Sri Lanka Society of
Transport and Logistics

Journal of South Asian Logistics and Transport
Volume 1 Issue 2 September 2021
JSALT 1.2.3: pp. 35-56
DOI: http://doi.org/10.4038/jsalt.v1i2.33

INNOVATIVE APPROACH FOR RAILWAY SIGNALLING IN SRI LANKA: AN APPRAISAL OF TECHNICAL AND ECONOMIC RATIONALE

J I D Jayasundara

General Manager's Office, Sri Lanka Railway, Colombo, Sri Lanka

Correspondence should be addressed to *jid.jayasundara@gmail.com*

ABSTRACT

Sri Lanka Railway has been increasingly dependent on foreign sources for its signalling, particularly after the introduction of computer-based electronic technology for signalling. Not many companies have competence in the subject, and the resultant deficiency of market competition has compelled the Sri Lanka Railway to depend on foreign third-party contractors to obtain signalling solutions at high cost. Developing a home-grown railway signalling system, anchored on local technological knowhow which would use components that are readily available in the market, has been a long-felt need.

This paper summarises the research and development activities undertaken by the Railway Department in designing and installing a new signalling system to ensure a greater degree of self-reliance in maintenance, sustenance, and further improvement at lesser costs. The technology innovated was used to install colour-light railway signalling at four railway stations and over 28 km of automatic block signalling, resulting in a capital cost saving of around 90% compared to recently procured imported systems.

The new system has been found operationally reliable and easily maintainable. With this technological innovation, continued improvements to it, and expansion of its coverage in the railway network, Sri Lanka Railway could look forward to securing very significant operational and cost advantages while generating national economic benefits as well in the years to come.

Keywords: *Railway Signalling, Sri Lanka Railway, Technological Innovation, Self-Reliance, Operational Sustainability, Cost Economics*

1. INTRODUCTION

1.1. Background

An effective and reliable signalling system is a necessary condition for the provision of safe and efficient passage of trains operated by a railway network. Railway signalling systems are designed as fail-safe systems to avoid erroneous signals resulting from equipment failure. At a time of signal failure, trains have to be operated using manual signals in accordance with established rules and regulations. These manual operations carry much higher risk as well as delays, and thus have to be avoided as much as possible. Therefore, safety, reliability and ease of maintenance of a railway signalling system are of paramount importance for the safe and efficient train operations.

According to an analysis of train delays conducted by the Sri Lanka Railway Signalling and Telecommunications Sub-Department [1], there have been seven signal breakdowns in average per day in the Sri Lanka's railway network, causing approximately 43 minutes of overall train delays per day. This questions the reliability of the existing system and highlights the need to procure a new system or to upgrade the existing system.

This paper presents a summary of an innovative research undertaken to design, construct and implement a new signalling system for the Sri Lanka Railways.

1.2. Practices hitherto adopted

Signalling systems evolved from the initial mechanical systems to multiple-aspect colour light signalling in the early 20th century. Multi-Aspect Signalling (MAS), adapted in 1923 in Great Britain, is the leading method of operation throughout the world even today. In this system, unsafe situations are prevented by an arrangement of tracks and junctions by a signal apparatus (interlocking) in a way that bars conflicting movements [2].

Mechanical signalling systems introduced to the then Ceylon Government Railway (CGR) by the British colonial administration are still operational in much of the Sri Lanka Railway network. This relies on manual operations and adheres to safety regulations. With increasing traffic densities, however, it is unavoidable that inefficiency and human error would cause delays and accidents.

Colour light railway signalling was first introduced to Sri Lanka Railway in the 1950s. This relay-based system is currently in operation in Colombo and suburbs. Relays used for these systems were manufactured by a company called Ericsson from Sweden. Unfortunately, they no longer manufacture these relays.

Computer-based colour light signalling systems replaced mechanical signalling in the coastal line from Kalutara North to Galle in the year 2000. Even in this system, interfacing of wayside equipment to the electronic interlocking unit is done through relays, using half as many relays as in a totally relay-based system. It is a complex system to maintain.

The Sri Lanka Railway's network, indicating different sections with different signalling technologies, is depicted in the Figure 1.

