INDEPENDENT TRANSPORT SAFETY REGULATOR

Report on the Worksite Protection Systems Analysis Toolkit

ITSR

Safe transport for NSW

Foreword

The Worksite Protection Systems Analysis Toolkit supports the investigation of worksite protection occurrences. It facilitates the identification of factors contributing to human failure in worksite protection incidents when using the five forms of protection specified by rules in NSW. The creation of the toolkit required a formal analysis of the systems of worksite protection and as such has identified areas where the safeworking systems are vulnerable to failure.

Worksite protection in NSW and nationally relies heavily on administrative risk controls. That is, rules and procedures with little use of engineered systems for risk control. Thus, worksite protection is extremely vulnerable to human error and consequently to any factors that impact negatively on human performance.

However, when it comes to investigations of worksite protection incidents, in many cases the reports only go so far to establish that a person did not comply with a rule or procedure. In order to put effective mitigation strategies in place, it is crucial to identify and understand any conditions or factors that are likely to affect human performance and often represent the root cause of someone deviating from procedures.

The toolkit provides rail transport operators with a structured process for investigating track work incidents, following a root cause analysis approach. As a first step, it provides investigators with a fault tree which represents the various mechanisms that can lead to workers and track vehicles being unexpectedly exposed to rail traffic. Once the investigator has reached the endpoint in the incident pathway, a more specific question set is presented that helps identify ‘performance shaping factors’ and root causes.

Rather than imposing a specific method onto operators, this toolkit is intended to assist investigators in thinking more broadly and providing them with some information about how to look beyond human failure and attempt to improve the overall safeworking systems for track work protection. It is also important to note, that while the tool has been validated with NSW accredited operators, it has not been validated through comprehensive scientific research. The toolkit is intended as a starting point for taking a fresh look at worksite protection issues and to initiate further activity in human factors management, especially in respect to rules and procedures development.

While the initial concept of the toolkit was to focus on understanding factors that lead to rules and procedures not being followed, the formal analysis undertaken during the development process uncovered a number of weaknesses or ‘vulnerabilities’ in the systems of track worker protection being used. System modification and development to remove the vulnerabilities will take significant effort and time. In the meantime, the application of this toolkit will assist rail transport operators to better understand the contributing factors that lead to worksite protection failures and help with devising suitable mitigations until such time as the systems can be modified or changed.

It is important that railway infrastructure managers better understand and manage the human factors issues associated with their current rules and procedures. Application of toolkits such as this collection will assist when used as part of the formal processes to address the systemic weaknesses or vulnerabilities of safeworking methods for track work protection.

Acronyms

Acronym	Definition
CSB	Controlled signal blocking
LPA	Local possession authority
NAR	No authority required (now lookout working)
NCO	Network control officer
PICOP	Person in charge of possession
PO	Protection officer
PPO	Possession protection officer
PSF	Performance shaping factor
RTO	Rail transport operator
SFAIRP	So far as is reasonably practicable
SME	Subject matter expert
SPAD	Signal passed at danger
STN	Special train notice
TA	Task analysis
TC	Train controller
TOA	Track occupancy authority
TWA	Track work authority
WSP	Worksite protection

Executive summary

ITSR has a role to promote and influence improvement in transport safety risk management. As part of a strategy to influence improvements in track worker safety, ITSR has developed a toolkit to assist investigators in identifying factors that affect human performance or human judgement that result in worksite protection incidents. In developing the toolkit ITSR, with the help of the rail industry, also identified vulnerabilities with the current systems of track work protection.

It is a common observation that many investigation reports fail to identify the systemic factors that contribute to rail transport operators 'deviating from procedures'. Accordingly, recommendations to improve the systems may be ineffective since they have not identified or addressed some of the principal root causes. This is borne out in the fact that there has not been a decrease in worksite protection incidents over time.[1]

ITSR engaged Lloyd's Register Rail Ltd to develop the first part of the toolkit, focused on track work authority (TWA) and track occupancy authority (TOA) safeworking rules.

A systematic approach was adopted to ensure identification of potential human factors issues at worksites. The first stage of the process was to conduct a detailed task analysis of TWA and TOA methods of providing for worksite protection to capture all of the tasks and roles associated with the setup, maintenance and then fulfilment of worksite protection.

For each task identified, potential human failures (errors and violations) were assessed, including the likely performance shaping factors (factors that were influential in workers making errors or not following rules and procedures) behind these failures. The failures used in this analysis were identified based on:

- review of the literature relevant to human factors issues in worksite protection
- site visits to observe and interview operators at worksites, signal boxes and a train control centre
- discussions/workshops with subject matter experts (SME) and ITSR personnel.

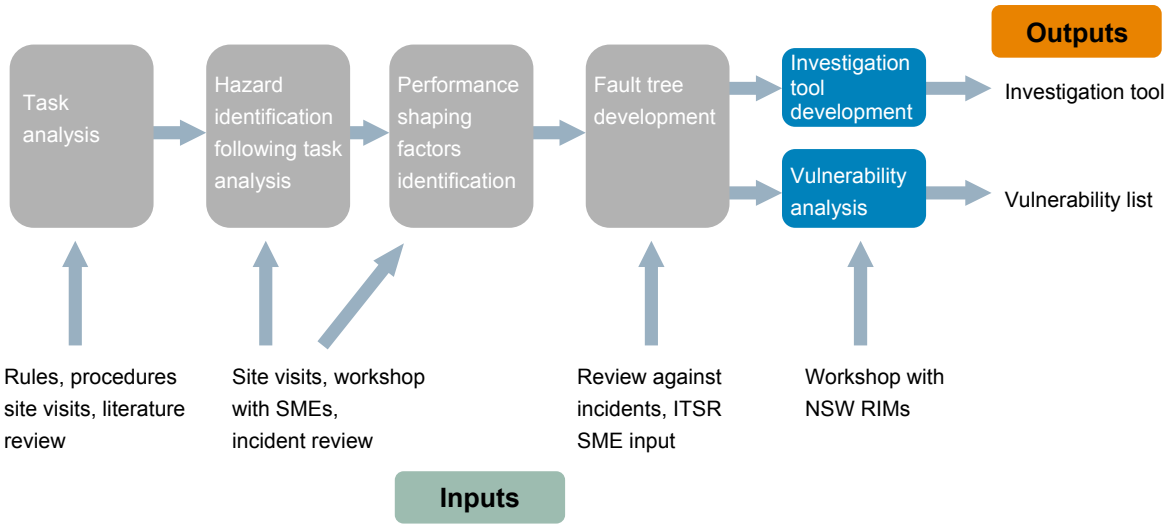
Subsequently, fault trees were developed to illustrate and understand the mechanisms involved when performance shaping factors lead to an accident or near miss. Detailed question sets were also developed to guide investigators in identifying the performance shaping factors that contributed to the incident.

