I. Introduction

Railway safety is a crucial aspect of rail operation the world over. Malfunctions resulting in accidents usually get wide media coverage even when the railway is not at fault and give to rail transport, among the uninformed public, an undeserved image of inefficiency often fueling calls for immediate reforms. This paper is aimed at helping the railway administrations concerned to strengthen their safety culture and develop the monitoring tools required by modern safety management.

Rail/road intersections are very unique, special, potentially dangerous and yet unavoidable in the World. Here two different entities with entirely different responsibilities, domains, performances come together and converge for a single cause of providing a facility to the road user. During the normal operation also, there is every possibility of accidents occurring even with very little negligence in procedure and the result is of very high risk.

The potential for accidents is made higher as the railways control only half the problem. The other half, meanwhile, cannot really be said to be controlled by one entity, as even though traffic rules and road design standards supposedly exist, the movements of road users are not organized and monitored by one specific entity as rigidly as rail movements. The railway systems of Asia and the Pacific are no exception to this. Each year, accidents at level crossings not only cause fatalities or serious injuries to many thousands of road users and railway passengers, but also impose a heavy financial burden in terms of disruptions of railway and road services and damages to railway and road vehicles and property. A very high number of these collisions are caused by the negligence, incompetence or incapacity of road vehicle drivers, who by and large operate their vehicles in environments in which safety consciousness is practically non-existent.

Since it is the railway which must bear the responsibility for ensuring that it is protected from the transgressions by road users (despite the fact that in many countries the law gives it priority of passage over road users), it is the railway which also has to shoulder most of the financial burden of providing this protection. Similarly, it is the railway, which has most of the responsibility for educating road users on the safe use of its
level crossings. Notwithstanding this, it appears that in many regions, railways are ill-equipped to be in a position to monitor level crossing safety effectively and to take both corrective and pro-active measures to improve the safety of their level crossing installations.

Scope: To

- Review the present status of level-crossing accidents
- Present statistics, indicators, technology and problems relating to the systems adopted for level-crossing protection; in practice
- Analyze various alternative systems for level-crossing protection; and
- Make recommendations pertaining to the selection of cost-effective protection systems.

Methodology:

The following analyses are considered:

1. Evaluation of the requirements of a Safety Management Information System which adequately addresses the needs of railway management for information on level crossing safety performance;
2. Review of the essential and effective safety, enhancements, measures and priorities for level crossings;
3. Assessment of level crossing safety performance and safety measures in some countries;
4. Examination of Cost Benefit Analysis of investments on level crossing safety enhancement;
5. Review of the technical attributes and suitability of Networked Anti Collision System (ACD) for level crossing protection system;
II. Necessity

In general it appears that, Railway safety, and particularly safety at intersections between roads and railway lines, is perhaps not accorded the priority it deserves.

Much of this has to do with the lack of a strong safety ethos. Personal safety, as such, is not highly valued and hence safety consciousness is not generally something which is stressed in educational program, either in schools or in the wider community.

Nevertheless, the high rates of economic growth experienced in the region within recent years, coupled with the growth in personal disposable incomes and the related growth in motor vehicle populations have stressed the need for attitudinal change as far as personal safety is concerned. There is little doubt that road accidents and their associated casualties have increased almost in parallel with the explosive growth in the vehicle populations of several countries of the region.

The evidence is that, accidents at the intersections between road and rail contribute only a very small proportion of total road accidents in most countries of the region. However, it is a growing proportion as increasing road construction and road vehicle populations create greater opportunity for level crossing accidents to happen.

Additionally, level crossing accidents tend to have casualties which are disproportionate with their number and frequency within the overall road safety picture. For example, where accidents involving collisions between two or more motor vehicles usually generate limited casualties, collisions between road vehicles and trains at level crossings can, and often do, generate multiple casualties of both rail and road users, particularly when such collisions result in train derailments. Therefore, too much is at stake to allow level crossing accidents to grow uncontrolled.

Of paramount importance in any program is to improve level crossing safety and the need to have access to continuously updated information – to detailed level crossing inventories, to details of accident circumstances, causes and casualties as well as to details of the growth in the road and rail traffic passing level crossings.
Such a program will depend upon regular hazard assessments being made of individual level crossing locations, in order to allow calculation of accident risks and probabilities and to be able to establish valid priorities for safety enhancement measures at level crossings. Essentially this will require the establishment of a comprehensive Safety Management System, of which a Safety Management Information System will be a vital component. Thus the characteristics of a Safety Management Information System and the application of Quantified Risk Analysis (QRA) and Cost–Benefit Analysis (CBA) techniques to level crossing safety management is given priority.

Finally, technical descriptions of the wide range of level crossing protection systems and technologies available, as well as guidelines for making technical assessments and selections from among this range are also given equal importance.

The concept of having to assign a value to human life in order to justify expenditures on life–saving projects may be distasteful to some railway safety managers. Yet, this is precisely what is being demanded of them, as safety projects increasingly fall within the ambit of the capital expenditure justification processes of the respective railways.

The difficulty with the application of this approach in Asia is that the values notionally placed on human life have been low in relation to the costs of life–saving measures. Historically, the failure of some railway systems in the region to commit expenditures to the elimination of unofficial level crossings and to the adequate protection of official level crossings has provided implicit evidence of the generally low valuation of human life throughout the region.

It is possible through the application of Quantified Risk Analysis to historical data to establish the probabilities of fatalities and serious injuries in level crossing accidents, with and without improvement of level crossing protection. These probabilities will provide an indication of the life–saving potential of various safety enhancement measures, such as the installation of full width protective barriers at crossings which formerly had no protection.

For example, if it is established that there is a probability that six fatalities per year will occur at a given crossing, currently without any form of protection, but that this probability will reduce to only one fatality per year after installation of full width protective barriers, then it
might be concluded that this initiative has the potential to save 5 lives per year. In the case of several railway systems of the region, the lifesaving potential of protective barrier installation at level crossings is very high.