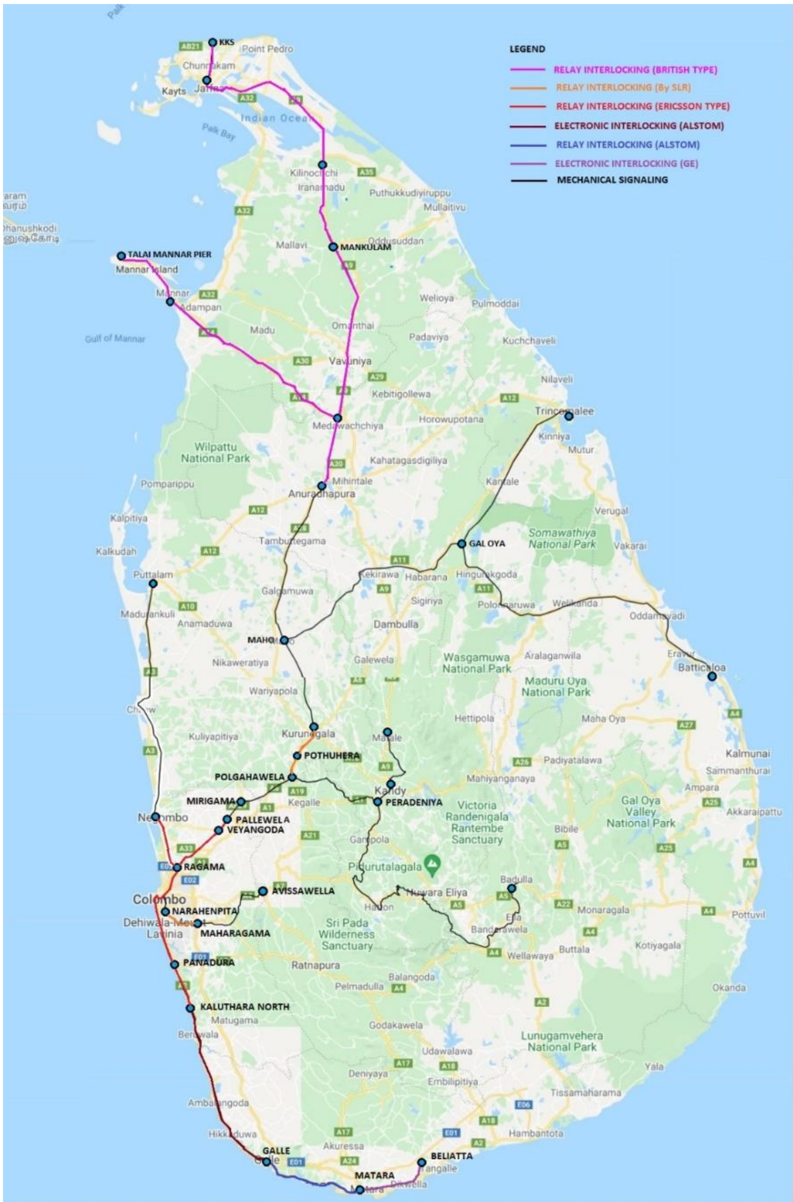

Figure 1: Sri Lanka Railway Network

1.3. Issues diagnosed

Railway Signalling systems introduced to Sri Lanka Railway since 2000 have many issues related to technology, diversity of systems and lack of components for replacement. For instance, the versions of electronic interlocking cards installed in the coastal line in year 2002 are no longer in production. Newer versions are not compatible with the system in place. To make matters worse, due to the complexity of the system, the contractor’s assistance was required to carry out modifications, at an enormous cost and a significant delay. Although the signalling system on the coastal line from Matara to Beliatta was installed by the same company, the new section had to be installed with a different type of electronic card system; the reason being the non-availability of the existing older type, which was out of production.

The problems are not merely due to lack of components, diversity of systems or technical issues, but also to the cost involved in installation and maintenance. The Table 1 illustrates the escalation of capital cost intensity of signalling installation over a decade since 2008.

Table 1: Cost of installation and diversity of existing imported Railway signalling systems - Sri Lanka Railways

No	New signalling Project	Year	Cost per station	Type of interlocking used
1	Panadura - Veyangoda Ragama - Negombo	1960	Unknown	Swedish Ericson type relays
2	Kalutara - Galle Restoration	2008	USD 1.0 Mn	VPI Alstom (Computer based)
3	Northern Line beyond Anuradhapura	2014	USD 2.0 Mn	British interlocking using Q type relays
4	Matara - Beliatta	2018	USD 3.0 Mn	GE_XP 4 (Computer based)

Source: Author’s estimates

As reflected in the Table 1, the signalling systems procured by the Sri Lanka Railway during the last two decades were from different manufacturers. This has made transferring of technical knowledge and keeping inventories, challenging tasks. Even if a single manufacturer with uniform systems was to be selected to upgrade the signalling, Sri Lanka Railway would then have had to be wholly dependent on that supplier for any future modification or expansion due to the proprietary nature of signalling equipment.

1.4. Research Problem and Objectives

Due to high costs and difficulties in technology transfer, Sri Lanka Railway could no longer depend on foreign contractors for signalling systems. Repairing and expanding the old and obsolete systems, currently in operation were becoming increasingly difficult, costly and unreliable. Yet, there were no locally designed systems which could meet Sri Lanka Railway's criteria. Hence, the problem arose as to how best it could design a reliable, safe, and locally adoptable system at an affordable investment and low cost of operation and maintenance.

The objective of this research and development effort was, therefore, to design and implement a new signal system which would be safe, maintainable, sustainable and economically viable, giving priority to local businesses and national development.

2. LITERATURE REVIEW

2.1. Technical consideration

The publications of the Office of Rail Regulation of UK [3], RISSB of Australia[4] and Pachel [5] described the criteria for developing an appropriate signalling system for railways and Safe management of movement, prevention of traffic from colliding with other rolling stock, derailing, colliding with pedestrians or vehicles at level crossings, being incompatible with infrastructure or colliding with rail safety workers or equipment in the rail corridor, can be identified as functional requirements of a railway signalling system. Palumbo [6] discussed the evolutions of the three main interlocking systems that are available for these purposes, namely the mechanical, relay-based and computer-based systems, analysing in detail their advantages and shortcomings. Mocki et al. [7] [8], takes the position that more sophisticated signalling arrangement would be desired for modern double, triple and more track arrangements, even though the manual interlocking is very sustainable. This is because the mechanical systems are time consuming with high technical risk due to the human factor and needs manpower, even though their life cycle is impressive. According to Knutton [9], even though the Computer-Based Interlocking (CBI) system has the advantages of saving space and remote operability, there could be delays in the acceptance process for CBI systems, caused due to lack of formality, diversity of applications, difficult maintenance and low estimated average of life of equipment. On the other hand, relay interlocking got a low technical risk regarding safety, operational performance that could meet all requirements, and economic life long enough to match the capacity of the industry to maintain and renew installations in the long term [9]. Mocki et al. opines that CBI would provide an interlocking similar to what relay interlocking could offer.

