Safety Certification for Rapid Transit Systems in Singapore

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(Received from the Guest Editor on July 31, 2006)

Abstract: Project Safety Review (PSR) is a safety certification process launched by the Land Transport Authority (LTA) of Singapore in year 2000. Its objective is to provide a staged and robust check-and-balance process on safety assurance of new rapid transit system (RTS) projects. The PSR process also facilitates the certification of the overall system for a RTS project before the system is permitted to commence passenger service. Under the PSR process, a project is divided into stages, namely concept, design, handover and operation. At each stage, a safety submission is required to be prepared and subject to an independent audit. When all the safety submissions are found to be satisfactory and together with the operator’s declaration of its readiness to operate the system, the Chief Executive of LTA will give his consent to the operator to commence revenue service. This paper will give an overview of the PSR, its requirements, together with the challenges and lessons learned from its implementation.

Key Words: Project Safety Review (PSR), check-and-balance process, safety certification, independent audit

1. Introduction

Singapore has a good reputation for its RTS safety records. Such records are by no means easy achievements. The success hinges on LTA’s commitment to give top priority to the safety of all users of the RTS in the development of new systems. The strategies for realising this commitment include the implementation of rigorous processes in managing safety at system development stage, the adoption of state-of-the-art technology, and the selection and appointment of competent RTS operators.

LTA, acting as an agent for Ministry of Transport, is responsible for developing and regulating RTS in Singapore. As the RTS touches many lives in Singapore everyday, LTA is very conscious that a safe journey is a fundamental requirement for the users. Hence, it has always been in LTA’s priority to regard safety as an integral part in any new RTS development. Safety has always been incorporated into the systems as early as possible.

LTA is a unique organisation in that it acts as Singapore’s RTS developer as well as the regulatory authority of the system operators. As a developer, LTA needs to certify the overall fitness for use for a new RTS. On the other hand, as a regulatory authority, it

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gives consent to the appointed operators to commence passenger service for the systems and regulate the service performance including safety during the operation of the systems.

During the system development stage, LTA engages consultants and contractors to design and build the systems. Once the systems are tested and commissioned satisfactorily, they are handed over to the appointed operators for them to operate and maintain the RTS services. From then onwards, LTA regulates the service performance. From the safety aspect, LTA places a great emphasis in ensuring the delivery of a safe RTS where layers of safety reviews and audits are carried out. Fig. 1 shows the inter-relationship between LTA and the consultants/contractors, and the RTS operators. LTA has to be convinced and satisfied by the demonstration of safety by both the consultants/contractors and the RTS operator before the overall safety certification for a new RTS project is completed.

An initiative taken by LTA to strengthen its safety assurance framework was to develop a process called “Project Safety Review (PSR)”. The PSR imposes a staged and robust check-and-balance process on safety assurance of new RTS projects including projects that comprise major modifications to the existing RTS. The implementation of PSR process is currently a contractual requirement for any development and operation of a new RTS whereby the understanding and fulfilment of this requirement by the consultants/contractors and the RTS operators is essential.

2. Background

During the development of RTS in Singapore in the 1980s, also known as Phase I and Phase II, comprehensive safety assurance activities had been implemented. However, safety audits were not required to be carried out so systematically at each stage of a project as required by PSR. As was practised at that time, LTA invited Her Majesty of Railway Inspectorate (HMRI) of UK to carry out final audits on the systems before the appointed operator was permitted to commence passenger service. The audits were aimed at providing additional confidence to the management that the systems were fit and ready for passenger service. The audits were carried out based on the guidelines outlined in the “Railway Safety Principles and Guidance” [1] published by Health & Safety Executive.
(HSE) of UK. For the subsequent Woodlands Line that opened in 1996, an external safety consultant was engaged in addition to the service provided by UK railway inspectors to conduct the final audits. While LTA has benefited from their findings, some recommendations could have been incorporated earlier and more effectively during the design stage.

Following the commissioning of Woodlands Line, LTA decided to develop a more structured safety certification process for all rapid transit projects. An external safety consultant was engaged for the development of such a process. The best international practices in rail safety management such as the safety case [2] approach adopted in UK railway industry were adopted and adapted to suit LTA’s requirements and expectations. Eventually, a formal structured process entitled “PSR” was developed and integrated into the LTA’s existing engineering and management processes.