ITSR specialists and investigators then subjected the final fault trees and associated performance shaping factors delivered by Lloyd's Register to further detailed review and subsequent modification. In addition, fault trees for controlled signal blocking, local possession authority and lookout working were then developed by ITSR and a variety of performance shaping factors categorised into a comprehensive set of performance shaping factors that accompanies each fault tree.

ITSR also undertook a vulnerability analysis for each form of worksite protection, identifying areas in the fault trees where errors and violations could lead to hazardous situations without multiple failures required. The fault trees and identified vulnerabilities were workshopped with the key rail infrastructure managers accredited in NSW.

[1] Based on data available up to June 2011

The overall analysis and tool development process is illustrated below.



By addressing the identified vulnerabilities, the overall systems for worksite protection should become more robust. This, however, will take some time to implement. While this is happening, effective investigation into the performance shaping factors influencing worksite protection incidents and accidents will provide valuable input into the management of safety risk for effective worksite protection.

Recommended next steps are as follows:

1 Rail infrastructure managers who maintain systems of rules and procedures for track work safety need to consider the identified vulnerabilities in the safeworking rules. They need to determine how each vulnerability is to be treated in light of the need to reduce risks so far as is reasonably practicable.

2 Rail transport operators should be encouraged to start using the toolkit and to incorporate it into their safety management systems for use in investigation/risk management/HF processes. The usability of the toolkit should be evaluated and the structures of the fault trees refined (as needed in context) to ensure the toolkit effectively identifies the performance shaping factors that contribute to incidents.

3 Rail transport operators that perform or permit track work should use the toolkit, or its derivatives, to collect more detailed data for track work incidents and accidents. Data collected from using the toolkit can be used to improve the data and understanding on human factors issues leading to worksite protection incidents. An improved dataset allows the prioritisation and refinement of mitigation strategies to better control the performance shaping factors. This process will also provide information on the effectiveness of various controls.

Contents

1 Introduction

1.1 Background

There are five forms of worksite protection under the New South Wales Network Rules. Ranked from the lowest to the highest form of protection, they are:

- lookout working, which has replaced no authority required (NAR)[2]
- controlled signal blocking (CSB)[3]
- track work authority (TWA)
- track occupancy authority (TOA)
- local possession authority (LPA).

The Worksite Protection Systems Analysis Toolkit is intended to be an investigation tool for track work incidents and accidents. However it can also support other activities related to worksite protection such as audits or system risk assessments. This provides a systematic approach to the identification of any factors[4] that influence human performance and behaviour contributing to track work incidents and accidents.

1.2 Project aim

The initial aim of this project was to identify the performance shaping factors (PSFs) that influence human errors and violations associated with worksite protection incidents. Such insights into why errors and violations occur in following rules and procedures could be used by industry to more effectively manage risks of worksite protection. As the project progressed and systemic weaknesses or vulnerabilities were identified with the methods of worksite protection, the aim expanded to raising awareness of such vulnerabilities with rail infrastructure managers and addressing them.

1.3 Scope

The original scope of this project was to develop a tool that allowed investigators to determine the root causes and human PSFs in worksite protection incidents and accidents at NSW worksites. This scope expanded to include a vulnerability analysis once it became apparent that potential vulnerabilities existed.

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[2] Lookout working replaced NAR on 18 December 2010. This report references both terms depending on when the analysis of this network rule was undertaken

[3] ASB (Absolute Signal Blocking) has replaced CSB on the RailCorp and John Holland Rail networks since this report has been written

[4] Those factors might be of an operational, environmental, personal, organisational or technical nature

2 Methodology

2.1 Overview

An overview of the processes undertaken and the outputs generated in the development of the toolkit are summarised as Figure 1.