Table 2: Comparison of lifetime and capacity of different signalling systems

Signal System	Lifetime (years)	Capacity (Minutes/train)	Reference
Mechanical	75	30-50	Mocki [8]
Relay-based	25	3-5	Knutton [9]
CBI	10	3-5	Dohwa [10]

Source: Author

When considering the Sri Lanka situation, it is obvious that the country has to move fast away from the existing mechanical signalling system, because, as indicated in the Table 2, the desired train frequencies and punctualities could not be achieved with the train operating capacity provided by such systems. However, the data also indicate that there would be no advantage in going for CBI systems compared to the relay-based system, at least in terms of their comparative train operating capacities.

There is no consensus, however, on the preferable type of relay be used in a signal system. They have observed that, even though reasons were not specified, many relay rooms in Australian railway were using Q-type relays mounted in racks [7].

There is no particular compulsion, however, to use a single interlocking technology either. A combination of interlocking systems may be preferable, as stated by Mocki et al. [7], because some sequential process would be necessary whenever new technology or/and concurrent interlocking processing are introduced. Accordingly, advantages of both relay and CBIs could be combined when seeking new interlocking process and new technology implementation. Accordingly, the best technical option for Sri Lanka Railways would be to design a relay-based interlocking system with the incorporation of computer interface (hybrid system) to facilitate local and central control, event logging and the ability to integrate the system with future advancements.

2.2. Economical consideration

Mocki [8] compared the railway interlocking functionality of different systems with their respective costs involved. Accordingly, the CBI would possess improved functionality at a similar cost compared to a relay-based system. However, this cost-benefit relationship was not observed in the Sri Lankan experience.

Advantage of increasing local content in the procurement of infrastructure projects in low-income countries was clearly explained by the Institute of Civil Engineers and Engineers Against Poverty in their briefing notes in 2008. Wells et al. [11] explained that increasing the input of local labour, goods and services (local content) in the delivery of infrastructure projects in low-income countries could make a major contribution to economic growth. According to them, the immediate benefits of increasing local content in projects would include more employment in the construction and supply industry opportunities for local consultants, more work for local contractors and market opening for suppliers of materials and components [11].

The benefits of a national endeavour would not be limited to activities relating to procurement and installation but would extend to the area of further modification as well. When railway signalling systems are installed by foreign contractors, transfer of technology to local staff is not always forthcoming. Even if a certain degree of transfer takes place, it is often incomplete. Therefore, the institution and the country have to continue to depend on technical assistance from abroad for future modifications, implying significant costs and delays.

Furthermore, during the production of items used for signal systems installations, specific requirements of the railway would be transferred to manufacturers. Thus, with a steady stream of demand from railway signalling projects, reliable and technically competent manufacturers for railway signalling equipment would emerge in the economy. This initial opportunity, and the resultant space for further technological advancement, could one day enable them to enter into international markets.

ADB guidelines for economic analysis of projects stipulate that “resource inputs used by a project have an opportunity cost because, without the project, they could create value elsewhere in the economy. An economically viable project requires that, first, it represent the least cost or most efficient option to achieve the intended project outcomes; second, it generates an economic surplus above its opportunity cost; third, it will have sufficient funds and the necessary institutional structure for successful operation and maintenance” [12]. Similarly, when evaluating projects, the common practice is the selection of the most cost-effective solution that meets technical, functional and quality requirements. This criterion is clearly explained in the European Commission’s Guide to cost-benefit analysis of investment projects: “If different alternatives have the same, unique, objective and similar externalities, the selection can be based on the least cost solution per unit of output produced” [13] When these criteria are applied to railway signalling projects, importing a system having an expected useful life of 10 years, to run a train every 7 minutes along a railway line, at a cost of more than USD 3 million according to feasibility study done for Kelani Valley line signalling [10], cannot be justified, if the same requirement could be met by spending just USD 0.1 million with a 40-year life backed by readily available technical expertise.

In conclusion, promoting local technologies would result in reduction of foreign debt burden of the nation, and would possibly help economise Government expenditure. Also with reduced government borrowings, private sector would secure greater access to finances without being crowded-out by the Government spending. Injection of money into local economy would result in fiscal stimulus as emphasised by the Keynesian effect [14]. Therefore, the development of railway signalling using locally developed technologies would bring multifaceted benefits for the country's economy in the current juncture.

3. METHODOLOGY

The approach used in developing the new system, schematically represented in the Figure 2, included (a) gathering of knowledge from lessons learned from the past, (b) identifying features that need to be incorporated in the system, (c) examining the available technologies in the world and mapping them against the criteria that have been identified, (d) selecting the best model and developing a new signalling system, (e) comparatively assessing techno-economic viability, (f) implementing the new system and (g) conducting a post-implementation analysis of the degree of achievement of objectives.