Notable examples are provided by countries such as Vietnam and Thailand, which experience a high frequency of level crossing fatalities, mostly at unofficial level crossings.

Hence it is absolutely necessary to protect the gate in a very efficient and safe method to protect the lives of people and the property of Railways and the Public.

Hence the big question is:

*Is there any system that can rescue us from such ghastly events?*
III. Criteria For Providing Protection at Level Crossings

Having examined the necessity of greater protection at the level crossings, now let us evaluate the criteria for level of protection at level crossings, which is in turn linked with the risk profile of the level crossing. At the core of the rail track approach to railway risk assessment is the application of so called ALARP principle.

The ALARP Principle:
Criterion for Road / Rail gate protection is as per ALARP Principle (shown in the figure below).

Application of this principle is intended to ensure that the risk, or probability, of railway accidents with serious consequences in terms of loss of life and injury, is kept to a level which is “as low as is reasonably practicable.” ALARP defines three levels of risk:

1. Intolerable risk, which cannot be justified or accepted, except in extraordinary circumstances;
2. Tolerable risk, which can be accepted only if risk reduction is impractical or if the cost of risk reduction greatly exceeds the benefit gained; and
3. Negligible risk which is broadly acceptable and does not require risk mitigating measures.
The implications of ALARP are that if risk is determined to be at the intolerable level, measures must be taken immediately to reduce it to a tolerable level. Similarly, if risk is found to be at a tolerable level, risk mitigating measures should still be applied, provided that they are capable of practical application and that the benefits to be gained exceed the costs of their application.

It should be noted that the ALARP principle, by accepting risks for which there are no cost effective mitigating measures, stands in marked contrast to the European approach to public safety and safety in the workplace as set out in the Framework Directive of the European Union (89/391/EEC). This states that safety “is an objective which should not be subordinated to purely economic considerations.”

Capital shortages typically threaten the capacity of most railway systems of the region to provide more than just a very basic level of protection against road/rail collisions at level crossings. Given the stringency of budget restrictions, it becomes essential to establish priorities for level crossing improvement activity. Level crossings are certainly not homogeneous in terms of accident risk probabilities.

Some have a much greater propensity for accidents than others. Quantified Risk Analysis (QRA) provides a suitable basis for establishing level crossing improvement priorities. This is done by allowing a ranking of level crossings in terms of their accident risk probability. Those crossings with high accident probabilities would normally qualify for funding allocations (subject to satisfactory cost/benefit results), while those with low accident probabilities would be assigned a low priority for improvement funding. QRA results should be linked to the Level Crossing Inventory Recording System which provides for the reporting of hazard probabilities against each level crossing. Factors influencing the probability of accident occurrence at level crossings include:

1. Rail traffic density (measured in terms of the maximum number of trains passing the crossing within a 24 hour period);
2. Road traffic density (measured in terms of the maximum number of motor vehicles of all types passing the crossing within a 24 hour period);
3. Presence of physical obstructions restricting the visibility of the track, warning signs or signals to road users;
4. Absence of full width barrier protection at level crossings;
5. Absence of flashing lights and audible warning devices at level crossings;
6. Poor road surface condition at level crossings (leading to the grounding of low slung road vehicles); and
7. Poor alignment and elevation of the road crossing the track (the road may cross the track at an oblique angle or may approach the crossing on a steeply rising grade).
8. Weather conditions;
9. Human errors.

It is strongly recommended that accident probabilities should be calculated for all official level crossings on the railway system (and possibly for the more critical of the unofficial crossings) and that these calculations should be updated to continuously to cater to the changes to any of the factors listed above.

In addition to accident probabilities, it would also be highly desirable to calculate the probability of multiple fatalities and injuries resulting from accidents at individual crossings. The probability of such outcomes is influenced by all of the above factors and also by the level of usage of crossings by crowded road and rail passenger vehicles. The latter may be difficult to calculate in the absence of adequate information, but may be substituted by Fault Tree Analysis (FTA) and Event Tree Analysis (ETA).

For example, if only the daily number of trains and the number of road vehicles passing through a crossing is known, the probable frequency of conflicts between the two at that location may be calculated. For a crossing which carries 5,000 road vehicles and 60 trains per day, the probable frequency of conflict between road and rail movements at that crossing is 5,000/30,000 (60 x 5000), or 1.66 in 100 – a very high frequency.

The presence of full width protective barriers and integrated warning signals at that crossing will, all other factors being equal, reduce the probable frequency of conflict to zero, but of course other factors are rarely, if ever, equal. Equipment failure or human error in particular will intervene in this case to increase the probable frequency of conflict to some point between zero and 1.66 in 100. If data from accident reports can be used to indicate the frequency of such occurrences at a particular
crossing the probability of occurrence can be calculated as the ratio between the number of such occurrences in a year and the annual traffic moment (daily number of trains x daily number of road vehicles x 365 days) for that particular crossing. For example, if from a sample of accident reports for a particular crossing carrying 60 trains and 5,000 motor vehicles per day, it is established that on average 10 collisions per year are caused by motorists failing to observe warning signals then the probability of such accidents occurring at the specified crossing (Pr_c) is given by the following equation:

\[ Pr_c = \frac{10}{300,000 \times 365} = 1 \text{ in } 15.3 \text{ million} \]

In this case there is very low probability or risk of collision due to failure of motorists to observe signals results from the low frequency of such accidents in relation to the volume of road and rail traffic using the crossing. Similar calculations may be done in order to estimate the probability of collisions at the specified crossing being caused by other factors, such as the failure of signalling or barrier equipment, human error on the part of railway employees etc.

Subject to data availability, the probability of collisions involving particular types of road vehicles, such as buses, tractor-trailers, long chassis vehicles, container carriers, tankers etc., may also be calculated for particular crossings, as may the probability of fatalities and injuries resulting from such collisions. The difficulty is that most often the safety databases maintained by the railways of the region are incapable of providing this level of detail.