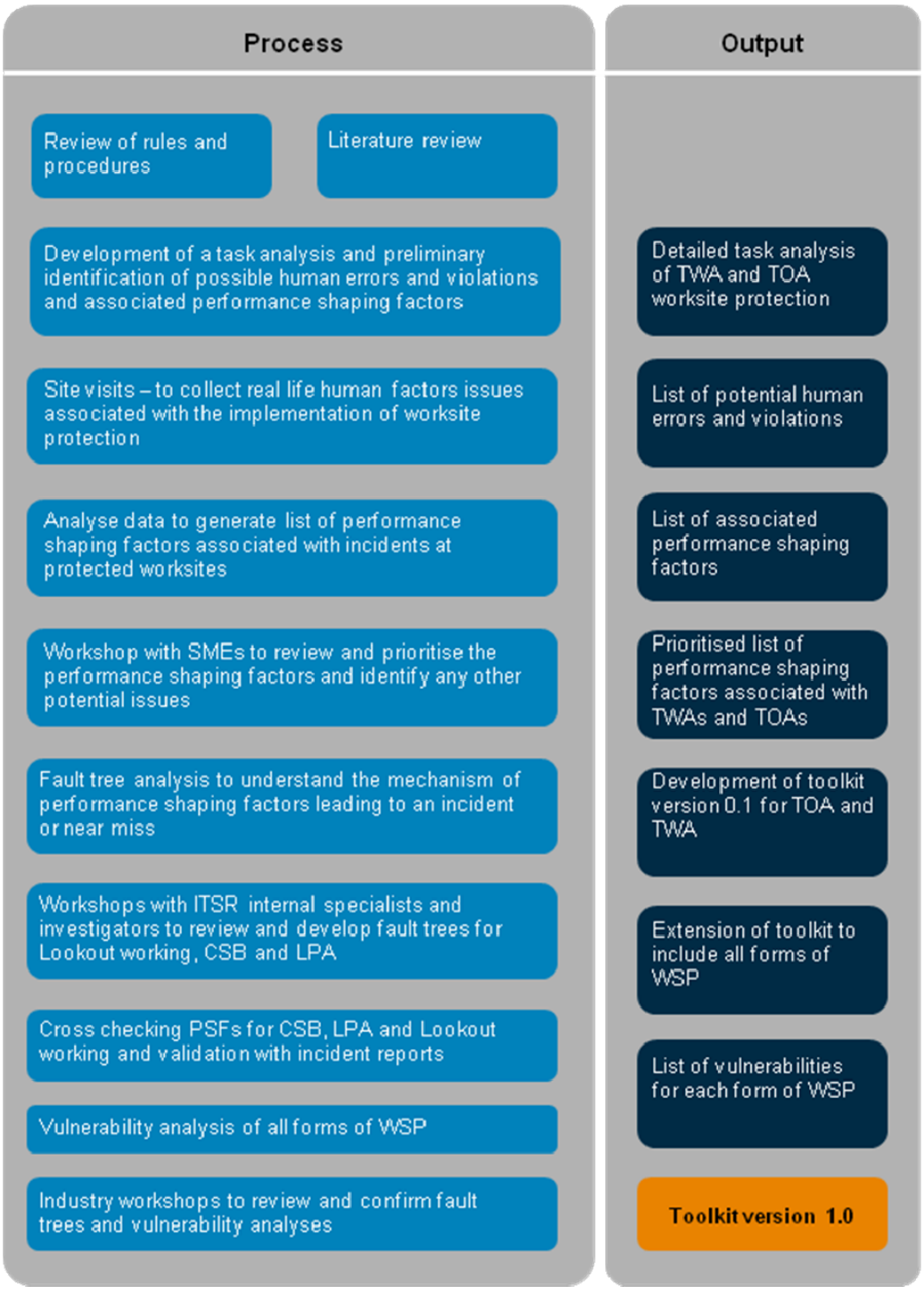

Figure 1: Overview of process and outputs

3 Results – development of worksite protection toolkit

3.1 Literature review

A review of international literature and research was undertaken by Lloyd's Register Rail Ltd to identify issues, risks and lessons learned associated with human performance and behaviour at protected worksites, along with best practice approaches to managing those issues.

The literature review provided supporting evidence for the human errors, violations and performance shaping factors identified throughout the course of the project. The key findings of the literature review are summarised below.

Key findings

This literature review sought to research human factor issues that contribute to worksite protection incidents. Documentation examined included incident investigation reports, risk-based task analyses, worksite protection rules and procedures as well as various articles and papers.

The review found a number of common methods in the application of worksite protection. These methods and controls range from the use of lookouts and physical barriers, to mobile worksites and automatic train warning systems.

The prevalence of factors impairing human performance associated with worksite protection is obvious and the following aspects are highlighted:

- the importance of planning and scheduling of track maintenance to take into account the pressures of maintaining network on-time running
- the pervasiveness of procedural non-compliance within the industry, which eventuated out of:
  - the perceived inappropriateness of procedures
  - the complexity of rules and the rule structure
  - the general culture of the organisation
  - the insufficient number of people for the task at hand
- the quality of pre-track work risk assessments

- supporting appropriate situational awareness, whether that is in regards to manual processes such as the use of hand signallers and lookouts, or automatic processes such as the automatic train warning system.

Some conclusions that can be drawn from this literature review in terms of mitigation strategies against human failure include:

- increasing the effort and support that goes into the planning task
- improving the hierarchy of controls (that is, considering engineering controls)
- increasing the quality of training provided to key personnel involved in worksite protection, especially in regards to communication
- improving the pre-track work risk assessment process
- improving the quality of rules and procedures
- improving worksite boundary identification
- improving the exchange of information between relevant parties.

3.2 Task analysis

A comprehensive set of procedures exists for the implementation of all forms of worksite protection. A review of these procedures was conducted to develop detailed task analyses (TA) of TWA and TOA methods of worksite protection.

However, procedures are soft controls and as such are entirely dependent on human reliability. As part of ensuring that as many as possible errors and violations associated with implementing these forms of protection were captured, network rules and procedures as well as operator specific procedures were reviewed and a range of worksites visited to identify differences that may exist in the implementation of these procedures in the operational context.

3.3 Site visits by Lloyd's Register Rail Ltd

Overview

Lloyd's Register Rail Ltd conducted site visits at a range of worksites in order to:

- validate the task analysis and preliminary performance shaping factors
- identify other human factors issues that may impact on the safe implementation of TWAs and TOAs.

Visits were undertaken at sites managed by several different operators and a variety of roles were observed, as shown in Table 1 below.

Table 1: Summary of site visits

Date	Location	Type of protection	Roles
02/04/09	Site 1	TWA	Rail safety coordinator PO Handsignaller
12/05/09	Site 2	TWA	PO Inner hand signaller x 2
18/05/09	Site 3	TWA	PO Inner hand signaller Outer hand signaller Train driver Safeworking support mentor – north region
25/05/09	Signalling control centre	TWA/TOA	Signal box supervisor
25/05/09	Train control management centre	TWA/TOA	Train controller x 2 including shift handover involving a TOA

During the site visits, operators were observed to be performing their normal duties associated with TWA level of protection. A range of workers were interviewed to gain an understanding of the issues they perceive to exist and any barriers or influences that prevented them from working in a safe manner.

The main issues identified from the site visits and discussions with rail safety workers are summarised in Table 2 below.

Table 2: Summary of issues identified at site visits

Ref	Issue	Comments/observations from visits
1	Insufficient pre-track work risk assessment competence of POs	POs receive no formal training in risk assessment
2	Insufficient pre-work planning	Site visits suggested that POs are not performing an adequate risk assessment and are not adequately planning the work. For example: • PO contacting signaller to request TWA/TOA without completing track diagram or worksite protection plan • POs do not know which signals or points they need blocked • Site not having enough detonators to protect site against rail traffic
3	Pre-work briefing not communicated effectively to work gang	• Not all workers are listening to pre-work briefing • PO not always reading out morning brief, but only placing it on dash board for workers to sign • Briefing may be overly complicated or not sufficiently site specific to be effective
4	Insufficient safeworking staff	• At one location within the past few months, there were two TWA worksites on parallel tracks. The PO of one TWA was standing on the track of the second TWA acting as the clearance handsignaller for that worksite • It appears management are not employing the correct number of safeworking staff • POs requesting TOAs in times of frequent train running rather than TWA because of limited safeworking staffing
5	NARs ‘piggy backing’ on TWA worksite	• NAR 'piggy backing on TWA' - a work group under NAR commenced work between the inner and outer handsignaller. The signal box was aware that the NAR workgroup was on-site but they did not warn the PO. A train travelled past the outer handsignaller. The train then travelled past the NAR crew who gave an all clear hand signal, the driver then powered up instead of travelling at caution up to the inner handsignaller. The inner handsignaller had to pull the driver up quickly • Signallers and TC do not inform TOA/TWA PO of NAR within the area. Signaller requests that NAR PO informs the TWA/TOA PO
6	Lack of PO competence	• One PO did not fulfil worksite protection before closing the worksite protection so TC had to contact PO • PO not sure of position of all track workers