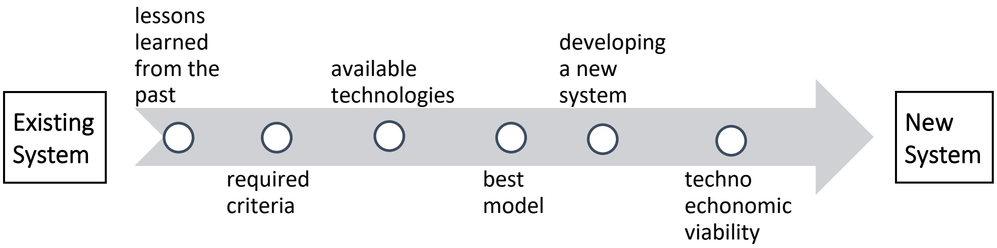

Figure 2: Schematic representation of methodology

4. ANALYSIS TOWARDS DEVELOPING A NEW SIGNALLING SYSTEM

4.1. Lessons learnt from the past

The relay-based interlocking systems had been in function since the 1960s and had been time-tested in Sri Lanka. The systems between Panadura-Veyangoda and Ragama–Negombo sections (Figure 1), installed in 1960, are still functioning, although they have out-lived their life span. With the modernisation of railways, new complex CBIs were introduced to railway sections between Kalutara and Galle, and Matara and Beliatta, at much higher costs. In addition to the high initial installation cost, Kalutara-Galle section had to be restored at a similar cost, following the Tsunami devastation in 2004.

The problems faced in expansion of Kalutara-Galle signal system taught a lesson to Sri Lanka Railway that it needed to adopt a system with universally available material and technology. The lack of uniformity in the system and the need for foreign contractor help for any modification highlighted the need for a simple system that could be locally produced and maintained.

This mandated the author to critically evaluate the systems that were available worldwide, and to adopt a system that would be technologically and economically suitable for Sri Lanka.

4.2. Required criteria and features

The fundamental criterion adopted was that the innovated system should be locally manufactured, reproducible, and maintainable at a low cost. It also had to meet the safety, reliability and operational efficiency standers required.

4.3. Available technologies

The Planning and Construction Division of the Signalling and Telecommunication Sub-Department of Sri Lanka Railways looked into the available options for upgrading the existing system. The first option considered was a CBI based Multi-Aspect Signal (MAS) system which was a widely used system in the world. An initial market survey, conducted mainly through vender websites, revealed the availability of a number of CBI based MAS systems from different manufacturers such as VPI (General Railway Signals, Now Alstom), Micro Lock (General Railway Signals, now Ansaldo STS), West Lock and West Trace (Invensys Rail, now Siemens), and Smart Lock (Alstom), MEI 633 (Medha), K5B series (Kyosan) and E132FA (Nippon Signalling).

However, there were many constrains to adopt this system. The first and the most important among those being the fact that these systems were rapidly evolving and thereby needing money and expertise to either upgrade or replace quite soon. For example, Nock in his study remarked that first generation processor-based MAS systems developed with the collaboration of British Railway, GEC-General Signals and Westinghouse Signals in the 1980s under the brand name of Solid-State Interlocking were no longer being manufactured [2]. The second factor was related to the installation and maintenance of the system, which concerns the impossibility of guaranteeing that the same brand, used for initial installation, would be selected, as per the available procurement guidelines, when bids are entertained for replacement or extension of the existing system. Due to the diversity of vender specific programming applications and programming techniques, it is not feasible or sustainable to have systems supplied by different manufactures. Even though both systems were installed by the same company, the latest system was installed using equipment manufactured by a different vendor and not the previous one. The original equipment manufacturers are not willing to provide spare parts or components for new installations due to small market size and differences on procurement guidelines. As a result, Sri Lanka Railway has to depend on middlemen to procure new signalling systems or spare parts for maintaining the signalling systems. Furthermore, due to complex nature of proprietary programming languages, it is difficult to sustain in-house capabilities for programming for future modifications or new installations.

When one considers these two electronic railway-signalling-systems installed in Sri Lanka, it could be clearly seen that the electronic interlocking systems consist of significant number of relays. Both systems depend on interface relays to connect wayside equipment to the interlocking systems. This requirement for interface relays in the electronic interlocking systems clearly indicates continuing demand for railway Signalling relays and their sustainability. Thus, when considering the requirement of interfacing relays in electronic signal interlocking systems for interfacing, it is difficult to see any advantages in implementing electronic interlocking-based railway signalling systems at stations other than at larger ones like Colombo Fort.

Figure 3: VPI interlocking at Gintota, 2002

Figure 4: GE interlocking at Kekanadura, 2018

A good example of the lack of universality is illustrated in the electronic signal systems in the Coastal Line at Gintota (Figure 3) and Kekanadura (Figure 4) of Sri Lanka Railways.

Furthermore, in a tropical country like Sri Lanka where lightning and electrical surges are prevalent in railway environment, maintaining a susceptible electronic system would not be easy; thus, interface relay usage becomes inevitable. In such a situation, saving 50% of relays used in a typical relay-based railway signal interlocking system, by substituting those with a complex manufacturer-specific electronic hardware, does not make sense.

The second option considered was the relay-based MAS systems. Just as much as CBI-based MAS systems, a number of different relay-based MAS systems were found available in the market. According to vendor websites, Siemen's relays, B-style relays used in USA, N. S1 relays based on French standard (SNCF), Arteche auxiliary relays and Q-type relays were a few in the lead. However, the relay-based MAS system (Ericsson) that has been in operation in Sri Lanka Railway since 1960s, is no longer available in the market.