FTA helps to identify the chain of events leading up to the top event (i.e. a collision between a train and a road vehicle) and for which indicative data must be obtained in order to calculate the frequency or probability of accident occurrence. If the necessary data are not available then estimates of the frequency of the identified events will have to be substituted in order to produce the final probability calculation. While the safety of railway passengers and of road users must be a paramount issue in the appraisal and choice of a suitable and cost effective level crossing protection system, some consideration must also be given to the operational efficiency of the system. In this context, “operational efficiency” means the capability of keeping delays to both rail and road traffic to the minimum consistent with safe operation of level crossings.
Field inspections undertaken during the course of fact finding missions to India and Vietnam in connection with this study revealed that delays to motor vehicle traffic can be extensive at manned level crossings. If these delays could be cut to a minimum perhaps as a result of installing electrically actuated crossing barriers, it is likely that significant economic benefits in the form of travel times savings would accrue to road users. Further, if warning signals facing train drivers could be installed at manned level crossings, the maximum permissible speeds of trains through these crossings might also increase with the result that the railway would realize financial savings in the form of reduced running times, a reduced requirement of motive power and rolling stock, and an associated reduction in operating costs, while there would be economic benefits to rail passengers in the form of reduced travel times.

Barriers which are operated manually tend to be closed for longer periods than barriers which may be remotely controlled by crossing staff using electrical actuation systems, simply because the physical act of closing barriers will require more time than if the barriers can be activated remotely by mechanical or electrical means.

Typically, if barriers remain closed for excessive periods on crossings carrying a high volume of road and rail traffic, the build-up of road traffic will exceed the capacity of the crossing to safely discharge this build-up before the next train arrival at the crossing. Road traffic build-up in this situation obeys the rules of Queuing Theory: the longer the barrier closure, the greater the build-up and the slower the passage of motor vehicles over the crossing once the barriers have been raised. Queuing theory is seldom followed in Asian regions.

An inspection of level crossings in the vicinity of Agra provides ample evidence of difficulties encountered with traffic build-up when crossing closures are excessive. At one crossing within the Agra city limits, a Class A level crossing protected with double half boom barriers on both sides of the crossing was closed for 8 minutes awaiting the passage of a fast electric passenger train on the double-tracked Mathura–Agra–Bhopal mainline. This train was followed by another in the opposite direction about 10 minutes later, but it took 2–3 minutes to clear the crossing of traffic which had built up while the barriers were closed awaiting passage of the first train. Clearly, excessive crossing closure times will severely limit the train carrying capacity of a railway line if the road traffic using
the crossings on the line exceeds a certain critical level. The Indian Railways has specified a daily TM (traffic moment) level of 100,000 at which grade separation of crossings would be justified, but budget restrictions have prevented this work being done except for a limited number of railway crossings of the national highway system. The current norm for grade separation is as under:

<table>
<thead>
<tr>
<th>Item</th>
<th>Daily traffic density / traffic movement</th>
<th>Type of crossing indicated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TVU &lt; 6,000</td>
<td>Unmanned Level crossing</td>
</tr>
<tr>
<td>2</td>
<td>6,000 less than or = TVU &lt; 10,000</td>
<td>All unmanned level crossings to be manned on programmed basis</td>
</tr>
<tr>
<td>3</td>
<td>10,000 less than or = TVU &lt;100,000</td>
<td>Manned Level Crossings</td>
</tr>
<tr>
<td>4</td>
<td>TVU greater than or = 100,000</td>
<td>Road flyover / overpass</td>
</tr>
</tbody>
</table>

For the purposes of this analysis, IR costs have been used to assess the relative costs and benefits of grade separation. The same approach can be used for the assessment of more modest improvements to level crossing warning and protection systems. There are two types of benefits resulting from grade separation of level crossings: financial benefits accruing to the railway in the form of increased line capacity and reduced operating costs and economic benefits accruing to individuals, i.e. railway passengers and road users in the form of travel time savings.

Finally the criterion for selecting the type of gate protecting equipment is based on the road traffic, rail traffic, financial constraints, performance reports of the system selected etc.,

The Level crossing protection system can thus be classified broadly into 3 categories:

**1. Manned or operated level crossing protection system:**

In case of Manual operated Level crossing protection system, the man at the gate actuates the Level crossing protection, acts when he receives communication from the signal room by means of a telephone call. Since it is mainly based on human operations, there is every likely hood that it may fail due to human errors. However, since this system is being cost effective it is very much in place in the developing countries like India, Bangladesh, Iran, Egypt etc.,
2. **Train sensor based Automatic Level crossing protection system:**

   This system is based on Rail wheel sensors viz., Track Circuits, Proximity Sensors etc., which are located at about 2 kms from the Level crossing and provides a time lag for about 2 kms for a bullock-cart in rural areas to cross the Level crossing, but the system has no parameters which make the system cumbersome and available. The system demands extension of power supply to remote places to run long cables from sensor to the system, which is expensive and reduces reliability.

3. **Radio based Level crossing protection system:**

   Radio based level crossing protection system, such as ACD (Anti Collision Device) provides safety at level crossings, in addition to other features such as anti collisions on track. This network based radio system keep communicating with Gate ACD system (either manned or unmanned) and indicates the train arrival by wireless. With this information, Level crossing protection system then start activation by lowering the barrier, flashing the road side lights and sounding alarm bells etc.,

   The Architecture of a typical railway level crossing is given below:
Architecture of a Typical Railway Level Crossing

Level Crossing Organisation

<table>
<thead>
<tr>
<th>Railway Vehicle Detection</th>
<th>Road User Detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railway Vehicle Information</td>
<td>Road User Information</td>
</tr>
<tr>
<td>Railway Vehicle Warning</td>
<td>Road User Warning</td>
</tr>
<tr>
<td>Railway Vehicle Protection</td>
<td>Road User Protection</td>
</tr>
</tbody>
</table>

Laws

Loco ACD

Plates

Signs

Gate ACD

Road User Protection

Barriers/ Hooters/ flashers

Traffic Lights

St. Andrews Cross

Loops

Camera

Laws

Railway

Road
IV. Currently available Level Crossing Protection Systems

(a) Crossing Warning Signals:

In general, these are of two types: automatic and manually operated signals. Manually activated signals are operated by level crossing staff, on instructions transmitted by telephone or telegraph signal from the nearest station. Automatic warning signals need short track circuits or markers which detect trains and activate warning indications at level crossings. These warning indications are usually flashing lights, or sounds emitted by bells or claxons (horns), or a combination of these two. If visibility at a crossing is a problem, then flashing lights may be increased in intensity and may be installed so as to suit the layout of the surrounding land and buildings. Similarly, audible-warning devices may be increased in frequency and amplitude, to compensate for the sound absorption qualities of the physical environments of level crossings.