Ref	Issue	Comments/observations from visits
7	Lack of handsignaller competence	• Handsignaller gave driver incorrect hand signal and forgot which hand signal he gave driver so worksite needed to be cleared • Handsignaller placed protection on the incorrect line (up instead of down) despite PO walking to the track with the handsignaller to show where the protection was required • Handsignaller placed the detonators on the correct rail but then stood on the wrong side of the track, assuming that the driver would have a better view of his signal • Handsignaller did not place detonators back in plastic container • Contracted safeworking staff are able to work for a second or third company after they have been disciplined by a separate company
8	Handsignaller/worker fatigue	• One safeworking staff member allegedly worked a shift at Singleton then drove to Sydney and worked an 8-hour shift • PO stated the responsibility is with the worker to inform the PO or supervisor when they are feeling fatigued. However, there may be repercussions from team mates or supervisor, such as not being placed on future worksites • No system in place to replace handsignallers when they go on breaks • Insufficient shelter for handsignallers. May need to stand in hot or cold conditions without protection for prolonged periods
9	Driver distraction on approach to worksite	• Distraction occurs for driver between the outer handsignaller and the worksite, such as a station, a hill or speed sign. These may result in the driver powering up, and thereby forgetting the caution from the outer handsignaller • End of platform reminder boards not always effective. At short platforms, drivers will not be able to see them. Design of signs not optimised to attract drivers attention 

Ref	Issue	Comments/observations from visits
10	Communication issues between PO and TC/NCO	• PO (or PPO) will decide level of protection. LPA not considered because too difficult to obtain. TOA difficult to obtain. If traffic is more frequent than one train a TWA will be used. If only one train, TOA will be used • Difficult communications between signallers and TC due to authority gradient • Communication difficulties between operational staff and English as a second language POs and POs with other language/speech barriers • Communication difficulties are often exacerbated by poor radio and telephone lines
11	Lack of operations worker competency and knowledge and adequate handover procedure	• NCO informing PO of incorrect rule/procedure. NCO not knowing correct procedure • Signallers not sending TC infrastructure bookout authority form so TCs are unaware that equipment/infrastructure has been booked out • TCs and signallers do not receive retraining in TWA and TOA procedures. Training in changes to rules only. • Signaller informing TC they have applied blocking facilities when they have actually forgotten • There is a lack of understanding regarding TC and signaller shift handover to ensure all details from previous shift including current worksite protection area provided to incoming TC/signaller
12	Clearance of worksite not clearly marked	• Drivers not sure, when they are clear of the worksite. Passenger trains frequently power up before the last cars have left the worksite • In the case of freight trains, PO will contact driver over WB radio or contact NCO to contact driver to inform them when they are clear of the worksite

Conclusion

The site visits identified a number of organisational and operational factors impairing human performance at TWA and TOA worksites. These issues have been incorporated into the toolkit for these types of protection.

The actual extent that these issues exist can be determined once the toolkit has undergone a period of trial and sufficient data have been collected. This can assist in the assessment of risk and prioritisation. However, the fact that those issues do exist means that they need to be addressed for effective risk mitigation.

Since the above issues were collected from a limited number of site visits it can be expected that there are more, and gaps need to be filled in accordingly throughout the use of the toolkit.

3.4 ITSR site inspections

ITSR conducted site visits as part of its 2009-10 compliance strategy for worksite protection. The purpose of the site inspections was to understand the degree of conformance to the rules and procedures for track work protection.

A total of 149 worksite inspections were conducted by ITSR between 6 April and 2 July 2010. Of these, 67 were at RailCorp worksites, 78 were at Australian Rail Track Corporation (ARTC) worksites and 4 were managed by other organisations outside the RailCorp and ARTC networks. Further worksite inspections by ITSR continue to be performed.

Commonly identified issues were:

- diaries and log books not being completed correctly
- no copies of network rules and procedures accessible
- rail safety worker having expired certificates of competencies.

Less frequent observed issues were:

- a PO, who was the designated lookout, was helping spread concrete
- detonators not placed in accordance with NPR709
- detonators and flags not identified on worksite protection plans
- unclear worksite protection plans
- worksite incorrectly protected with NAR (with a machine with the potential to enter the danger zone)
- employees working in corridor without a protection officer (requested to cease work and leave corridor).

The findings of these inspections were similar to those of the earlier Lloyd's Register Rail Ltd site visits.

3.5 Issues register

Based on the task analysis, literature review and site visits, a range of worksite protection issues were identified and collated in an issues register. These issues and the subsequent prioritisation with SMEs helped focus the register on worksite protection factors most relevant to the NSW operating environment.

It is important to note, however, that due to the limited scope of the project, the issues register might have missed relevant factors, which will need to be added to revised versions of the toolkit. Because of this, more general items have been included into the list of PSFs to ensure all issues can be captured.

3.6 Validation and prioritisation of issues

Overview

The issues identified in the site visits and from the review of the literature and TWA/TOA rules and procedures were validated and prioritised in a workshop held by Lloyd's Register Rail Ltd on 16 June 2009 with industry and ITSR personnel. Any additional aspects raised by the group were recorded and discussed. CSB-related aspects were validated in an additional workshop.

The purpose of prioritising the issues was to allow the development of the issues register to focus on those aspects of worksite protection failure most likely to occur.