3. **PSR Strategy**

As mentioned earlier, LTA is a unique organisation in that it acts as Singapore’s RTS developer as well as the regulatory authority of the system operators. As a result, any certifications done by LTA for the overall system of a RTS project including safety certification under the PSR process is considered self-certification. The PSR process provides safety certification only for an overall integrated system of a RTS project. The responsibilities of safety certification for the individual system within the integrated system such as signalling and rolling stock systems, etc lie with contractors and suppliers/manufacturers.

The PSR process requires implementing a 4-stage safety certification process. A project is divided into 4 stages, namely concept, design, handover and operation. At the conclusion of each stage, a safety submission is required to be prepared and subject to an audit. Fig. 2 shows the overview of the PSR process.

![Fig. 2: Overview of PSR Process](image-url)

For the safety submissions at the concept, design and handover stages, the project team is required to demonstrate that it has adequate commitments and resources to manage safety effectively and that the project is designed, installed, tested and commissioned to achieve a high level of safety. Correspondingly, the appointed operator has to demonstrate in the
safety submission at the last project stage that all the necessary organisational structure and processes are in place to operate and maintain the system to an acceptable level of safety.

3.1 PSR Process

The PSR process starts with the establishment of a committee called Project Safety Assurance Committee which is chaired by the project director/project leader. The objective of the Committee is to oversee all safety assurance activities. These activities include discharging safety responsibilities and overseeing the progress of safety submissions. Fig. 3 shows the organisation of a Project Safety Assurance Committee.

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**Fig. 3: Project Safety Assurance Committee**

The PSR process involves four main roles, namely reviewer, submitter, auditor and endorser or arbitrator.

LTA’s System Assurance & Integration Division, acting as an internal consultant to the project director/project leader, is responsible for producing the safety submissions on behalf of the project team. It plays the dual roles of reviewer and submitter. It reviews the contractors’ system assurance submissions, integrates them and makes its own safety assertions on the overall level of system safety in the safety submissions before forwarding the submissions to LTA’s Safety Division for audits. The System Assurance & Integration Division is also responsible for establishing and continually updating the hazard log of a RTS project, ensuring all hazards managed by the contractors are credible and their mitigation measures are effective.

The PSR process is eclectic. While LTA can engage safety consultants to carry out safety reviews and audits at the various project stages, they are unlikely to be able to meet LTA’s expectations unless they are in full-time involvement. This is also deemed to be impracticable in view of the cost incurred. On the other hand, it is impossible to have a totally independent party within the LTA to carry out such reviews and audits. The final decision was to integrate and adopt the best practices of the two options above into the PSR process. The PSR process strengthens the level of checks while maintaining a certain level of independence. The System Assurance & Integration Division would maintain a level of independence from the developer’s designs by refraining from decisions that could directly alter those designs in a specific manner. This would give a greater degree of confidence in the credibility of the safety submissions prepared by them. Safety
Division, being a division within a group that is independent of other divisions involved in the project, would also be deemed to be appropriate and impartial to carry out the audits.

Being an auditor, Safety Division has the duty to express an opinion on the assertions made in the submission based on the audit findings while the material facts in the submission is the responsibility of the submitter. Through the audits, Safety Division is to obtain reasonable assurance that the assertions are free of material misstatement and can be substantiated by the various documents and analyses.

Upon the completion of audit, Safety Division will recommend to a committee called the PSR Committee (RTS) for the endorsement/acceptance of the safety submission or otherwise. If necessary, the Committee can appoint a technical working group that is independent of the project under deliberation to assist in investigating into specific safety-related matter. If the Committee rejects the submission and the submitter does not accept the decision made by the Committee, then a higher committee called the Corporate Safety Committee will be required to arbitrate. Fig. 4 shows the endorsement/acceptance process for safety submissions.

![Flowchart](image)

**Fig. 4: Endorsement/Acceptance Process for Safety Submission**

### 3.2 Types of Safety Submission
The fundamental element of PSR is the safety submission through which safety at each stage of the project is demonstrated. There are four types of safety submissions. They are as follows:

(a) Concept safety submission;
(b) Design safety submission;
(c) Handover safety submission; and
(d) Operation safety submission.