From experience, the level of safety afforded by these devices on their own is insufficient. This is particularly true in the case of level crossings accommodating two or more tracks. If unmanned level crossings are to be contemplated in these situations, then some form of train approach indication becomes very essential.

(b) Mechanical Crossing Barriers:

Mechanical crossing barriers are operated by level crossing staff using hand or electrically powered levers, winches or windlasses. In addition, mechanical barriers providing complete protection of level crossings are connected to manually operated warning signals. Combination systems of this type are widely used within the developing countries of Asia since they may be manufactured inexpensively within the region. By contrast, automatic electronic crossing devices are wholly manufactured within developed countries and must be imported at substantial cost for installation within the developing countries of the region. There are three main types of mechanical barriers: lifting booms, swinging booms or gates, and trolley gates. Of these types, the trolley barrier provides the most effective form of protection against break-through by heavy goods vehicles. However, of necessity trolley barriers are of heavy construction
and are best deployed by means of remotely controlled electric motors. This type of barrier is used at a major level crossing intersection in Hanoi, Vietnam, but the Vietnam Railways has encountered problems with maintenance of a sufficient stock of spare parts in order to keep the motor systems functioning. Swinging type barriers afford a generally greater level of protection than lifting barriers against breakthroughs, but particularly when installed at double track level crossings they must be equipped with efficient locking systems.

(c) Train Detectors

Automatic devices of this type detect the presence and speed of a train in block sections at the approach to a level crossing. They are installed only near unmanned level crossings and usually consist of a series of transponders inserted in track at certain intervals and interlocked with level crossing barriers and warning signals. Such devices must be capable of detecting train speeds since the elapsed time between a train’s detection and its arrival at a crossing will be a function of its speed. The alternative to installation of automatic train detectors is to have train starting signals at stations interlocked with level crossing barriers and warning signals. These signals have the capability of identifying the type and hence speed of different trains and will transmit the appropriate signal to the level crossing protection system in order to activate it at a specified time before the arrival of a train.

In the case of manned level crossings the function of the train detector is substituted by level crossing staff, who receive advance warning by telephone or telegraph from the nearest station of the arrival of a train.

(d) Obstruction Warning Devices for Level Crossings:

These types of devices are generally installed at unmanned level crossings. Their function is to provide signal warnings to train drivers when level crossings are blocked by motor vehicles or other obstructions. They mainly consist of phototubes, supersonic wave emitting devices or laser beam transmitters which detect obstructions on crossings and are interlocked with distant signals before level crossings. When activated by the presence of obstructions (e.g. stalled motor vehicles), they transmit a flare indication to distant signals via short track circuits, allowing train drivers to apply emergency braking and to stop their trains short of the crossing.
(e) Automatic Crossing Barriers

These have multiple functions, including provision of:

1. Physical barrier to prevent or (perhaps more realistically) to dissuade motorists from entering a level crossing into the path of an oncoming train;
2. A crossing warning signal, indicating the presence of a level crossing;
3. A train approach warning indicator of oncoming trains; and
4. A crossing failure indicator warning of mechanical or electrical failure of level crossing equipment.

If desired, train detectors and obstruction warning devices based on a phototube system may be connected to automatic crossing barrier mechanisms. There are many types of automatic level crossing barriers, the most commonly used types being swinging or lifting booms. Automatic trolley gates exist and a small number in fact have been installed within the Asian region (mainly in Vietnam), but in general use of the trolley gate system is restricted to manned level crossings.

Automatic swinging boom barriers have a greater number of mechanical parts than automatic lifting boom barriers and thus are exposed to greater risk of spare part shortages. Automatic half barrier level crossings are found in many countries of Europe.

This system functions satisfactorily when the road carriageways may be physically segregated. In the case of many two lane rural roads in Europe, however, lane segregation has not been possible and accidents caused by motorists making slalom (or S pattern) moves through half barriers are frequent. Despite the relatively low cost of the half barrier system it has not been widely used in Asia. Indeed, Japan withdrew from use of this system several years ago. To enhance the visibility of barriers to motorists, a number of different methods have been devised including painting in tiger stripes and use of large diameter booms, double booms and high positioned booms (for trucks).
V. Future Trends

Systems likely to be available in future for the protection of level crossings are of following types:

(a) Advanced Radio-Based Train Control System – General Features

The American and Canadian Railway Associations began to study Advanced Train Control Systems (ATCS) in 1984. The systems then involved the use of radio, satellite and radar communications. Following the lengthy appraisal of this technology, it was operationalised in San Francisco’s Bay Area Rapid Transit System (BART) in 2001. Transmission Based Train Control Systems (TBTC) which are similar to ATCS have been under study by the French National Railway (SNCF) and in Japan by the JR Technology Research Institute. This type of control system is close to practical application in Japan. Application of ATCS allows elimination of track circuits and signals and facilitates high density and unmanned train operations.