Q-type relays based on BS 930 standard were widely available around the world. This was due to the fact that, BR 930 specifications had a number of variations catering to different applications leading to universality and versatility unlike others which were region specific. Also, the carbon-to-carbon relay contacts in Q-type relays would give lesser probability of contact welding than Ericson relays which used metal-to-metal contacts. This was an improved safety of the system. Furthermore, Q-type relays had a competitive price advantage, possibly due to availability of a large number of manufacturers. According to IRSE, UK had a demand for 50,000 Q-type relays in year 2013. Q-type relays were being produced by multiple manufacturers based in India, Australia, United Kingdom, Netherlands and USA [15].

Following are among the companies which manufacture Q-style/BR930 relays today:

- (i) Mors Smitt Ltd. (UK)
- (ii) Siemens Ltd. (UK)
- (iii) Selectrail Pty. Ltd. (Australia)
- (iv) Crompton Greaves Ltd. (India)
- (v) Arteche Pvt. Ltd. (Spain)
- (vi) M/s Radha Raman Eng. Co. (India)

Due to the generic nature of these products, they are all readily compatible with each other. The universal availability would offer the advantages of a competitive market with product availability for many decades to come.

Reliability and safety of BR930 based Q-type relays (Figure 5) have been proven by 50 years of service. Those relays were well adapted for operation in countries like Sri Lanka. Based on performance, the mean time between failures (MTBF) for BR 930 relays would be around 550 years.

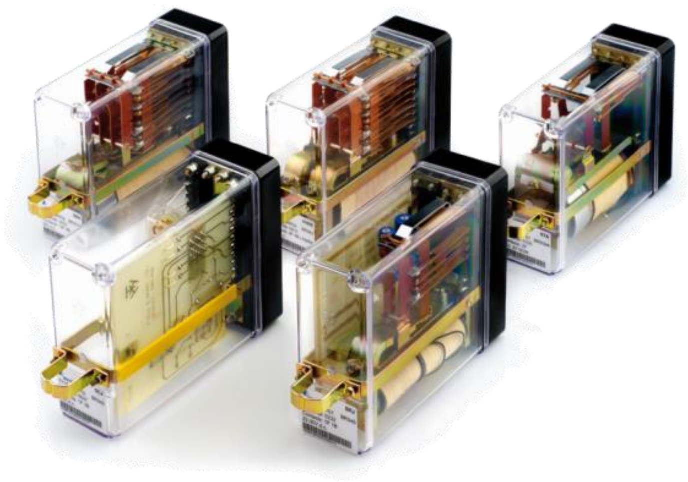

Figure 5: BR930/Q type signalling

In addition, operational safety of the Q-type relays also would meet SIL4 safety requirements by enabling a “Mean Time Between Wrong Side Failure” (MTBWSF)[1] of 6.89 x 10^9 hours [16].

The BS 930 based Q type technology is an evolving technology, coming up with innovations for better performance even today. BS 930 based solid state railway signalling relays are now coming to market to replace electromagnetic ones with longer lifetimes and lower energy consumptions.

Relay-based railway signalling interlocking technology is well established in Sri Lanka, having been used over more than half-a-century. Electronic railway signalling systems are now becoming more popular due to ease of installation and troubleshooting. Even though electronic railway interlocking systems have advantages over relay-based interlocking in power consumption and space saving, they are handicapped by the need for isolation from the hazardous external environment, complex proprietary programming languages and change of hardware versions with changing technologies.

Considering the above, and particularly the universal availability, reliability, economics and sustainability, a relay-based railway signalling systems using locally developed design technologies was decided as better suited for Sri Lanka. Furthermore, it would not be a farfetched idea to start manufacturing Q-type relays in Sri Lanka, possibly with private sector collaboration.

[1] Mean Time Between Wrong Side Failures (MTBWSF) is the measure of the average duration between two occurrences of erroneous signals being issued to trains by a signalling system.

5. THE INNOVATIVE DESIGN

5.1. Data and information gathered

Several factors, pertaining to both the relay type and positioning of signals, were taken into consideration when designing.

Q-type relays are available in both latch and non-latch types. But Q-relay based colour light signalling already introduced to Sri Lanka do not use latch-type relays and as a result of that design technique, power failures can result in memory loss of previous operations. Therefore, this approach requires extensive power arrangements to ensure power availability for safety. In comparison Latch relays retain memory of operations in progress even after power failure and they would give better safety with less demand on power supply. Also, using latch relays allows safety interlocking to be achieved with fewer relays relative to the Indian-Q relay interlocking approach.

Train accidents happen due to trains overshooting beyond a signal at danger if another train happens to be there in front within that range. During recent past, number of train accidents got reported in Sri Lanka railway network under the similar circumstances and therefore addressing this issue was a long-felt need. It has been statically proven that at 100Kmph operational speed, signal passing at danger seldom happen beyond 183m [2]. Therefore, under overlap protection principle, before activating an *Amber* signal to reach *Red* stop signal ahead, 183m section ahead of that Red stop signal also must be clear of trains. Even though overlap protection had been provided at varying degrees at station limits in earlier installations, overlap protection for block signalling was never provided before this.

5.2. Designing the New System

This new signalling system was designed using Q-type latch relays, deviating from the common practice of not using latch relays in Q-type relay-based systems. Under this new design approach, when train movement is allowed by one of the signals, locking relay relevant to that signal would be dropped to prevent any conflicting movements. In addition to locking conditions of relevant signals, track conditions, point conditions, level crossing and other required conditions were added to the relay diagram circuits as per safety requirements.