LTA’s System Assurance & Integration Division is to prepare the concept, design and handover safety submissions whereas the appointed RTS operator shall make the operation safety submission.

3.2.1 Concept Safety Submission

The concept safety submission is required at the end of the concept definition phase which starts from project initiation to the award of system contracts. The aim of the submission is to demonstrate that major risks along the alignment of the new RTS project have been identified and assessed, and major safety features and design criteria have been defined for each system.

At this concept definition phase, initial hazard identification is carried out through preliminary hazard analysis. From the hazard analysis, major safety issues are evaluated and the resultant safety requirements are translated into design requirements. Other sources for safety requirements include the relevant design criteria and performance specifications from the similar projects, design safety principles, design safety standards, Code of Practice, as well as experience and lessons learned from past projects.

One of the key tasks in preparing the concept safety submission is to compile a table of design safety principles adopted by the project. Comparisons are made on the safety principles adopted by LTA for the past projects, local design standards and Code of Practice, with the operating philosophy, strategy and requirements from the “Railway Safety Principles and Guidance” [1] of UK. When there are departures of LTA’s design safety principles/local design standards and Code of Practice from the UK’s railway safety principles, the former will normally take the precedence as they have been customized to suit to the local applications.

Like any other projects, the concept safety submission requires a well-defined project safety assurance plan to be produced and approved from the beginning of a project to lay down the safety management framework and processes for strict adherence in the execution of follow up works. The plan defines the management and technical tasks of a project, and organisational structure required to manage safety.

3.2.2 Design Safety Submission

The design safety submission is required at the end of the final system design stage. The aim is to verify that the design has achieved all its safety objectives and requirements. Evidence is collated to demonstrate that safety was considered and incorporated into the design and all design-related safety issues have been addressed to a level of acceptability.

At this stage, a listing of hazards is derived from the various analyses across the different disciplines of a RTS. Comprehensive safety analyses/methodologies are necessary to provide an effective and thorough mechanism to achieve the highest level of safety. Top-down approach such as fault tree analysis (FTA) should be used to show the
convergence of risks by identifying the combinations of contributors that can lead to major incidents such as train collision, derailment, etc. To complement the top-down approach, bottom-up approach such as failure modes and effects analysis (FMEA) should also be carried out to analyse the effects of failures of components on the system.

Another methodology namely hazard and operability (HAZOP) study is also recommended. A HAZOP study considers not only design issues across the various systems but also operational interface issues. It provides a systematic way to study potential hazards associated with human interactions with complex systems such as the systems in the railways. It is also useful in identifying hazards that arise due to deviations in the system performance and the operating parameters.

Another focus in the design safety submission is on the mitigation measures for major safety-related design issues. Assertions are to be made on their residual risks. Demonstration is required to show that hazards that can be addressed by design have been mitigated as far as reasonably practicable. Also, the respective reviewer of the hazards is required to verify the effectiveness of the mitigation measures based on the documentation as well as the implementation on the ground. Evidence is also required to show that regular system safety audits have been carried out on the contractors to ensure that the agreed programmes in the contractors’ safety assurance plans are being followed and implemented.

It is also necessary to demonstrate that the design of the systems is in compliance with the adopted safety principles and requirements and that the systems are able to achieve the safety targets stipulated at the concept stage.

3.2.3 Handover Safety Submission

This is the final stage of submission by the project team and is made for audit prior to the handover of the system to the operator. The submission aims to demonstrate that the integrated system has been installed in accordance with good quality control standards and successfully tested and commissioned to achieve the level of safety specified at the concept and design stages. The system is, therefore, considered to be adequately safe for handing over to the operator for them to start trial running.

The submitter has to demonstrate that functional as well as performance safety testing regimes identified and proposed by the designers have been rigorously implemented. Focus is on the performance of safety-related systems in carrying out the safety functions. Hazards that require closures by testing and commissioning should have been validated and those that require operational and maintenance procedural control should have been explicitly transferred and accepted by the operator.

One of the key sections of the handover safety submission is on the operational and maintenance restrictions and constraints. This is an important section to inform the operator about the restricted activities and the degraded operating situations that require procedural controls.