This system provides for the detection of a train’s position by means of a radio transmitter installed on the locomotive which then transmits this information to a wayside base. The wayside radio base determines the velocity at which the train will be able to run safely within the section given information inputs as to the gradient, curvature and condition of the track. It then transmits this information back to the train either as data displayed within the cab or as direct commands to the train’s throttle and braking systems. For operation through level crossings, the train onboard computer calculates the time at which the level crossing warning lights or bells are switched in, based on the train velocity and level crossing position. This system may be overridden by train controllers in the event of equipment malfunction.
In addition, the system has blocking control, level crossing control and the functions of ATC (Automatic Train Control) and CTC (Central Train Control) systems. The basic components of the ATCS are a Train Radio Set (TRS), a Wayside Radio Set (WRS), a Station Radio Set (SRS) at Control Stations, a Level Crossing Controller (LCC) and connecting systems between the train, wayside locations, level crossings and control stations. TRS are installed at both ends of each train. WRS are installed at the trackside (at intervals of 500m to 1500m on the BART system). SRS are installed at 20 station locations on the BART system. Signals and track circuits between stations are not needed at this system.

**(b) ATCS – Level Crossing Safety Features:**

Existing level crossing systems represent a weak point of safety management and control on railways. Adequate warning time is needed for safe level crossing operation. Existing systems having electronic train detectors work on the basis of short track circuits installed in the track approaches on either side of level crossings.

These systems control the beginning and end of the warning indication. The disadvantage of this system is that the warning interval becomes disproportionately long with slow trains, because maximum train speeds normally determine the interval between the beginning and end points of track circuited sections, and thus a train operating at slow speed will take
significantly longer to pass between these two points. Further, existing crossing obstruction detectors do not stop trains automatically if crossings are obstructed – they merely provide a wayside signal indication of such obstructions to the train driver, leaving the responsibility for brake application to the driver.

With new ATCS systems, warning indications begin from the position at which an emergency brake application would be needed in order to bring a train to rest before a crossing, the braking distance being calculated automatically by the system on the basis of a train’s speed past the radio relay point. The computers on board trains calculate their position and send the train number, train position and time until beginning of the warning indication to the Level Crossing Controller (LCC) through the Wayside Radio Station (WRS). The WRS picks up signals from the closest approaching trains, but only begin to transmit the signal to the LCC in order to activate the warning indication at the calculated control time. If no level crossing obstruction indication has been received by this time, the WRS will permit the approaching train to pass and will transmit crossing warning and barrier activation messages to the LCC. The train will then be permitted to pass through the level crossing on schedule. However, if an obstruction warning indication is received, the WRS will transmit a signal to the train receiver (TRS) in order to activate emergency braking.

**GPS–based Advanced Train Control System**

Global Positioning Satellite (GPS) communications systems are now in common use for sea, air and land transport navigation applications. GPS uses communications links with number of satellites to establish the navigation coordinates of aircraft or surface transport receivers. GPS systems are on the whole very inexpensive – a receiver for an automobile now costing as little as US$ 500. The BART system, known as an AATCS (Advanced Automatic Train Control system) was developed by Nippon Signal in conjunction with Hughes and Harmon of the United States.

As compared with ATCS, the advantage of using GPS for train control functions it is more economical. However, the system does have some shortcomings, the most significant of which is that for certain applications it contributes error certainly excessive for locating trains in relation to level crossings. Considerably more accurate navigational information be desirable at minimal cost. Another problem associated
Cost effective system for Railway level crossing protection – Konkan Railway

with GPS is that of setting the marks for revision of distance errors. These marks must be set accurately on maps or route charts. In the case of ATCS lines, trackside receivers may be used as markers for validating GPS co-ordinates, but in the case of lines not equipped with ATCS, new markers must be established within reasonable margins of error on maps or route charts. The cost of radio-based and GPS-based ATCS are comparable; however GPS-based systems will overtake the radio-based systems to become the cheapest form of train control system available in future.

Financial analysis of alternative methods of safety enhancement at level Crossings:

A recurring theme throughout this study has been the relative advantages and disadvantages of installing manually operated barrier protection systems, as compared with automatic systems, at level crossings. It is desirable, therefore, to propose a method for comparing the quantified costs and benefits of each. It should be noted that this is one case where a financial, rather than an economic, evaluation is appropriate, since it is the railway which must seek a minimum cost solution to the problem of safety enforcement at its level crossings.

An example of a financial comparison of the two alternative systems, based on Indian Railways data, is provided in Table below. The two alternative systems are:

1. A manually operated full width barrier system, with block signal and flashing road warning lights; and
2. A train-activated full width barrier system, with a block signal, flashing road warning lights, and an obstruction detector connected to the block signal.

It is important that exactly the same level of protection should be provided by the systems being compared, so that the comparison is on a strict like-for-like basis. For this reason, it is necessary to equip the automatic system with an obstruction detector, activated by an optical sensor which will send a signal indication of the presence of any type of obstruction on the level crossing – to which the train driver may respond before the train reaches the level crossing. In the case of the manually
operated barrier system, the Gateman has the function of an obstruction detector and is able to provide the signal warning to the train driver.

Table showing financial comparison of manual and automatic barrier systems

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>US$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Cost of Manual Barrier Installation</td>
<td></td>
</tr>
<tr>
<td>(i)</td>
<td>Capital Cost – lifting barrier with flashing light and block signal</td>
<td>38600</td>
</tr>
<tr>
<td>(ii)</td>
<td>Present Annual Value of (i) [15 year life; 12 % discount rate]</td>
<td>5667</td>
</tr>
<tr>
<td>(iii)</td>
<td>Annual staffing cost</td>
<td>5682</td>
</tr>
<tr>
<td>(iv)</td>
<td>Annual Maintenance Cost (assume 10% of staffing cost)</td>
<td>5682</td>
</tr>
<tr>
<td>(v)</td>
<td>Total Annual Cost</td>
<td>11917</td>
</tr>
<tr>
<td>B</td>
<td>Cost of Automatic Barrier Installation</td>
<td></td>
</tr>
<tr>
<td>(vi)</td>
<td>Capital Cost – Automatic Lifting Barrier with flashing Light &amp; Block Signal</td>
<td>53900</td>
</tr>
<tr>
<td>(vii)</td>
<td>– Optical Sensor Obstruction Detector</td>
<td>81600</td>
</tr>
<tr>
<td>(viii)</td>
<td>– Sub-total</td>
<td>135500</td>
</tr>
<tr>
<td>(ix)</td>
<td>Present Annual Value of (viii) [15 years life; 12% discount rate]</td>
<td>19895</td>
</tr>
<tr>
<td>(x)</td>
<td>Annual Opening &amp; Maintenance Cost (assume 2 x maint. cost of manual system)</td>
<td>1136</td>
</tr>
<tr>
<td>(xi)</td>
<td>Total Annual Cost</td>
<td>21031</td>
</tr>
<tr>
<td>C</td>
<td>Net Cost Advantage for Manual Installation</td>
<td>9114</td>
</tr>
</tbody>
</table>