In addition, a computer based human-machine interface to counteract the difference in functionality between the relay-based systems and CBI was introduced for the first time by Sri Lanka Railways to be used by the Station Master for operational convenience and event logging. Centralised Traffic Control (CTC) allows a single controller to operate multiple stations, which would improve the efficiency of train operations. As an initial step in facilitating CTC, Programmable Logic Controller

(PLC) was incorporated as the interface between relay interlocking and human-machine interphase (HMI). Furthermore, it enabled the introduction of Graphical User Interface for high level process supervisory management (Supervisory Control and Data Acquisition - SCADA) while facilitating data logging for trouble shooting and incident investigations. Computer hardware for the local Control Panel and communications was obtained from compatible sources readily available in the market and software development was undertaken by the technical personnel of the Signalling and Telecommunications Sub-Department of the Sri Lanka Railway. LED bulbs were used for signal aspects, instead of incandescent bulbs to improve visibility and reliability.[2] Even gate signals were provided with five-aspect LED signalling manufactured at Dematagoda Signal Workshop for better visibility and distinction.

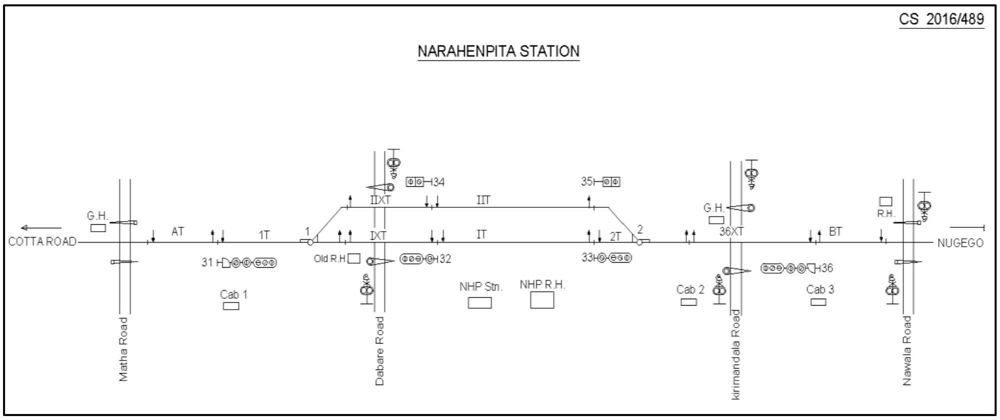

Figure 6: Narahenpita Station Signal Arrangement

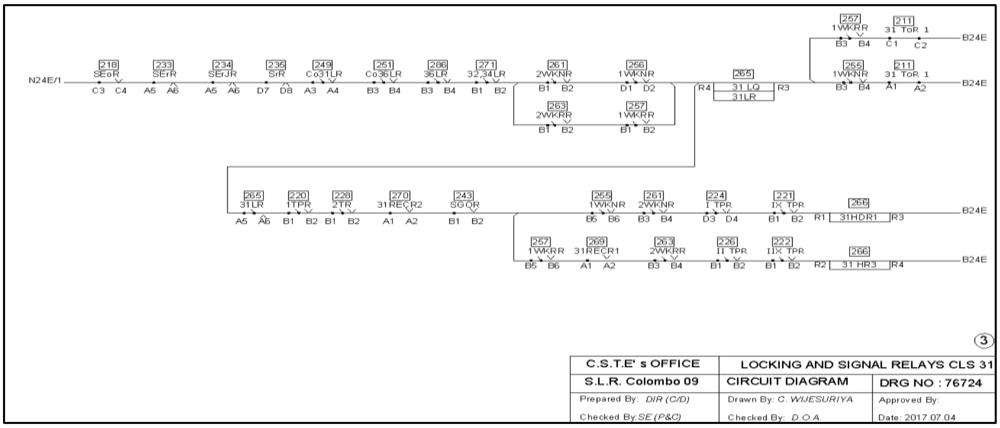

Figure 7: Relay Design Diagram

[2] Sri Lanka Railway has been using incandescent bulbs for signal lighting, except in the Northern part of the network. They frequently fail, and their focus and brightness are inferior to LED bulbs.

5.3. Implementation of the New Innovation

5.3.1. Features and functions

It was decided to implement the designed system at a single loop station as the first step towards standardising the signalling system of the Sri Lanka Railways. Narahenpita Railway Station (geographical location indicated in Figure 1) was thus selected to implement the newly designed signalling system for its close proximity to Colombo, and also for the ease of monitoring and implementation.

The earlier signalling system at Narahenpita consisted of C-type mechanical signalling, where points for track deviations were hand-operated by the station employees and the trains were admitted to the Station by the Station Master. The new system allowed the Station Master to operate points and signals, to admit trains to the station and also to dispatch them using the computer-based local panel, which minimises the manpower needed. Unlike before, the safety of train operation is assured by the new interlocking system.

Figure 8: Relay based system at Narahenpita, 2016

6. RESULTS AND DISCUSSION

6.1. Practical observations

This new system was installed at Narahenpita railway station in the year 2016. A continuous monitoring of its functioning, and entertaining any issues reported was ensured through the project. Several issues that were reported since commissioning, mainly owing to various teething problems, were related to contact defects in Q-type relays used, poor condition of tracks due to creeping of rails, flooding and defects in power supply. System performance improved to the expected level when inverters and relays with contact defects were replaced, and track defects were rectified, and rainwater drainage facilities at the yard was improved.