3.2.4 Operation Safety Submission

The operation safety submission is made in three stages, namely preliminary, pre-final and final stages. The preliminary submission is prepared when the operator has established its safety management system. The pre-final submission is to be made before the trial running (after handover and before commencement of passenger service) starts while the final submission is required just before the commencement of passenger service.
In the operation safety submission, it is most important for the operator to demonstrate that it has necessary organisational structure and effective processes in place to operate and maintain the system to an acceptable level of safety. The operator must demonstrate that they have developed their operational and maintenance procedures with consideration of the system constraints and restrictions defined by the project team in the handover safety submission. They must also be able to demonstrate that they have understood the implications of those hazards transferred to them and addressed the hazards through effective procedural controls.

One of the important elements in the operation safety submission is staff competency. The operator must demonstrate that the training scheme has been developed based on a structured training need identification process. The training materials must be reviewed and prepared professionally and the training methodologies are in line with the international best practices.

The operator is also required to demonstrate that they have validated the effectiveness of critical procedures by executing them under simulated scenarios. Emergency exercises with the participation of the civil defence force and the police force are also required to familiarise the personnel in fire fighting and rescue work and to test the emergency preparedness of the operator’s staff.

3.3 Handshaking Process

To obtain a final consent from LTA for the commencement of passenger service, it is necessary that all the safety submissions at the various stages have been audited and endorsed/accepted. In addition, the project team is required to make a declaration that the system is fit for use and the operator to declare their operation readiness before the Chief Executive of LTA gives his consent. The handshaking process of the PSR involving the project team and the operator towards the final opening of the system is illustrated in Fig. 5.

Fig. 5: Handshaking Process for Commencement of Passenger Service
4. Challenges and Lessons Learned

This section is to share the LTA’s experiences on some of the problems, challenges and lessons learned in implementing the PSR process. The cases quoted here are not intended to be exhaustive and are used for illustration purposes.

A number of challenges were encountered during the initial implementation of the PSR process. Prior to the establishment of the PSR process, safety reviews and acceptance of the contractors’ design and system assurance submissions were carried out by the individual responsible divisions in LTA and the safety audits were conducted by the external parties. The PSR process imposed a challenge as it was the first time a team effort was required to produce a consolidated safety case titled “safety submission” and a specific division in LTA was assigned to integrate the findings from all different sources and come out with its own assertions on safety. Also, it was the first time an in-house division was appointed to conduct safety audits and the certification was carried out at each project stage.

As there was a learning curve to be overcome, a partial PSR process was initially implemented in Changi Airport Line which was a line extension project to the existing East West Line. Unlike a totally new rapid transit line, the design of the core systems for Changi Airport Line was largely similar to its predecessor, i.e. East West Line. The PSR process for Changi Airport Line started from design safety submission rather than concept safety submission as would have been the case for a totally new rapid transit line. The contents of the design safety submission also differed from those under the full PSR application where their scope was narrowed by focusing on any design deviations from the East West Line. As all the systems designed for Changi Airport Line were considered as “legacy systems” [3], many PSR requirements for safety analyses were exempted or fulfilled in a simplified but focused manner. The submission focused on the suitability of the design in respect with its local applications.

When the Circle Line (CCL) Project was started in year 2000, it was the first project to be subjected to full PSR process application. One of the key challenges was to definite safety targets quantitatively for the project. The development of safety targets is usually based on benchmarking international best practice and/or statistics related to operations of existing systems. As CCL Project is one of the pioneers in the world in the development of heavy steel wheel to steel rail driverless system, there were limited comparable systems that could be referred in setting the safety targets. A benchmarking exercise was performed by the project team to ensure that the CCL’s safety targets were comparable or even more stringent than other modern RTS. The exercise involved a study on top-level safety targets adopted in a number of RTS in Asia and Europe. The study, however, produced a wide range of figures with no clear risk allocation patterns. A safety consultant was engaged at the later stage to assist in the study. It was finally concluded that a set of targets comparable to UK Jubilee Line Extension would be used in CCL Project.

Following the benchmarking exercise, the next challenge was on the apportionment of targets to each system. It required certain levels of operational experience and sufficient real incident data. The challenge was eventually overcome by taking into account the engineering judgement as well as the current worldwide practice of apportioning most of the risks to active systems such as signalling and rolling stock systems.

The PSR process requires demonstration of robust hazard management system. During the management of hazards, it was noticed that different contractors for the
building services identified quite a number of similar hazards. This was made worse due to the fact that CCL Project would be built in 5 different sections and similar hazards would be repeated across all sections. To manage this situation, a common hazard analysis integration review (CHAIR) process was developed by LTA to review hazards and merge them if they were found to be similar. This process reduced the number of hazards being managed and ensured consistent approaches were applied to the closures of similar hazards across all CCL sections.

The operation safety submission calls for demonstration by the operator in the areas of adequate resources, robust operating and maintenance processes, and competent staff. Various safety assessments such as operating and support hazard analysis (OSHA) were required by the PSR. The operator had to demonstrate that effective mechanism and procedures were established to defend against sources of error being introduced during the operation and maintenance. Focus of the safety audit was placed on the safety-critical work such as maintenance of signalling system. One of the merits found from the audit was that critical check points were highlighted in the operation and maintenance manuals where a second-party check system by a supervisor was adopted to verify the correctness of the work before further work can proceed.

The next challenge was to complete the trial running activities within a tight timeframe and yet without compromising the comprehensiveness of the trial running. The operator had to determine those important procedures to be subject to verification and validation. Certain operating procedures were verified using the tabletop exercises while some were validated through the physical scenario-based exercises. In addition, overseas RTS operator and railway consultants were engaged to carry out peer reviews and assessments to further enhance the operator’s confidence on the integrity of the procedures. A railway operating company which has the experience in operating and maintaining driverless metro systems was also engaged by LTA to assist in the operation safety submission audit.

Some other lessons learned during the OSS audit included the need to define minimum operating requirements. These were important criteria that determined the conditions under which the train service shall be terminated or the incident train shall be withdrawn from service. Understanding on such requirements was vital for safe operation of train services. Consolidation of those requirements into a reference listing was useful for fast decision making during emergencies.

5. Critical Factors of Success of PSR Process

The successful implementation of the PSR process hinges on the commitment and support from the management, and well defined processes.

Like all other new processes, the management needs to lead the implementation, evaluate the progress regularly and take corrective actions for any departures from the process. Cooperation from all the relevant parties is also essential in ensuring the continued success of the process.

Another crucial factor of success is clear definitions of roles and responsibilities and processes. All personnel involved in the process must be sure of the roles they are playing and ways to contribute to the overall success. The PSR process has been well defined in a manual entitled “Project Safety Review for Rapid Transit Projects”. However, the Manual may appear to be too specific to the roles and responsibilities of the
individuals. In order for all the parties involved in PSR to have a holistic appreciation on the process, PSR awareness courses have been organized every quarterly. These courses only not encompass the scope of work of the individuals but also highlight the importance of cooperation among all the relevant parties for delivering quality safety submissions. The participants have responded positively to the courses. To date, they are getting well into the implementation of the PSR process.

6. Conclusion

The PSR process is a self-certification process customised for Singapore’s railway environment. It is a check-and-balance process to ensure that a new RTS is planned, designed, commissioned, operated and maintained safely. It imposes a systematic safety certification through a 4-stage safety reviews and audits throughout the project lifecycle.

The benefits of the PSR process are very visible. It renders additional confidence to the management that the project is progressing well in achieving a high level of safety. The staged audits are more structured than a final check and provide opportunities to avoid costly late-stage design changes. The PSR process also enhances the visibility and transparency of safety management. Commitments and outstanding safety-related issues are to be reported by the submitters and monitored by PSR Committee (RTS) till their closures.

In a broader sense, the implementation of the PSR process has reinforced safety culture in LTA as well as external organisations, i.e. operators and contractors. It makes everyone involved in the process to be more aware of his/her roles and responsibilities in delivering and operating a safe RTS. To date, the PSR process has been successfully applied to a number of RTS projects. These projects include Changi Airport Line, North East Line, Sengkang & Punggol LRT, etc, and Circle Line currently under construction. The debut of the PSR process has inked a new chapter in the Singapore’s RTS safety certification history. The process works well so far. The challenge ahead is to further enhance the process to strive for excellence in ensuring railway safety.

References

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