This example shows that a manual barrier system has a substantial cost advantage over an automatic barrier system, provided that it can provide the same level of safe operation as the automatic system. Clearly, the need to incorporate an obstruction detector in the automatic barrier installation reduces the cost effectiveness of this alternative by a substantial margin. However, the very low cost of labor in this example from India also contributes significantly to the cost effectiveness of the manual barrier system, since labor rates would have to be expanded by a factor of nearly 2.6 to equate the overall costs of the two systems.
VI. Examination of Suitability of Radio based Networked Anti Collision System (ACDs), for providing Cost–effective Safety System at Level Crossings – A Case Study – Indian Railways.

Indian Railways is massive and has approximately 63,000 route kilometers of track with 8500 stations, 17,550 manned level crossings, 21,880 unmanned level crossings with an average of one at every 1.5 kilometers. These are various types of level crossings such as, some are equipped with barriers, some are open crossings, some abetting canals etc.,

Though the total number of accidents taking place on Indian railways is on the decline, the accidents at level crossings (LCs) are also comparatively low when compared to advanced railway systems (0.1 per million train kilometers). However, there is a concern due to the raising trend and associated severity of LC accidents. The composition of the LC accidents and the fatalities associated with the LC accidents out of the total railway accidents, on Indian railways, is depicted in the following charts:

Type Wise Accidents per Year (1995–96 to 2006–07)
Chart showing the Trend of Accidents in Indian Railways from 1998–99 to 2006–07

Chart showing the Trend of % share of Level Crossing Accidents in Indian Railways from 1998–99 to 2006–07
Causalities in Train Accidents during 1995–96 to 2006–07

Chart showing the Trend of fatalities in Level Crossing Accidents in Indian Railways from 1998–99 to 2006–07
The accidents at LC, during 1996–2006 increased by 23 %, compared to the previous decade, and so also the fatalities increased to 49 % from 43 %. Amongst these, 85 % accidents occurred at unmanned LCs and 15 % at manned LCs. Fifty percent of the accidents at manned LCs were due to ‘Gates Open’/improperly closed gates, inspite of 40% of the manned LCs are inter-locked. If all unmanned level crossings are to be manned, Railways require approximately Rs. 2450 crores (US $0.7 Bn) as Capital cost to man them and approximately Rs. 700 crores (US $0.17 Bn) per annum will be required to meet the maintenance and operation cost. The cost of manning with interlocked signals will be around Rs.5500 crores (US $ 1.4 Bn) However, to eliminate probability of any accident at manned and unmanned level crossings, construction of Road Over Bridges (ROB’s) and Road Under Bridges (RUB’s) may be envisaged, but it will involve staggering amount of Rs.4,00,000 crores (US $ 400 Bn).
Level Crossing Accidents at Gates

<table>
<thead>
<tr>
<th>Type of LC Gate</th>
<th>% of Share of Total Accidents on IR</th>
<th>% of Share of fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manned</td>
<td>4%</td>
<td>9%</td>
</tr>
<tr>
<td>Unmanned</td>
<td>17%</td>
<td>40%</td>
</tr>
<tr>
<td>Total</td>
<td>21%</td>
<td>49%</td>
</tr>
</tbody>
</table>

Though, the Indian railways has a corporate safety plan and policy for safety enhancement measures like, reclassification of LCs based on revised TVUs etc., fiscal and other constraints make safety at LCs more difficult, due to several hazard factors, including human errors as listed earlier. Various solutions are attempted both passive and active, technical and educational to minimize the accidents at the LC gates.

India has developed its own train collision prevention system or an Anti Collision Device (ACD) called the RAKSHA KAVACH™ under the technology partnership between Konkan Railway Corporation and Kernex Microsystems (India) Limited, which is a Train Collision Prevention System, also providing enhanced safety, effectively, at level crossing gates, at a minimal cost.

Out of 2500 ACDs installed, approximately 310 gate ACDs, at Manned and Unmanned Level Crossing have been installed in Indian railway network, and have been working satisfactorily, providing safety to the road users at the level crossings.
LAYOUT OF THE NETWORKED ANTICOLLISION DEVICE SYSTEM
The RAKSHA KAVACH™ is a network of ‘self-acting’ microprocessor based data communication devices called Anti Collision Devices (ACD’s) which ‘automatically’ apply brakes to the trains fitted with the ACD’s, thereby protecting the traveling public as well as the road users at level crossing gates from ‘collision’ related accidents.

**General Description of the ACD System:**

ACD System or the RAKSHA KAVACH™ consists of several networked Mobile and Stationary Anti-Collision Devices, which communicate with each other via radio communication within a range of 3 kms (2 miles). The network of ACD’s consists of on-board (mobile) ACDs for locomotives and Guard Vans and Track-side ACD’s such as Station ACD’s, Level Crossing ACD’s, Loco Shed ACD’s, Sensor based ACD’s and ACD Repeaters. All of these ACD’s work on the principle of distributed control systems. The following schematic diagram represents the top level architecture of the RAKSHA KAVACH™. It consists of the following different types of ACDs networked together.

Only Mobile ACDs namely Loco ACD and Guard ACD interfaces with Global Positioning System (GPS) for determination of the train location, speed, course of travel and time. This is done by obtaining the Latitude, Longitude, speed, course angle of travel and time variables which are taken as inputs for further processing. All ACDs are provided with data radio modems through which they can communicate with each other in broadcast mode (ACD transmits at every 3 seconds the data packets for all the ACDs in the vicinity) or unicast mode (ACD transmits at every 2 seconds with ACD ID for which the data is intended for till such time it receives an acknowledgement).