Workshop participants were asked to rank the likelihood of the issues occurring as high, medium or low, as per the ranking scale below:

Table 3: Prioritisation ranking

Ranking	Description
High	• Occurs frequently in TWA and TOA worksites (For example, expected to occur once every 2 or 3 occasions)
Medium	• Occurs occasionally in TWA and TOA worksites (For example, expected to occur approximately one in 10 occasions)
Low	• Occurs infrequently in TWA and TOA worksites (For example, may occur only in exceptional circumstances - one in every 100 occasions)

Overall, the workshop participants rated the likelihood of most of the issues occurring as low. However, a number of issues were given a likelihood rating of medium to high.

The issues and their likelihood rating are shown in Table 4 below.

Table 4: Issues ranked as medium and high priority

Main task	Sub task	Issue/root cause	Likelihood
Plan TOA	Pre-work off-site planning	No operational monitoring of contracted workers records. Contracted safeworking staff are able to work for a second or third company after they are disciplined by a separate company[5]	H
Plan TOA	Pre-work off-site planning	No operational monitoring of contracted workers records. Contracted safeworking staff are able to work consecutive shifts on different projects	H
Plan TOA/TWA	Pre-work off-site planning	Worksite protection warning/reminder boards not always visible to drivers due to short platforms	H
Obtain a TOA from Network Control officer (NCO) responsible for that area of track	PO contacts NCO and provides details of TOA	PO unable to obtain freight train times from operations	H
Obtain a track work authority from NCO responsible for that proportion of track	NCO requests details of protection to be applied to the worksite	Train running given priority over track work (and as a consequence NAR is used for prep work before and after TOAs)	H
Plan TOA/TWA	Pre-work off-site planning	Use of old procedures/diagrams - route diagram is not up-to-date or not used	M/H
Return track to service	PO ensures that all equipment is clear of the line	Limited PO and handsignaller on-site training and experience	M/H
Plan TOA/TWA	Pre-work off-site planning	PO incorrectly identifies worksite entrance to worksite: • related to the frequency of the PO implementing a TWA • dependent on the track complexity	M
Plan TOA/TWA	Pre-work off-site planning	Staff complete required safeworking worksite plans inadequately - protection element	M
Plan TOA/TWA	Pre-work off-site planning	Contracted safeworking staff (PO/ handsignaller) has completed limited or no in-field experience within training and before certification	M

[5] Railway operators in NSW have subsequently implemented a contractor database to help railways avoid such situations

Main task	Sub task	Issue/root cause	Likelihood
Plan TOA	Pre-work off-site planning	Multiple TOAs applied instead of LPA because request for authority was not requested with Train Planning in required time and advertised STN	**M**
Obtain a TOA from NCO responsible for that proportion of track	PO contacts NCO and provides details of TOA	PO omits this step due to commercial pressure to perform the work/project quickly	**M**
Manage rail traffic movement through worksite	Pilot establishes and maintains effective communication with the NCO and PO	PO/NCO and Pilot not maintaining sufficient communication	**M**
Return track to service	PO ensures that all equipment is clear of the line	Handsignaller is distracted - i.e. operational factors	**M**
Manage rail traffic movement through worksite	Driver travels through worksite	Worksite limits are not clearly defined so driver is unsure of where speed limit is active	**M**
Manage rail traffic movement through worksite	PO receives notification from clearance handsignaller that track is clear up to first running signal beyond worksite that can show stop	Safeworking staff performing multiple duties due to understaffing, for example PO acting as clearance handsignaller	**M**

3.7 Fault trees

Fault trees were developed for all forms of worksite protection. They allow the investigator to navigate from the initial incident through to determining the root causes and subsequently identify performance shaping factors present during the incident.

The investigators apply the information that they have gathered from the initial incident data collection to the fault trees to navigate through the incident to identify the causal factors. Where the fault tree ends, there are references to more detailed question sets that will help determine the systemic contributing factors.

The fault trees remove a significant burden of the investigation task, as they form the basis for incident analysis that is usually developed as part of the investigation process. The fault trees also provide investigators with a method of systematically navigating through an incident to identify possible root causes and performance shaping factors. This ensures that investigators consider possible error routes as comprehensively as possible.

The diagrams on the following pages illustrate the typical structure of the fault trees.

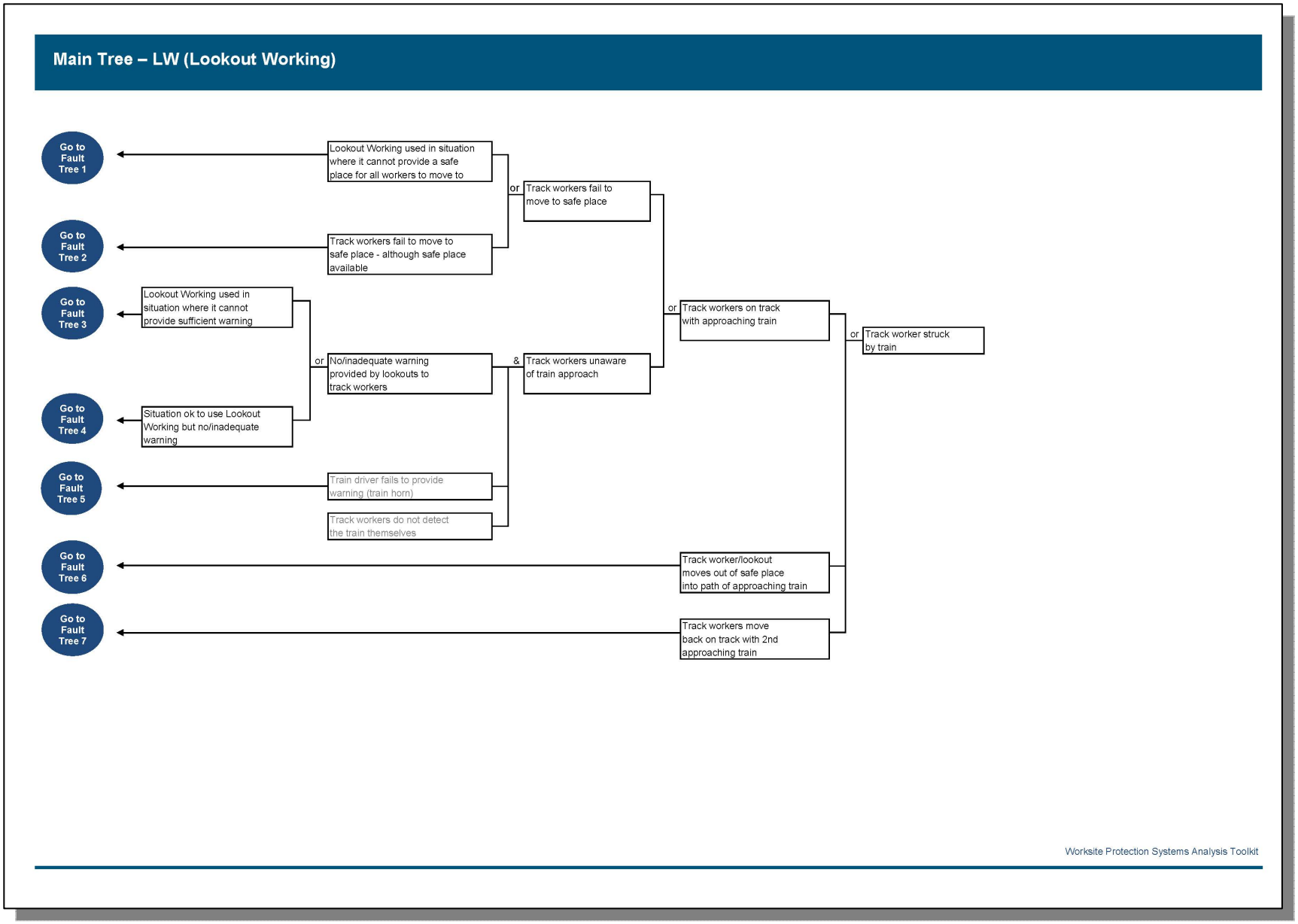

Figure 2: Example of main fault tree

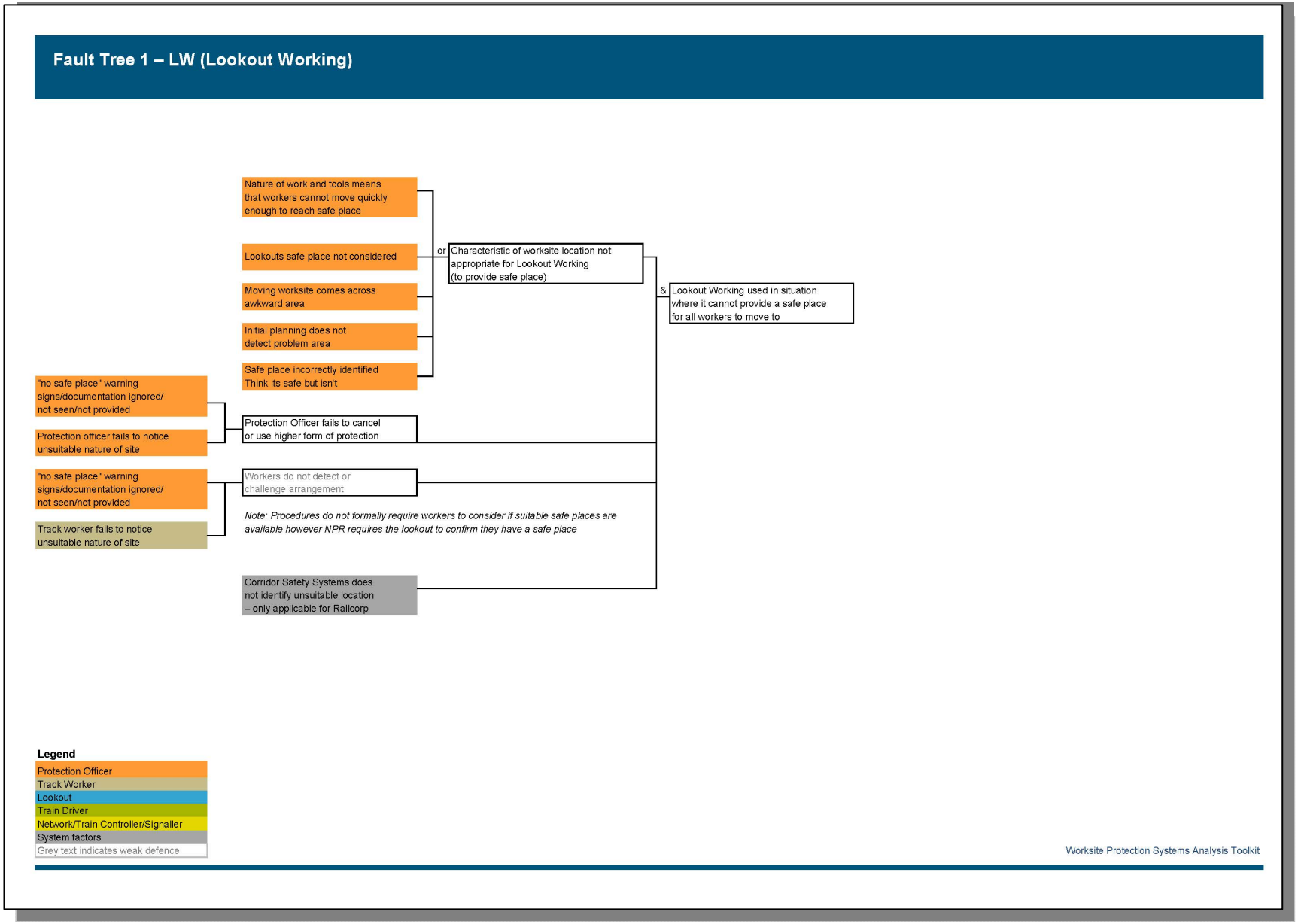

Figure 3: Example of fault tree

Note: Different colours at the ends of the tree indicate which role is primarily involved in the failure.

4 Structure

The toolkit is structured around the fault trees developed for lookout working, CSB, TWA, TOA and LPA levels of protection.

Investigators can choose from a set of performance shaping factors (PSFs) that are common error precursors in worksite protection incidents which are provided with each set of fault trees.

Investigators are supposed to establish the occurrence they are investigating in the relevant fault tree and to identify the pathway backwards to the end of the tree. Once established they should go to the worksheet labelled ‘HF checklist’ and select the relevant contributing factors for each role involved (e.g. the PO may have made an error and the NCO also may have made one). The recommended workflow and the linking of the tree to the question sets are shown below.

Steps involved:

1. Select the relevant Excel workbook for the form of worksite protection (e.g. CSB)

2. Identify the top event of the occurrence in the main tree (e.g. workers not clear of danger zone after CSB fulfilled)

3. Follow the incident pathway in the main tree to the end and select the fault tree as indicated (e.g. go to fault tree 5)

4. Identify the relevant incident pathway and note the role(s) associated with the last box (e.g. PO, NCO)

5. Go the human factors (HF) checklist worksheet, fill in the relevant role(s) and identify any contributing factors (e.g. poor or no briefing conducted, distractions).

5 Vulnerability analysis

During the development of the functional fault trees, vulnerabilities for each form of worksite protection were revealed. It became obvious that the vulnerabilities lie in the systems for worksite protection, not just the rules and procedures.

The vulnerability analysis serves the following purposes:

- to raise awareness regarding the weakest parts of the track work protection system
- to help focus work undertaken in the area of worksite protection safety to ensure critical parts are addressed
- to encourage rail operators to make the following consideration in regards to the identified vulnerabilities:
  - are identified vulnerabilities in current risk assessments?
  - what are the risks associated with vulnerabilities?
  - what controls are currently in place?
  - are the risks considered to be acceptable/tolerable?
  - in determining if risks have been reduced SFAIRP, have new technologies been considered?

ITSR went through a process of identifying all vulnerabilities systematically. Internal validation workshops with subject matter experts were conducted for each system of track work protection.

Vulnerabilities were identified where errors and violations could lead to hazardous situations and without multiple failures required to reach a hazardous situation.

All those vulnerabilities were highlighted and presented in the context of their relevant fault trees in various industry workshops. The purpose was to reach a common understanding and agreement on the most vulnerable systems of track work protection.

Table 5 on the following page lists all identified vulnerabilities for each form of worksite protection with examples provided and with a reference to the relevant fault trees.

Table 5: Vulnerabilities in various forms of worksite protection

Form of worksite protection	Vulnerabilities	Example	Fault tree reference
Lookout working	(1) Lookout fails to provide adequate warning	Area is okay for lookout working but the lookout can fail to provide adequate warning when they engaged in other work activities and distracted; situations where the lookout is looking at the wrong track; where a warning is not transmitted by a pair of lookouts, etc	Lookout working Fault tree 4
Lookout working	(2) Lookout working used when it cannot provide sufficient warning	Situations where the nature of the site means a lookout cannot detect and warn of a train's approach until it is too late for workers to safely leave the track. Examples are conditions of poor visibility (such as fog), poor sighting along track, noisy environment etc	Lookout working Fault tree 3
Lookout working	(3) No suitable safeplace provided for all workers	Situations where lookout working is used but there is no safeplace (such as on a bridge) or the safeplace is inadequate (such as another operational line has to be crossed to reach it)	Lookout working Fault tree 1
Lookout working	(4) Workers fail to move to a safeplace although safeplace available	Situations where workers move too slowly, too late, fall, or fail to move (for example, engrossed in work)	Lookout working Fault tree 2
Lookout working	(5) Workers move out of safeplace into path of approaching train	Situations where workers attempt to retrieve equipment, worry safe place is inadequate, become disorientated and move to danger zone	Lookout working Fault tree 6
Lookout working	(6) Workers move back on the track with second train approaching	Workers not aware of the second train due to lookout not back in position or disorientated after moving. Workers moving back onto track without all clear	Lookout working Fault tree 7
CSB	(1) Train already in area when CSB created but presence not identified by NCO.	If the NCO fails to recognise that there is a train within the CSB limits when creating the CSB, the PO is unlikely to be able to detect the error/omission. No protection for workgroup if they enter the danger zone	CSB Fault tree 1
CSB	(2) NCO assumes that train has already passed the worksite (train already in area known by NCO but relative position of train and worksite incorrectly identified)	The NCO and PO believe the train has passed the worksite but it has not. Another case is the NCO knows the train is in the area, but assumes it has passed the PO and so does not tell the PO of the train. No protection for workgroup if they enter the danger zone	CSB Fault tree 1

Form of worksite protection	Vulnerabilities	Example	Fault tree reference
CSB	(3) Train already in area when CSB created but presence not clearly communicated to PO by NCO	The NCO knows the train is in the area, but does not communicate clearly that there is a train in the area and so the PO does not wait for it to pass. No protection for workgroup if they enter the danger zone	CSB Fault tree 1
CSB	(4) All signals at entry points to the CSB area not set to stop or held to stop	The NCO does not hold all signals to stop at the entrance to the CSB, which could result from wrong identification of the work area, not realising or recalling the worksite is there or inadequate placement of blocking facilities	CSB Fault tree 3
CSB	(5) Workers not clear of danger zone when CSB fulfilled	If workers are not clear when the PO fulfils the CSB, they are directly exposed to train traffic	CSB Fault tree 6
TWA	(1) Train passes inner handsignaller without authorisation Inner handsignaller not positioned to allow driver sufficient sighting time Driver does not receive correct caution signal from outer handsignaller Driver forgets caution signal from outer handsignaller and increases train speed	Driver may not recognise the inner handsignaller as at stop, or the train cannot stop at the inner handsignaller in time as they are travelling too fast, couldn't see the outer handsignaller, didn't get the right signal from the outer handsignaller, misjudged the braking capacity of the train etc	TWA Main tree TWA Fault tree 2 TWA Fault tree 3 TWA Fault tree 5
TWA	(2) Driver does not receive stop signal at inner handsignaller Inner handsignaller incorrectly authorises train to proceed Entry to worksite not protected	Inner handsignaller may not be at their post or provides an incorrect authorisation to proceed, entry to the worksite not protected, or protection lifted prematurely such as a protecting signal being cleared	TWA Main tree TWA Fault tree 7 TWA Fault tree 8
TWA	(3) Workgroup moves back into danger zone after train is authorised to proceed		TWA Fault tree 13
TWA	(4) Workers remain in danger zone after TWA is fulfilled		TWA Fault tree 14

Form of worksite protection	Vulnerabilities	Example	Fault tree reference
TOA	(1) Train already in area when TOA created but presence not identified by NCO	If the NCO fails to recognise that there is a train within the TOA limits when creating the TOA, the PO is unlikely to be able to detect the error/omission. Protection may not be available as it may be placed at the TOA limit, be not yet deployed or be not effective in stopping the train. Protection not required for non-fixed worksites	TOA Fault tree 1
TOA	(2) NCO assumes that train has already passed the worksite (train already in area known by NCO but relative position of train and worksite incorrectly identified)	The NCO or PO believes the train has passed the worksite but it has not. Protection may not be available as it may be placed at the TOA limit, be not yet deployed or be not effective in stopping the train. Protection not required for non-fixed worksites	TOA Fault tree 1
TOA	(3) Train already in area when TOA being created but procedure not correctly followed by NCO to confirm the train has passed	The NCO knows the train is in the area, but does not ask PO to provide the train number when it passed. NCO also does not communicate clearly to the PO that there is a train in the area Protection may not be available as it may be placed at the TOA limit, be not yet deployed or be not effective in stopping the train. Protection not required for non-fixed worksites	TOA Fault tree 1
TOA	(4) All signals at entry points to the TOA area not set to stop or held to stop (RVDT)	If the NCO does not hold all signals to stop at the entrance to the TOA, the only line of defence now is the protection such as detonators, red flags/lights Failure of the NCO to maintain all signals at stop can arise from errors such as: • wrong identification of the work area • the NCO not realising a TOA is in force due to inadequate placement of blocking facilities • the NCO not realising a TOA is in force due to not recording the TOA etc	TOA Fault tree 3
TOA	(5) Train enters TOA limit without authority (passes signal at stop or authority exceedance) and driver proceeds		TOA Main tree

Form of worksite protection	Vulnerabilities	Example	Fault tree reference
TOA	(6) Electric staff, staff and ticket - Train driver gains staff, incorrect or no authority to proceed from NCO, proceeds into TOA	If the PO/NCO have decided not to take the staff for the section or the PO has failed to take it, then it remains available for a train driver to collect. If the train driver does not get authorisation from the NCO or the NCO does not recognise that a TOA is on the section, the only line of defence now is protection such as detonators, red flag/light. For non-fixed worksites protection will most likely be absent, leaving the track vehicle exposed	TOA Main tree TOA Fault tree 5a/5c
TOA	(7) Workers not clear of danger zone when TOA fulfilled	If workers are not clear when the PO fulfils the TOA, they are directly exposed to train traffic	TOA Fault tree 8
TOA	(8) Track vehicle passes red flag/light detonators at worksite limit (does not respond to protection)	If a track vehicle sharing (or has a joint TOA) a TOA with a worksite approaches the protection for the worksite too rapidly or the protection is at the TOA limit, the track vehicle can run into the worksite	TOA Fault tree 6
TOA	(9) No red flag/light or detonators at worksite limit	If no protection is put out and a TOA is shared (or has a joint TOA) between a fixed worksite and a track vehicle the track vehicle can run into the worksite with no warning	TOA Fault tree 7
LPA	(1) Train already in area when LPA created but presence not identified by NCO	If the NCO fails to recognise that there is a train within the LPA limits when creating the LPA, the PPO is unlikely to be able to detect the error/omission. Protection may not be available as it may be placed at the LPA limit, be not yet deployed or be not effective in stopping the train	LPA Fault tree 1
LPA	(2) All signals at entry points to the LPA area not set to stop or held to stop (RVDT)	If the NCO does not hold all signals to stop at the entrance to the LPA, the only line of defence now is the protection such as detonators, red flags/lights	LPA Fault tree 3/3a/3b
LPA	(3) Train enters LPA limit without authority (passes signal at stop or authority exceedance) and driver		LPA Main tree

Form of worksite protection	Vulnerabilities	Example	Fault tree reference
LPA	(4) Electric staff, staff & ticket – train driver gains staff, incorrect or no authority to proceed from NCO, proceeds into LPA	If the PPO/ NCO have decided not to take the staff for the section or the PPO has failed to take it, then it remains available for a train driver to collect. If the train driver does not get authorisation from the NCO or the NCO does not recognise that an LPA is on the section, the only line of defence now is the protection such as detonators, red flag/light	LPA Fault tree 5
LPA	(5) Workers not clear of danger zone when LPA fulfilled	If workers are not clear when the PO/PPO fulfils the LPA, they are directly exposed to train traffic. Situations where there is miscommunication between the PO and PPO	LPA Fault tree 9
LPA	(6) Track vehicle/work train does not stop at worksite limit	For multiple worksites a track vehicle approaches the protection for the worksite too rapidly or does not notice or respond to the protection or there is no protection, the track vehicle can run into the worksite	LPA Fault tree 7
LPA	(7) Track worker does not appreciate or know of limits of danger zone and enters danger zone		LPA Main tree

6 Conclusions

6.1 Summary

A first version of the Worksite Protection Systems Analysis Toolkit has been developed to enable investigators to determine the performance shaping factors behind incidents on lookout working, CSB, TWA , TOA and LPA protected worksites. The toolkit has been structured around fault trees that represent the mechanism behind human failure leading to worksite protection incidents.

At the end of each fault tree investigators can select from a set of performance shaping factors that are common error precursors in worksite protection incidents. They can do that based on information gathered throughout the investigation. A range of human factors issues associated with the implementation of lookout working, CSB, TWA, TOA and LPA levels of worksite protection in NSW were identified in this research. These issues need to be further validated through the application of the toolkit to rail safety incidents as they occur. Through using the toolkit, data can be collected to determine the frequency that the human performance shaping factors arise. This in turn will guide the development of mitigations to reduce the rate of incident occurrence.

A vulnerability analysis highlights areas in the system of track work protection that need attention. Addressing those vulnerabilities should increase the resilience of the system.

6.2 Next steps

Rail infrastructure managers who maintain systems of rules and procedures for track work safety need to consider the vulnerabilities identified. They need to determine how each vulnerability is to be treated in light of the need to reduce risks so far as is reasonably practicable.

Rail operators should be encouraged to start using the toolkit and to incorporate it into their investigation/ risk management/HF processes. The usability of the toolkit should be evaluated and the structures of the fault trees refined (as needed) to ensure the toolkit efficiently identifies the performance shaping factors behind incidents.

Rail operators involved with track work should use the tool or its derivatives to collect more detailed data for track work incidents and accidents. Data collected from using the toolkit should be used to improve the data on human factors issues leading to worksite protection incidents. An improved dataset allows the prioritisation and refinement of mitigation strategies for the performance shaping factors. It also will provide information on the effectiveness of existing controls.

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