During the entire period of operation, ever since installation, neither accidents nor any events reflecting violation of the principle of fail-safe operation, were observed.

6.2. Technical evaluation of efficiency

The mechanical yard signalling arrangement that existed at Narahenpita station before installation of the new system only provided entry signals at both ends. Other than preventing both entry signals being issued at the same time, no other safety mechanism had been provided by that system. Diversion between tracks at the station was done by manual operation of diversion points by a Pointsman, who would raise green flag to the train until it passed through the point. Then again, the Pointsman had to go to the other end of the station loop line to do the same. As those manual operations are no longer necessary, the newly implemented system has markedly improved the efficiency of the system; the train operational time of a train at the station has been brought down by around 2 minutes.

Average number of failures of the new interlocking system installed at Narahenpita was less than five failures per year during the past three years; well below the network average failure rate of around eight per year, demonstrating the enhancement of reliability the new system has enabled.

Besides, neither train accidents nor system failure causing erroneous signalling have been reported to date, ever since the commissioning of the new system. This was an expected outcome, as the innovation has provided system-driven safety mechanisms, in contrast to the hitherto prevailed excessive reliance on the Station Master for safety assurance by following railway rules and regulations in manual operation of trains.

6.3. Economic evaluation

Noteworthy benefit of the new system is its capital cost efficacy. Based on the experimental installation at Narahenpita, it could be reasonably estimated that a single line station could be provided with the new signalling system at a cost of only USD 0.1 million. When compared with recent procurements of similar signalling systems for Sri Lanka Railways at costs more than USD 2 million per station, this innovation by the Signalling and Telecommunications Sub-Department would have saved approximately USD 1.9 million per station to the institution and to the national economy.

In the last two decades, very high price variations could be observed between locally designed and installed signalling systems and the signalling systems installed by foreign contractors (Table 3).

Table 3: Comparison between installation cost of local and foreign Relay based interlocking systems and reproducibility - Sri Lanka Railways

No	Project	Configuration	Year	Cost $	By
1	Northern Line	Single line/Single loop	2014	2.0M	Foreign
2	Narahenpita KV	Single line/Single loop	2017	0.1M	SLR
3	Nugegoda	Single line/Single loop	2017	0.1M	SLR
4	Pothuhera	Double line*/Single loop	2019	0.2M*	SLR
5	Maharagama	Single line/Single loop	2020	0.1M	SLR

Note: Geographic locations are indicated in Figure 1.
Source: Author

The replicability of the Narahenpita experiment to other localities could be observed through the information summarised in the Table 3. It is apparent that the designed system would be reproducible with similar costing as illustrated in the cases of recent installations of the new system at Nugegoda and Maharagama. The cost difference at Pothuhera was due to the different configuration of the track layout necessitating higher number of components to cater to the double line

It must be emphasised that this economic advantage is not limited to capital costs of installation, but also extends to favourable effects on national value addition and Balance of Payments. The new innovation reduces foreign inputs, and thus creates demand for local industries[3], stimulating a demand-pull effect on the domestic value added, as advocated by John Maynard Keynes [17]. Besides, only less than 20% share of the total costs involved in the locally designed system was purchased through foreign currency. This generates a positive impact on the country’s Balance of Payments, compared to the imported systems where almost the entirety of capital expenditure (excepting for those spent on a few local inputs) drained out of the national economy.

The locally designed system has the added advantage of being more efficient in terms of operating costs as well. It gives rise to lower power consumption, in comparison

[3] In the new system installed at Narahenpita and other locations, the supply of copper cables, metal cabinets, power equipment and other items were sourced largely from local small and medium sized manufacturers, thereby supporting local industries.

to the foreign system. The average power consumption as mirrored through the payment requests on monthly electricity bills was only USD 150 at Narahenpita, when comparable stations in the Northern Line, signalled by a foreign company, have been receiving an average monthly electricity bill per station of around USD 250. The labour cost savings associated with the new system would not be negligible either, because, the station cadre could be reduced owing to automation of the point operation, who could be deployed elsewhere in more productive work.

It is in this context that Cumaratunga Munidasa's vision becomes relevant and important; according to which, "*Patriotic consumers would prefer local products. By this local product preference, local manufacturers would get motivated to invest more to increase production*" [18]. When foreign contractors undertake infrastructure development projects in a country, innovations, manufacturing capacity expansion and increase in productivity take place in the countries of the contractors, and not in the country receiving supplies. Therefore, such situations are nothing but lost opportunities for developing countries like Sri Lanka. Unfortunately, Sri Lanka appears to have failed to be guided by this wisdom of Cumaratunga Munidasa expressed many decades back; the financial difficulties the country is facing today could be, at least partly, a result of this failure.

6.4. Potential of Expansion of the Coverage and Associated Benefits

It is apparent that the relay based signalling system is a safe and reliable system that could easily be installed with the prevailing knowledge and could be maintained or upgraded according to the needs of the Sri Lanka's railway system. Therefore, the new system could be used to replace the old mechanical signalling system, which is still predominant in the railway network of Sri Lanka.