**LOCO ACD:**

The Loco ACD is installed in a pre-fixed outer case in the locomotive along with anti-vibration mounts. Each Loco ACD is provided with two Driver’s Consoles which are mounted on the Driver’s pedestal for easy access and visibility to the Driver. The Radio Modem antenna and the two GPS receiver antennae are permanently fixed on the rooftop of the locomotive and connected to the Loco ACD through RF cables. Loco ACD interfaces externally with Automatic Braking Unit (ABU) to facilitate application of brakes using intelligent braking logic,
whenever needed. Loco ACD taps the input signal from the existing speedometer’s pulse generator to compute location data in predefined GPS shadow zones. Loco ACD also interfaces with Inter–Cock Switch (ICS) to set the Loco ACD in rear Locomotive to passive mode in coupling / banking mode of train operations and to Guard ACD in case of EMU/DMU/MEMU.

**GUARD ACD:**

This unit acts as a redundant system to Loco ACD. SLR Guard ACD is Portable ACD, which can be fitted in the pre–fixed outer case in Guard’s Brake Van of SLR. It derives power from the existing power source in coach. However, to take care of momentary dips in the input voltage, one–hour battery backup is provided with the help of a built–in Ni–Cad battery. The Radio Modem and GPS Antennae are permanently fixed on the roof of the SLR coach and their respective cables are brought into the outer case of the Guard ACD. For bringing the Guard ACD into operation, it has to be inserted into the outer case, power and antenna cables have to be connected and ACD switched ‘ON’.

**STATION ACD:**

Station ACD is mounted in the Station Master’s (SM’s) office along with battery and battery charger cum power supply. Each Station ACD is provided with SM’s Console that is mounted on SM’s table or a nearby wall such that it is easily accessible and visible to the SM. The Radio Antenna is provided on a self–supporting triangular mast or guyed mast erected near the SM’s office. At stations where AC power is not available, provision is made to derive power from VRLA storage batteries charged by SPV modules. The Station ACDs interface externally with the Track Circuits and Points position detection circuits.
MANNED/UNMANNED LEVEL CROSSING ACDs:

ACDs provided at Manned and Unmanned Level Crossings actuate audio-visual ‘Train Approach’ warning for road users at the level crossings, when an ACD fitted train is approaching it and is within 2000m.

Photo of a typical Manned Level Crossing Gate ACD

Figure: Showing a typical Manned Level Crossing Gate with ACD Accessories – Tower having Solar Power Panels, Hooter & Flasher Units etc

Legend:

1) Radio Based Gate ACD and Wayside Location Box
2) Hooter & Flasher Unit
3) Gateman’s Cabin
4) PV Power Supply Module
MLCG ACD acts as a safety shield to prevent or minimize collisions between trains and between trains and road vehicles in Indian railways. MLCG ACD is installed at manned level crossing gates. If the gate is open or damaged, MLCG ACD warns the approaching trains which regulate their speeds to minimize collisions at level crossing gates. It is also provided with a Hooter and Flasher to provide an Audio-Visual Warning to road users at Level crossings, when train is approaching the level crossing.

Manned non-Interlocked Level Crossing Gate ACD monitors the gate ‘open’ / ‘closed’ status with the help of Gate position sensing devices, and communicate this status to the approaching train. The Loco ACD will impose speed limit of 30 Km/h when it detects through the Gate ACD that Gate is in ‘open’ condition.
VII. GPS based Wireless Level Crossing Protection system

General Description of the System

Another alternate system is being discussed here which is tailored only for Lx operations, is less complicated than the ACD system and could be made a SIL certified product. GPS based Wireless system is a sub set of ACD system, constituting mainly a Loco unit and a gate unit with only required Hardware and Software. However, as and when required at certain stations and at track bends closer to gates, Station units and Repeater units may be required to be installed.

GPS based wireless Lx protection system is a microprocessor based wireless communication system with 2 out of 2 logic and with SIL qualification. Both Loco and gate units will be provided with dual wireless communication system which provides a reliable communication system. The Loco unit identifies the level crossing zone appropriately and automatically senses the status of the Gate unit (either manned or unmanned). Upon sensing any potential danger at the gate such as gate open condition or a vehicle blocking the passage at the gate, the trains fitted with the GPS based wireless Loco unit will warn the driver of the Loco to and subsequently applies brakes (if required) to regulate the speed of the train to 15 kmps in case driver fails to respond within 10 seconds. The system is therefore capable of protecting the traveling public as well as the road users and vehicles at level crossings from the danger of collisions and related accidents.

Main Components of the System

The system consists of an on board Loco unit with a redundant GPS based dual wireless 2 out of 2 processing unit

There will be one gate unit (at the manned and unmanned level crossings) consisting of a unit similar to the Loco unit, with a radio tower to communicate continuously with the loco unit within a range of 3 kms. An Obstacle Detection Unit is also provided at the unmanned level crossing gates that provides information of any road vehicle or similar
obstructions at the gate to the approaching loco/train so as to avert accidents at the gate.

There will be a radio communication based station unit, which receives the health status of the gates collected from the loco units that pass within a 3 kms range of the station unit. This is for knowing the status of the gates quickly to reduce the down-time of the system in order to improve the safety at the gate.

There will be a unit called “Repeater Unit” which will be interposed wherever there is a curvature in the rail track within a 3 km range from the level crossing gate. This unit is similar to the loco unit and it helps to improve the communication between the gate and the loco.