The fact that the implementation of this innovative design at one station alone has resulted in savings up to USD 1.9 million to the Sri Lanka Railway indicates the possibility of securing substantial cost savings, particularly in foreign exchange, when this new system replaces the mechanical Semaphore signalling at other stations in the network (Figure 1). The railway stations up to Maharagama have already been converted to colour-lights with this innovative approach, and currently the conversion of the signalling system in the remaining sections of the Kelani Valley line up to Avissawella is in progress. The total estimated cost for the project to be implemented using this innovative design is USD 2.5 million, reflecting a cost saving of USD 75.5 million on the Kelani Valley corridor alone, as the earlier estimate for the same to be constructed through a foreign contractor was USD 78 million [10]. Similarly, the railway section between Kandy and Wadduwa through Colombo Fort (150 km with 110 km double tracks, 27 crossing stations including major interchanges like

Colombo Fort, Maradana and Loco Junction, Polgahawela, Ragama, and Kandy), which carries more than 80% of the passenger traffic, is being considered for renovation (Wadduwa-Mirigama portion, consisting of Ericsson relay system which is more than 60 years old) or conversion to colour light signalling (Mirigama-Kandy portion presently having mechanical Semaphore signalling at 11 stations). Signalling this entire section with the locally innovated system would cost approximately USD 20 million, while it would cost over USD 200 million (ten times) to the economy if the same is to be realised through a foreign contract.

6.5. Shortcomings and Lessons for Further Improvement

The post-evaluation exercise revealed several shortcomings and possible avenues for further improvement. One such concern is the possible dysfunction of signalling owing to failures in Carbon-to-Carbon contacts used in Q-type signalling deployed in the new system at Narahenpita compared to that in the Ericson system which used relays having metal-to-metal contact yielding better communication. Obtaining relays from manufacturers with higher quality assurance would be instrumental in reducing, to the bare minimum, the probability of such contact failure. Also, poor track conditions at station yards were found creating problems due to track circuit defects. Railway tracks need to be renewed in every 50 years and thereafter can be maintained efficiently through mechanisation and less manual labour. Railway track technology is almost 150 years old, and therefore, local construction companies now excelling in highway constructions could be enticed to enter into railway track construction, if the in-house capacity of the Railway Department is found insufficient. A track renewal plan to bring railway tracks back to standard is a pre-requisite for this purpose.

Even though Narahenpita station area signalling system was converted to colour light signalling, train operation between nearby stations is still done using Tyler Tablet instruments. This necessitates handing over of a metal disc or tablet to the train driver to proceed to the next station, interrupting the continuity of the signalling system. Continuous upgrading, while introducing automatic block signalling between stations and providing local control panels (as the first step) to stations, would be the solution for this problem. Unlike with the tablet in an absolute block operation between two stations, automatic block signalling will enable more than one train entering a section between two stations one after the other, thereby increasing line capacity. In addition, by connecting station operations to central control, train operations can be streamlined and made more efficient. With the inclusion of PLC in the local panel operations and with laying fibre-optic cables along the tracks, train controlling in all these newly colour-lighted sections also could be managed by a Central Traffic Control facility at Maradana, thus, enhancing operating efficacy and reducing train delays.

7. CONCLUSIONS AND RECOMMENDATIONS

The research and development into innovating an appropriate, manageable, self-reliant and cost-effective signalling system for Sri Lanka Railway yielded positive results with a new home-grown design of Q-type relay-based colour-light signalling system. Experience gained through implementation of the new system, and operating it for nearly four years, enabled concluding that the locally made relay signalling system is robust, durable and could be operated on par with computer based signalling systems.

This new signalling innovation has the potential of generating substantial cost savings for Sri Lanka Railways and the national economy. For instance, there are several signalling systems that need to be upgraded urgently in urban and suburban areas as a part of reducing delays, and the innovated system could save substantial amounts of financial resources, both to the Sri Lanka Railway and to the national economy. For instance, the potential cost savings in converting and upgrading the existing signalling systems in the KV line and Kandy-Wadduwa section alone using this local innovation would amount to approximately USD 260 million (Rs.52 billion), which is over 7% of the capital budget of the Government of Sri Lanka in 2020, and around thrice the capital expenditure voted in 2020 for Sri Lanka Railways. With the availability of skilled and experienced project construction group in-house, Sri Lanka Railway is well positioned to realise these cost economics successfully.

In addition, the outcome of this applied research stands as a good example to showcase the effect of innovation in the field of railway signalling and contribution it could make towards development. The advancement made possible through the initiative is significant, in terms of gaining cost advantages, developing innovative culture, enhancing the system’s technological self-reliance, developing economic linkages and stimulating multiplier effect, and also creating wealth for the nation.

The research also found solutions to the few teething problems diagnosed of this system, whereby it is recommended that the best quality Q type relays be used to minimise failures as the system totally depends on the functioning of relays. It is also recommended that the train yards and the tracks be first assessed and upgraded to support the functioning of a reliable system rather than just upgrading the signal system. Finally, this system is recommended for signalling as a pilot study when Centralised Train Control (CTC) system from Maradana is introduced to the entire Kelany Valley line.

Further studies are recommended to calculate the lifetime cost of the system implemented and to compare the functionality and capacity among the currently implemented systems in Sri Lanka.

Finally, the knowledge and skills gained through this hands-on experiment, together with the motivation and dedication of inventors and innovators, Sri Lanka Railways could confidently look forward to further expansions into railway signalling solutions and to upgrade its signal system in an economical and sustainable manner.

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