### Cost of the GPS based Wireless Redundant Level Crossing System

A cost based analysis of the GPS based wireless level crossing system is given in a tabular format:

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i)</td>
<td>No of Locos (assumed)</td>
<td>8000</td>
</tr>
<tr>
<td>(ii)</td>
<td>No of Gates (assumed)</td>
<td>33,000</td>
</tr>
<tr>
<td></td>
<td><strong>Costing</strong></td>
<td></td>
</tr>
<tr>
<td>(iii)</td>
<td>Cost of loco unit with min SIL certificate</td>
<td>0.8 mn</td>
</tr>
<tr>
<td>(iv)</td>
<td>Cost of Gate unit</td>
<td>1.00 mn</td>
</tr>
<tr>
<td>(v)</td>
<td>Total Cost including installation and commissioning</td>
<td>1.8 mn</td>
</tr>
</tbody>
</table>

**Note 1:** Proportional Cost of the loco unit either decreases or increases based on the increase or decrease of the number of gates and locos in the region of interest.

**Note 2:** Loco units are designed for minimum functions and activities at the gate.
**VIII. Cost Benefit Analysis – Benefits & Limitations of using Networked ACD System for Gate Protection**

The approximate costing for various protection systems at level crossing is given in a tabular form:

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>INR</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i)</td>
<td>ROBs &amp; RUBs</td>
<td>230 mn</td>
</tr>
<tr>
<td>(ii)</td>
<td>Automatic Level Crossing Gate (sensor Based)</td>
<td>6.0 mn</td>
</tr>
<tr>
<td>(iii)</td>
<td>Conversion of Unmanned Level Crossing to Manned with Signal Interlocking</td>
<td>5.1 mn</td>
</tr>
<tr>
<td>(iv)</td>
<td>GPS based Wireless Redundant Level Crossing system</td>
<td>1.8 mn</td>
</tr>
<tr>
<td>(v)</td>
<td>Gate Protection System using Anti Collision Device Networked System (without Loco ACD cost)</td>
<td>0.8 mn</td>
</tr>
</tbody>
</table>

Table: Cost–Benefit Analysis of ACD & Barrier Installation at Level Crossings vis-à-vis other systems.

**Benefits of the ACD /GPS based Wireless Lx Protection system:**

- Very economical and cost effective
- Easily adaptable and expandable
- Does not degrade the existing safety level
- Employs state-of-art hardware and software technology
- No way side equipment required, hence no requirement of Power
- No cabling on the track required (which is more expensive and cumbersome)
- Just by using gate ACD equipment, gate protection function is provided along with anti collision features.
• Less susceptible to Vandalism.

• Health of the gate system is monitored by the Loco unit and any malfunction is noticed. Loco unit logs this information and downloads this information to the Station ACD, dynamically which alerts the maintenance staff to repair the gate unit, which reduces the MTTR drastically.

• Movement of train traffic can be increased by having both ACD as well as GPS based wireless communication systems fitted gate protection system.

• The ACD level crossing system has high availability of the order of 99.99%.

• In the ‘Gate Open’ condition, the speed of the approaching train is regulated to 15kms/hr by the Loco unit, while passing through such a level crossing.

• It does not interact or compromise the efficiency of any co located existing signal and control systems outside the ACD. It also does not induce any new risks to the existing systems.

• Brings about improvement in rail traffic.

• Mainly uplifts the confidence levels of road users tremendously.

• On line health monitoring, hence down time is tremendously decreased.

Limitations of the ACD /GPS based Wireless LX protection system:

• As the communication is radio based, there is a likelihood of propagation and weather conditions affecting the communication and failure in communication may result in level crossing gate not functioning as expected. However, percentage of such incidents may be as low as 0.25% of total train crossings;
- Protection at level crossings is possible only when the train and the level crossings are fitted with ACDs, by this method.

- At times GPS data is not available in shadow zone; however this is taken care by supplementing with Dead Reckoning Devices.

- At times the Track side equipments may become targets of vandalism;

The ACD system does not disrupt the currently available signaling systems in the Railways and its safety. It is a safety layer above the existing signaling system.
IX. Recommendations

Level crossings are a key interface between the railway and the public. Level crossings represent a significant risk to passengers, drivers, and the public. The train accident risk from level crossings is higher than the collision and derailment risk from SPADs. There is currently considerable research and practical action being taken by the industry to better safety at level crossings and to implement additional controls and upgrades to improve level crossing safety performance. The risk at level crossings is dominated by fatality risk, rather than major or minor injuries.

The Seminar provided interesting and motivational look at advances in highway/railway crossing technology and operations. With over 38000 level crossings and complex nature of road traffic, India ranks better than many advanced countries in safety at level crossings with 0.10 accidents per million train Kms, surpassing France, USA and Japan etc. The Railways are persistently following the steps to reduce unmanned level crossing accidents and no effort is made to dilute the gravity and the seriousness of accidents.

In the control and scope of intervention in curbing unmanned level crossing accidents, the role of Railways is limited and highly constricted as most of them have been found occurring due to negligence on the part of road vehicle users.

It is almost impossible for a train driver to stop and prevent the collision if he notices a road vehicle on the crossing from a distance of 500 to 600 meters nor is it possible to change the course of a train similar to that of road vehicle. The maneuverability of road vehicle is much more than the train. As per statutory obligation, Railway’s liability is limited.

It has been experienced that manning of unmanned level crossings is not an ideal solution and a foolproof arrangement. The probability and ratio of accidents at **manned level crossings are 40% that of unmanned level crossings.**
It has emerged from a study of pattern of accidents that around 80% accidents generally take place at those unmanned level crossings where traffic is low and visibility is clear and they do not fall in identified five categories of manning. With proliferation of more manned level crossings in certain sections, slow down of train operation is also apprehended. The policy of manning unmanned level crossings is therefore under review with a view to making meaningful investment on manning in the interest of safety.

Anti Collision Device/GPS based wireless Lx protection systems, the latest innovation, will give additional safety shield at manned and unmanned level crossings, through an audio-visual indication to road users. Moreover, in case of emergent needs, gatemen at manned level crossings will be able to reduce the speed of an approaching train to prevent an accident at the crossing at a very nominal cost of procurement, installation and maintenance.

Thanks to the ACD/GPS based wireless Lx protection System!

Ghastly accidents can now be prevented.
X. References

The following publications and presentations have been taken as references in preparation of this paper: