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Bow Tie Analysis Overview Report

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Bow Tie Analysis of Mobile Equipment-Pedestrian Interface in Sawmill Operations – Overview Report

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EXECUTIVE SUMMARY

This report provides an overview of a bow tie analysis of the mobile equipment-pedestrian interface (ME-PI) in sawmill operations. There have been numerous loss-producing incidents involving the ME-PI in sawmill operations that have led to injuries and fatalities. This work was undertaken to understand how incidents involving the ME-PI may occur, examine current safety measures (barriers) that are in place to prevent incidents from occurring, and identify potential opportunities to enhance existing barriers and include additional safeguards to improve risk reduction. This report also describes a subsequent analysis that was completed to evaluate the barriers with respect to the hierarchy of controls (the preferred order of risk reduction measures) and examine the threats to understand personnel and areas most affected by the ME-PI.

The bow tie analysis was developed in a workshop involving numerous personnel from sawmill operations on April 11th and 12th 2022 in Prince George. The information provided by the workshop participants formed the basis of the analysis. In the bow tie analysis for the lumber activities, there were 28 threats identified that encompass many types of pedestrians and mobile equipment operators. It was found that administrative controls, such as closing off sections of the yard while personnel are working in the area, procedures for the removal of hearing protection while working in the yard and wearing high-visibility personal protective equipment (PPE), are the most frequently used type of barrier currently implemented to manage ME-PI risk. It is recommended that opportunities to integrate other types of safeguards that are higher in the hierarchy of

controls, namely inherently safer design (ISD), active engineered and passive engineered, be explored.

During the bow tie workshop, areas for improvement were identified and other potential barriers to improve ME-PI risk reduction were discussed. These barriers included administrative controls such as updating safe work procedures and enhancing training, active engineered controls such as automatic gates and lights, passive engineered controls including the installation of barriers to separate pedestrians and mobile equipment, and ISD options including redesigning areas of the site to improve pedestrian and mobile equipment movement paths. Areas for future work include finishing bow tie analyses for log yard activities, as well as production and storage indoors.

LIST OF ABBREVIATIONS USED

ADM	Administrative Control
ACT	Active Engineered Control
BCFSC	British Columbia Forest Safety Council
FLRA or FLHA	Field-Level Risk Assessment or Field-Level Hazard Assessment
ISD	Inherently Safer Design
MAG	Manufacturing Advisory Group
ME	Mobile Equipment
ME-PI	Mobile Equipment-Pedestrian Interface
MOC	Management of Change
PAS	Passive Engineered Control
PHA	Process Hazard Analysis
Pot. ADM	Potential Administrative Control
Pot. ACT	Potential Active Engineered Control
Pot. ISD	Potential Inherently Safer Design Control
Pot. PAS	Potential Passive Engineered Control
PPE	Personal Protective Equipment
SME	Subject Matter Expert
SOP	Standard Operating Procedure
SWP	Safe Work Procedure
WSBC	WorkSafeBC (Workers' Compensation Board of British Columbia)

ACKNOWLEDGEMENTS

Obex Risk Ltd. would like to thank each of the bow tie workshop participants, including production workers from the Manufacturing Advisory Group (MAG) companies and members of the MAG, for their active participation and contribution to the analysis. Obex Risk Ltd. also wishes to thank Cherie Whelan of the British Columbia Forest Safety Council (BCFSC) for arranging the project, and Bill Laturnus (BCFSC) for assistance with coordinating the onsite logistics of the bow tie workshop in Prince George, as well as workshop assistance.

Obex Risk Ltd. acknowledges funding from BCFSC to conduct this work.

1 INTRODUCTION

This report summarizes a bow tie analysis that was conducted to evaluate the mobile equipment-pedestrian interface hazard in sawmill operations. This bow tie analysis was conducted with BC Forest Safety Council (BCFSC), production workers from the Manufacturing Advisory Group (MAG) companies, and members of the MAG.

The introductory chapter of this report provides an overview of the project as well as the motivation, scope of work and objectives of the work. The organization of this report document is also outlined.

1.1 Sawmills and Mobile Equipment-Pedestrian Interface Hazards

Sawmills involve a wide range of mobile equipment, including forklifts, transport trucks, and loaders. There is also extensive pedestrian activity in a sawmill, including employees and contractors performing tasks like scanning loads, kiln spotting, clean up, maintenance, entering and leaving the sawmill site at shift change, and deliveries. The interaction of mobile equipment and pedestrians is referred to as the “mobile equipment-pedestrian interface” or ME-PI.

The ME-PI in sawmill operations presents the risk of loss-producing incidents that can lead to injuries and fatalities (BCFSC, 2022). The ME-PI was identified by the MAG as a key area of focus for the improvement of risk management.

1.2 Motivation for Conducting Bow Tie Analysis

Work was undertaken to conduct a bow tie analysis workshop, a type of process hazard analysis (PHA), for hazardous scenarios involving the ME-PI at sawmills. Bow tie analysis can improve the understanding of how incidents can arise, the barriers in place to prevent incidents from occurring, weaknesses in these barriers, and controls that are in place to help ensure barriers are more effective. The work also involved identifying areas for further investigation that may have the potential to enhance safety and address current issues. This workshop was a BCFSC initiative to support MAG and the sawmilling industry in BC. The results will be used to identify gaps and support the development of ME-PI safety resources for the industry.

1.3 Objectives

The purpose of this work was to conduct a bow tie analysis workshop for hazardous scenarios involving the ME-PI at sawmills. Subsequent work was undertaken within this project to examine the bow tie to evaluate several aspects to support resource development. Following the bow tie workshop, the barriers identified have been analyzed with respect to the hierarchy of controls, which is the order of effectiveness and preferred order of consideration for risk reduction measures, beginning with inherently safer design (ISD), followed by passive equipment, active equipment and procedural (administrative) controls). This would improve the understanding of the types of barriers being used and their effectiveness. The most frequently used barriers were also identified to understand

how they may fail to help improve their reliability. The different threats, or scenarios, that could lead to an ME-PI incident, were examined to understand which duties and pedestrians are most affected by the ME-PI.

1.4 Scope

The scope of the bow tie workshop was the hazard posed by mobile equipment to pedestrians in a sawmill. The physical scope of the bow tie analysis was the primary areas in a sawmill:

- Production (lumber yard),
- Log yard, and
- Shipping.

The analytical scope was the hazard of mobile equipment in a sawmill with the undesired event being a pedestrian incident involving mobile equipment.

The scope of the mobile equipment was:

- Forklifts,
- Loaders/Mobile Log Yard Equipment,
- Logging Trucks,
- Lumber Trucks,
- Dump Trucks,
- By-Product Trucks,
- Service & Delivery Vehicles,

- Light/Pickup Trucks,
- Employee Vehicles,
- Bob Cats (skid steers),
- ATVs, and
- Aerial Working Platforms.

The scope of pedestrians was:

- Employees,
- Contractors, and
- Visitors.

1.5 Organization of Report

The report structure is as follows:

Section 1 provides an overview of the ME-PI hazard in sawmills, and the scope, motivation, and objectives for conducting a bow tie analysis workshop.

Section 2 provides an overview of bow tie analysis, the ME-PI workshop that was conducted, and the evaluation of the developed bow tie analysis.

Section 3 highlights the bow tie analysis results and describes the evaluation of the ME-PI bow tie analysis with respect to the hierarchy of controls, common barriers, the identified threats, and identified areas for improvement.

Section 4 outlines a literature review of the management of ME-PI hazards in other industries.

Section 5 provides an overview of recommendations based on the current analysis for addressing risk reduction of the ME-PI hazard in sawmills.

Chapter 6 outlines conclusions of this report.

2 METHODOLOGIES

This chapter provides an overview of bow tie analysis, the ME-PI bow tie workshop that was held, and the methodologies used to evaluate the developed bow tie analysis.

2.1 Overview of bow tie analysis

Bow tie analysis (also known as a bow tie diagram) is PHA tool. Bow tie analysis demonstrates and communicates how different scenarios and conditions can lead to the loss of control of a hazard and lead to consequences. Figure 1 is a generic bow tie analysis to illustrate the structure. The elements of a bow tie analysis are shown in Figure 1 and are as follows: hazard, top event, threat, prevention barrier, consequence, mitigation barrier, degradation factor and degradation control. The definitions of the bow tie analysis elements are outlined in Table 1.

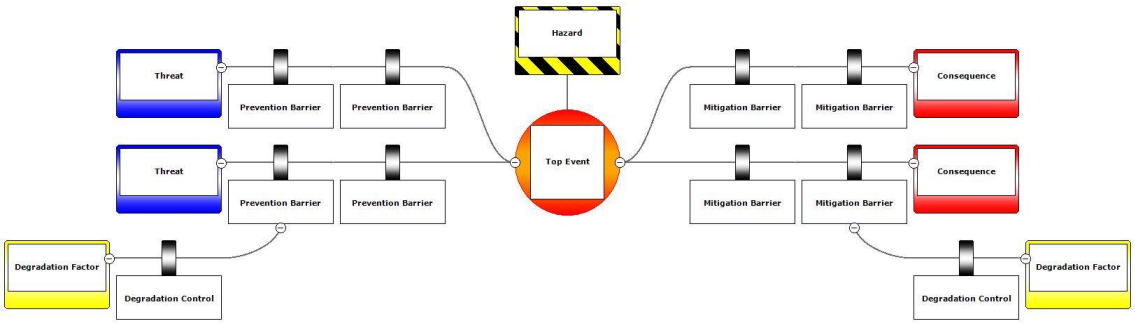

Figure 1. Generic bow tie analysis

Table 1. Definitions of bow tie analysis elements (CCPS/EI, 2018)

Hazard	An operation, activity, or material with the potential to cause harm to people, property, the environment, or business; a source of harm
Top Event	Within the bow tie diagram, a central event between a threat and a consequence corresponding to the loss of containment or loss of control of the hazard
Threats	A possible initiating event that can result in a loss of control or containment of a hazard (the top event)
Consequences	The undesirable result of loss of containment or control (top event); usually measured are health and safety effects, environmental impacts, loss of property and business interruption
Barriers	A control measure that on its own can prevent a threat developing into a top event (prevention barrier) or can mitigate the consequence of a top event after it has occurred (mitigation barrier). A barrier must be effective, independent and auditable.
Degradation Factors	A situation, condition, defect, or error that compromises the function of a main pathway barrier by defeating it or degrading its effectiveness.
Degradation Controls	Measures that help prevent the degradation factor from impairing the barrier. They lie on the pathway connecting the degradation threat to the main pathway barrier.

2.2 ME-PI bow tie workshop

The ME-PI bow tie was held on Monday April 11th and Tuesday April 12th for two daily eight-hour sessions. The workshop was held in-person in Prince George, BC. It involved a group of eight diverse subject matter experts, including mobile equipment operators, maintenance personnel, heavy equipment mechanics, health and safety specialists, supervisors, and managers. The workshop was led by K. Rayner Brown (Obex Risk Ltd.), who was facilitator and scribe. Workshop assistance was provided by B. Laturnus (BCFSC Senior Safety Advisor, Manufacturing).

Following the workshop, further analysis was undertaken by B. Laturnus to add additional information (including frequently occurring barriers, and degradation factors and controls) to the bow tie based on experience and expertise with sawmill operations. The bow tie was then provided to K. Rayner Brown for further evaluation.

2.3 Evaluation of developed bow tie analysis

After the bow tie analysis underwent review for quality and completeness, it was evaluated with respect to several areas. These areas include the hierarchy of controls, barrier frequency, threat category and frequency, as well as potential areas for improvement.

2.3.1 Categorization with respect to hierarchy of controls and inherently safer design (ISD)

The hierarchy of controls (Figure 2) is the preferred order of risk reduction measures. In order of preferred consideration and effectiveness, these are: ISD, passive engineered, active engineered and administrative. ISD focusses on the elimination of hazards and treatment of hazards at the source, rather than relying on only add-on equipment and procedures (Kletz and Amyotte, 2010). Effective risk reduction involves the implementation of ISD, engineered equipment, and procedural measures (Amyotte and Khan, 2020).

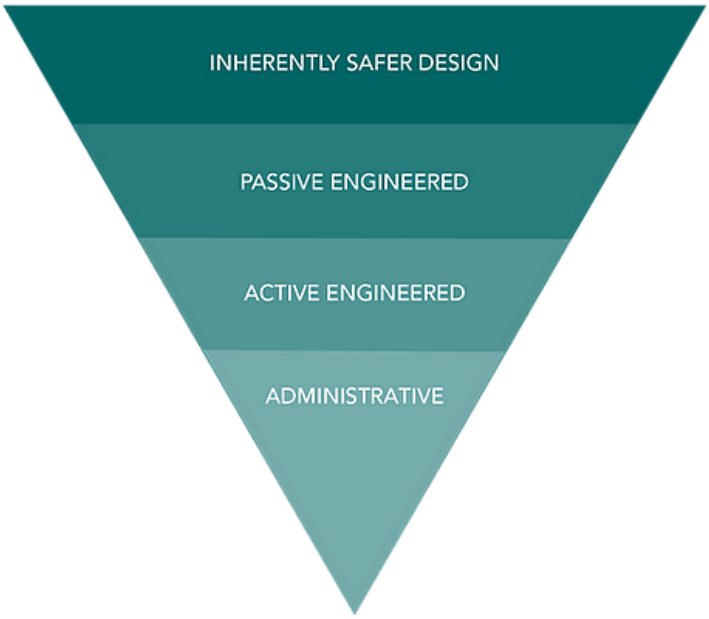

Figure 2. Hierarchy of controls

ISD is based on four principles – minimization, substitution, moderation, simplification. In the context of the ME-PI hazard, ISD is a component of the risk reduction strategy. Horberry et al. (2003) outlines traffic engineering interventions based on the hierarchy of controls:

1. Eliminate or minimize the ME-PI hazard by redesigning the site and improving the worksite so ME does not come into contact with pedestrians.
2. Install barriers between ME and pedestrians.
3. Improve warnings and markings, visibility and rules where ME and pedestrians occupy the same space.

While Horberry et al. do not explicitly name ISD, eliminating ME-PI hazards by worksite redesign is aligned with ISD.

Examples of ISD in the context of the ME-PI hazard are outlined in Table 2.

Table 2. Examples of ISD in the context of the ME-PI hazard

ISD Principle	Example
Minimization	Redesign areas and worksites to minimize or eliminate the presence of pedestrians in the proximity of mobile equipment
Substitution	Use alternate process methods that eliminate or minimize the use or presence of mobile equipment or pedestrians
Moderation	Relocate activities involving pedestrians away from the location of mobile equipment
Simplification	Redesign processes and equipment to make it difficult or impossible to produce a hazardous scenario due to operating or maintenance error

Within the scope of this work, the barriers identified in the bow tie analysis were categorized with respect to the hierarchy of controls. The following questions were addressed:

- Is there any existing ISD barriers currently being used?
- Are there administrative (procedural) barriers with ISD overtones? (For example, minimization of pedestrians or ME through administrative means)

2.3.2 Examination of barriers and threats

The identified barriers were also examined to determine the following:

- What are the most frequently used barriers? What are the degradation factors for them?

By understanding how frequently used barriers fail, these degradation factor controls (e.g., training, auditing, alarms) could be targeting for additional efforts to ensure reliability and effectiveness. The threats identified in the bow tie analysis were also evaluated, including quantifying (e.g., number identified) and categorizing them.

3 BOW TIE ANALYSIS RESULTS AND DISCUSSION

This section is an overview of the results of the bow tie analysis, with a focus on the hazard "Mobile equipment-pedestrian interface within lumber activities." BCFSC personnel have the comprehensive bow tie analysis files in BowTieXP and Visio format. Excerpts of the bow tie analysis are shown here for illustrative purposes. The bow tie analyses in tabular format is found in Supplementary Material A and Supplementary Material B generated using a BowTieXP Hazard Report.

3.1 Overview of developed bow tie analyses

There were three hazards identified in the workshop that were defined based on the location of the ME-PI within the sawmill, which established the physical scope for analysis. The hazards were:

- Mobile equipment-pedestrian interface within lumber activities
- Mobile equipment-pedestrian interface within log activities
- Mobile equipment-pedestrian interface within production and storage indoors

The top event identified was "Mobile equipment-pedestrian incident." During the bow tie workshop, the bow tie with the hazard "Mobile equipment-pedestrian interface within lumber activities" was focussed on based on prioritization within the workshop time. During the bow tie workshop, the threats associated with the hazard "mobile equipment-pedestrian interface within log activities" were identified and preliminary evaluation of prevention barriers was completed. The bow tie analysis for the

hazard “Mobile equipment-pedestrian interface within production and storage indoors” was not completed but was identified as a priority for future evaluation. Completion of the analyses associated with both the log activities, as well as production and storage indoors, is outlined in Section 5 Recommendations.

During the workshop, definitions were established for some terms, which are outlined in Table 3.

Table 3. Terms and definitions established and used in workshop

Term	**Definition**
Service providers/vendors	Routine authorized personnel, including waste removal, steel, recyclers, vacuum trucks
Upset condition	A non-routine or unplanned yard incident. Anything that may not have a written procedure. Includes: - spilled load - broken machine - burned out light replacement - broken water main - investigation - reactionary activities
Yard pedestrian	Personnel authorized to conduct activities outside of pedestrian controls zones. Includes: - kiln attendant - strip stacker - clean up - supervisors - pipe fitters - fire protection - security - maintenance

Table 4. Terms and definitions established and used in workshop continued

Term	Definition
Incident	An ME-PI incident includes all struck by incidents involving mobile equipment and pedestrians (e.g., struck by load, rock, board), not only pedestrian struck by mobile equipment. Incidents also include lumber going through wall (domino or cascade effects).

3.2 Categorization of barriers with respect to the hierarchy of controls

The bow tie analysis was examined to determine the following:

- What is the most common type (ISD, passive engineered, active engineered or administrative)?
- Are there currently any existing ISD barriers?
- Are there administrative barriers with ISD overtones (e.g., minimization of personnel or ME through administrative means)?

To determine the number of barriers identified in the bow tie analysis, a Barrier Type Count report was run in BowTieXP. The barrier count with respect to barrier type categorization is outlined in Table 5[1]. The complete report is found in Appendix A. There were a total of 1138 barriers identified in the bow tie analysis, including degradation factor controls, in both the bow tie for the lumber yard as well as the log yard. Of such,

[1] These values were calculated based on the qualitative categorization of the barriers with respect to the hierarchy of controls. Best efforts were made to accurately quantify the barriers, but there may be some minor error due to limited analysis methods.

851 of them are administrative, 2 are active engineered, 7 are passive engineered, and 1 are ISD.

Table 5. Barrier count with respect to hierarchy of controls

Barrier Type	**Count (Barrier and Degradation Factor Control)**
Administrative	851
Active Engineered	2
Inherently Safer Design	1
Passive Engineered	7
Administrative with ISD Overtones	49
Potential Administrative	156
Potential Active Engineered	5
Potential Passive Engineered	20
Potential Inherently Safer Design	6
Potential Administrative with ISD overtones	41
Total Barrier Count	1138

The barrier type count outlined in Table 5 shows that most current risk reduction strategies are administrative. Administrative barriers are the least preferred and least effective controls as shown in the hierarchy of controls (Figure 2). It is recommended that opportunities to implement barriers higher on the hierarchy (ISD, passive engineered, active engineered) be assessed. Section 3.5 outlines areas for improvement and potential additional controls for consideration that were identified during the workshop.

A challenge that can arise with administrative barriers is when the degradation factor controls are also administrative. This arrangement could lead to some difficulty ensuring the reliability and effectiveness of the barrier as administrative controls are least effective and least preferred as they rely on human input. It is recommended that when

administrative barriers are being used, the degradation factor controls be examined and opportunities to implement degradation factor controls that are higher on the hierarchy (ISD, passive engineered, active engineered) be evaluated and implemented.

Another barrier type seen in Table 5 that was used for categorization was "administrative with ISD overtones." This refers to barriers that have features of one of the ISD principles but are implemented using administrative means. An example of this is optimizing scheduling to minimize ME-PI interactions, such as postponing activities for when forklifts would not be in yard or scheduling kiln activities during less busy and congested times. This is an administrative control with ISD overtones - it is the ISD principle of minimization (reduced/minimized ME traffic during pedestrian activities) achieved through the administrative procedure of scheduling. Other examples of barriers that are administrative with ISD overtones are outlined in Table 6.

Table 6. Overview of administrative barriers with ISD overtones

Administrative Barrier with ISD Overtones	**Additional Information and Discussion**
Designated routes for specific deliveries	Depending on how this alternate route is established, this could be ISD. If the route was designed so that these pedestrians could not interact with ME, it could be ISD. If it is designated using tools like signage and communications, it is administrative.
Scheduled deliveries during off-peak traffic times (e.g., shift change) and communications around preventing additional traffic. Including "Note to Seller" with directions for times of delivery.	This is administrative with ISD overtones - it is minimization (traffic during deliveries is reduced/minimized); the result is reduced ME achieved through administrative means.

Table 5. Overview of administrative barriers with ISD overtones continued

Administrative Barrier with ISD Overtones	Additional Information and Discussion
Use of digital radios to improve coverage	While this may have overtones of ISD (substitution), fundamentally the barrier is still a radio, which is administrative
Scheduled activities to minimize ME-PI interactions. Optimized scheduling and consider postponing activities for when forklifts would not be in yard. Efforts to relieve congestion (e.g., schedule kiln activities during less busy/congested times, or scheduled for off-peak days)	The comment above regarding delivering during off-peak traffic times is relevant for this barrier. This barrier is administrative with ISD overtones. It is the principle of minimization where the result is reduced ME achieved through administrative means
Designated loading zones and designated tarping areas	This is administrative with ISD overtones (moderation) if administrative means (e.g., signage, directions) are used to achieve the designated area and create an increased distance between pedestrians and ME. If the worksite was designed in such a way that ME could not go into a designated pedestrian area, or pedestrian activities could not take place outside of the specified area, this barrier would be ISD (moderation).
Designated loading zones separated from where truck drivers wait	This is administrative with ISD overtones (moderation) if an increased distance between pedestrians in a waiting area and ME is achieved through administrative means (e.g., signage, directions). If the worksite was designed in such a way that drivers could not be within the loading zone, would be ISD (moderation).
Consider relocating muster[2] areas to eliminate ME-PI	This is administrative with ISD overtones (moderation) if the area is designated through administrative means (e.g., signage, training); the result is increased distance between pedestrians and ME.

[2] In the context of mobile equipment, muster areas refer to mobile equipment parking areas (rather than muster stations used in emergency response).

Table 5. Overview of administrative barriers with ISD overtones continued

Administrative Barrier with ISD Overtones	Additional Information and Discussion
Consider if forklifts may park elsewhere rather than at mobile shop (e.g., at other specific areas, such as the planar)	This is administrative with ISD overtones (moderation) if the parking lot is designated through administrative means (e.g., signage, directions); the result is increased distance between pedestrians and ME.
Designated walkway for pedestrians	If a given walkway was able to be designed in such a way that ME did not interact with it, and pedestrians could not leave it or avoid using it, would be ISD (minimization). A marked (designated) crosswalk through an ME path is administrative, not ISD.
Minimized traffic through parking lots (e.g., parking areas not used for through traffic)	If the parking lot was designed in such a way so that through traffic was not possible, would be ISD. If it implemented using signage and communication, it is administrative; ME is reduced using administrative means.
Lumber storage inside is considered a no pedestrian zone Inside storage closed off to perform a given task and temporary barriers are used to indicate that someone is working there (e.g., beams, piping on stands, pickups, sandwich boards) Drivers fuel up during slow time of shift (reduce congestion and backlog at fuel pumps). Minimized/controlled deliveries (on case-by-case basis) to only fuel, parts, lube and grease, and other bulk consumables; other deliveries are sent to warehouse and picked up.	These are administrative barriers with ISD overtones (minimization); the result is reduced ME traffic in a given area using administrative means.

Table 5. Overview of administrative barriers with ISD overtones continued

Administrative Barrier with ISD Overtones	Additional Information and Discussion
Single direction traffic (i.e., pedestrians expecting vehicle to come in one way)	Administrative with ISD overtone of the principle of simplification. If the space was designed in such a way that it would be impossible for ME to go in the wrong way and pedestrians are not in movement path, would be ISD.

There was one barrier identified that was categorized as ISD ("Consider yard design of where personnel are on the ground; avoid stacking in area") in the preliminary bow tie analysis work on the ME-PI hazard in log yard activities. This demonstrates that there is the need to examine and assess ISD options. One approach to this is conducting an ISD workshop (Disclaimer: this is a service provided by the author, Obex Risk Ltd.). An ISD workshop would involve examining the worksite and assessing opportunities to identify ISD options and apply minimization, substitution, moderation, and simplification.

3.3 Frequently used barriers and degradation factors

The bow tie analysis was examined to determine what barriers are most frequently used, as well as the associated degradation factors. Using the BowTieXP reports, a "Flat barrier report with customizable columns" was run, which produced an Excel spreadsheet. The barriers were sorted and tabulated by Excel. The most frequently used barriers and associated degradation factors are outlined in Table 7. They include:

- Close off sections of the yard (using barriers - beams, piping on stands, pickups, sandwich boards) to perform that task and indicate that someone is working there,
- Direction and training to remove hearing protection while working in yard, and
- Wearing of high-visibility PPE and ensuring in good working order.

Each of these barriers are administrative. Figure 3 to 5 are barrier overviews of these most frequently used barriers. Note that barriers that appear with the orange marking were added by B. Laturnus following the workshop. These additions were based on the information provided in other sections of the bow tie analysis.

It is also important to note that many barriers can be degraded by external factors including poor road conditions (e.g., slippery conditions increasing stopping distance, or potholes that may cause load upset) and environmental conditions (e.g., heavy snow on ground, nighttime, bright sun, fog, rain) which can reduce visibility and make loads slippery.

Table 7. Most frequently used barriers in ME-PI bow tie

Barrier	Barrier Count	Degradation Factor
Close off sections of the yard (using barriers - beams, piping on stands, pickups, sandwich boards) to perform that task and indicate that someone is working there	18	ME not available to relocate barriers as pedestrian move areas. Closes off larger section of yard and could create scheduling problems with areas. Could increase congestion in other areas. Cross-shift communication breakdown - shift change, ME does not know what activities are being performed in area. Barrier not available or cannot be found or broken. Barricades difficult to see due to weather conditions (e.g., snow). ME moves barricade and not authorized.
Direction and training to remove hearing protection while working in yard.	7	Hearing protection not removed. Hearing loss/impairment. Hearing protection needed to perform task.
Wearing of high-visibility PPE and ensuring in good working order	4	Pedestrian not wearing high-visibility or not effective anymore (worn out or dirty)

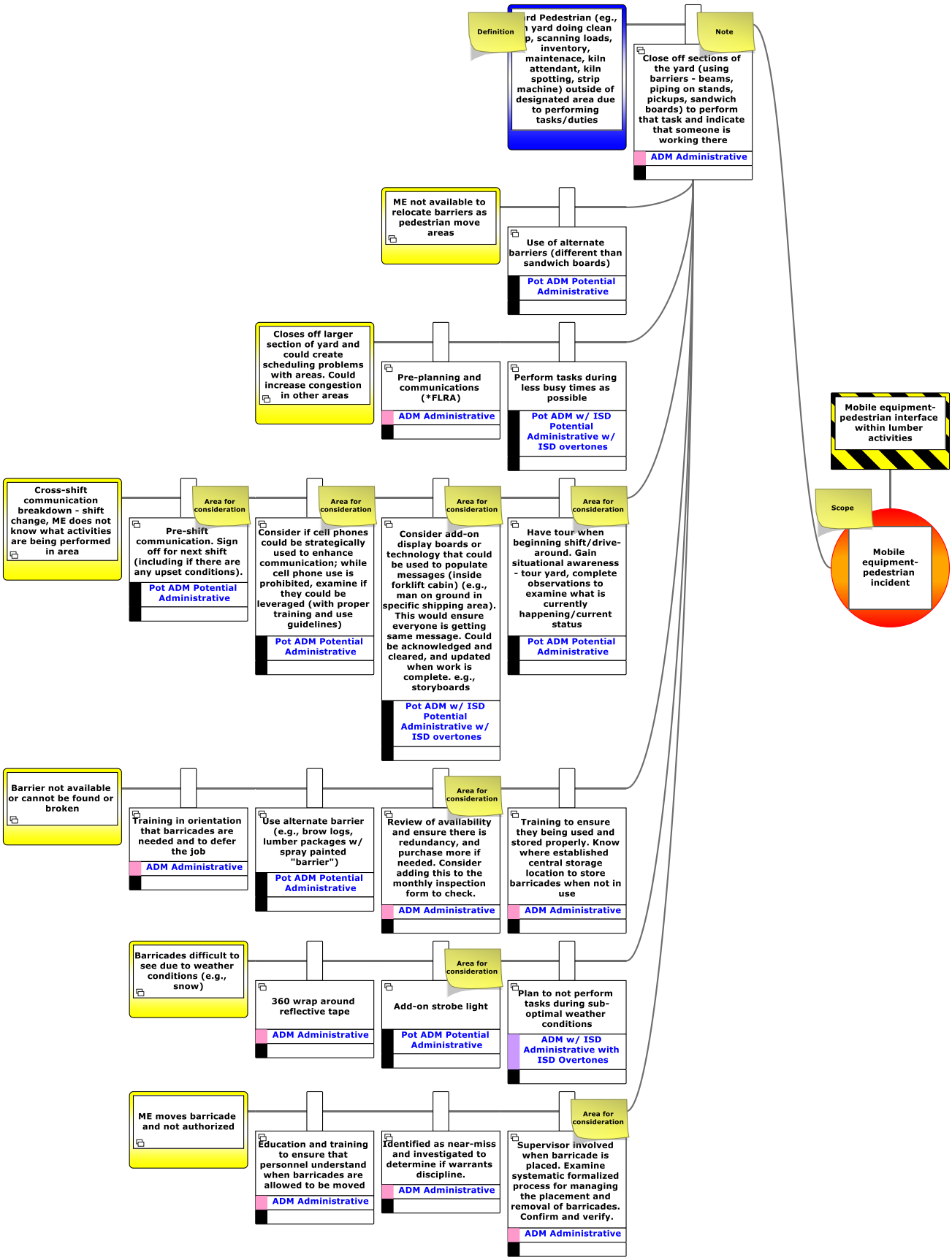

Figure 3. Barrier overview of the frequently used barrier "Close off sections of the yard"

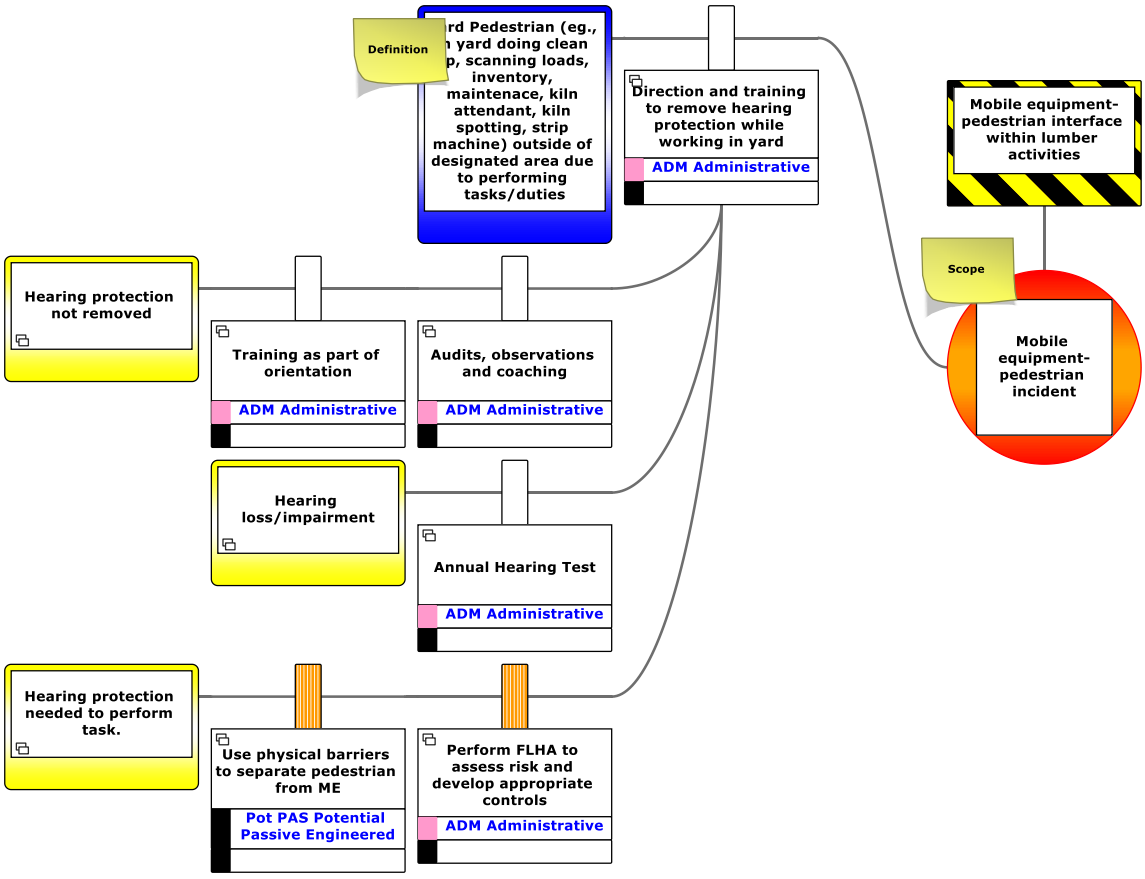

Figure 4. Barrier overview of the frequently used barrier "Direction and training to remove hearing protection while working in yard"

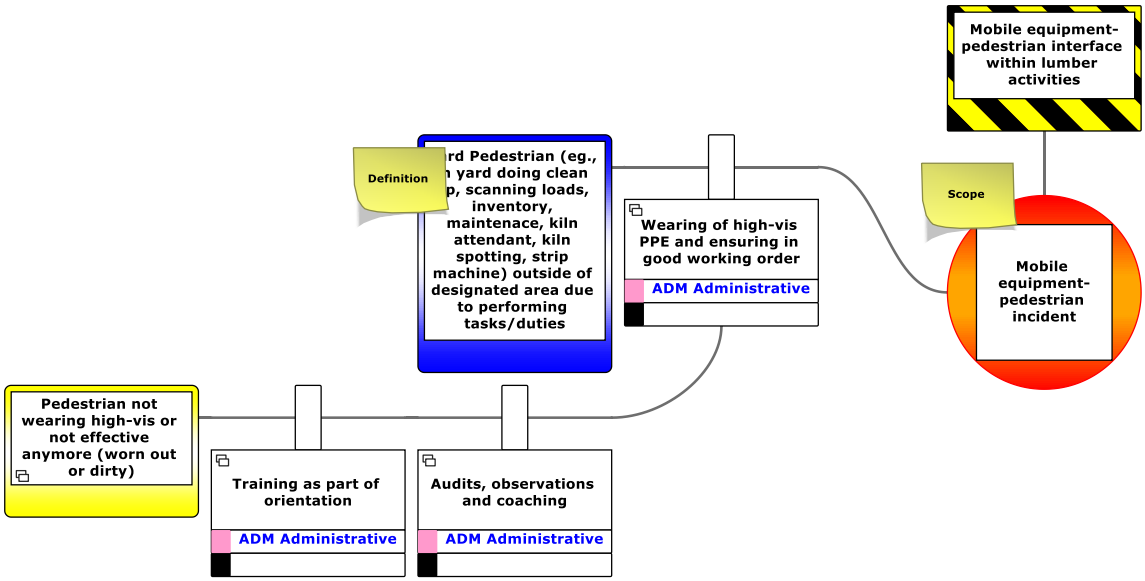

Figure 5. Barrier overview of the frequently used barrier "Wearing of high-visibility PPE and ensuring in good working order"

3.4 Quantifying and categorizing threats

The threats identified in the lumber yard were examined to improve understanding of the types of pedestrians (based on general location and duties) and areas most involved with ME-PI. There were 28 different threats identified in the bow tie analysis for the lumber activities; this large number of threats could be attributed in part due to the large number of different pedestrians and mobile equipment performing different tasks. The ME-PI hazard is heavily influenced by human factors and the actions of both ME operators and pedestrians, which also attributes to the complexity of the analysis.

In Table 8, an overview of the threats identified in the lumber yard are examined with respect to the type of pedestrian and type of threat. In Table 8, "ME threats" refers a threat that is explicitly involving a named piece of ME (e.g., ME is being operated and poses a risk to any pedestrian in the area). "Pedestrian threats" refer to a threat explicitly involves the presence of a pedestrian in the specified area that could be affected by any ME that could be in the area. The types of pedestrians that are most affected based on the frequency of appearance in Table 8 are:

- Yard pedestrian,
- ME operators becoming pedestrians,
- Mobile shop pedestrians, and
- Kiln personnel.

To visualize and improve understanding of the specific areas of the sawmills that are most impacted by the ME-PI hazard, it is recommended that each operation review their site plan map and identify the locations of the threats listed in Table 8 in their facilities.

Table 8. Evaluation of threats identified in lumber yard with respect to type of pedestrian and type of threat

Threat	ME Threat	Pedestrian Threat	Type of Pedestrian Involved
Yard Pedestrian (e.g., in yard doing clean up, scanning loads, inventory, maintenance, kiln attendant, kiln spotting, strip machine) outside of designated area due to performing tasks/duties		X	Yard
Pedestrian in yard performing duties during upset conditions (e.g., millwright, cleanup, spilled load, electrician, heavy duty mechanic, maintenance, pipefitter, etc.)		X	Yard
Kiln spotter conducting kiln activities	X	X	Kiln
Contractors (service contractors working on rail, mechanical, electrical, CN Rail, renovators)	X	X	Contractor
Contractors for longer term capital projects	X	X	Contractor
Service providers/vendors ME (e.g., delivery to mobile shop, fuel, custodians, parts)	X	X	Contractor
Residual truck drivers (sawdust, chips) becoming pedestrians when performing tasks (e.g., tarping station, ropes, loading at bins, discussions while entering office)	X	X	ME operator becoming pedestrian
Forklift operators become pedestrians when getting out of forklift to perform duties, like blocking, setting up the load, dropped board pick up	X	X	ME operator becoming pedestrian
Lumber truck drivers becoming pedestrians (during lumber truck loading, tarping)	X	X	ME operator becoming pedestrian
Pedestrians in car loading area (finished lumber onto railcars) (e.g., scanning, strapping, tallyman)	X	X	Car loading
Pedestrians near rails performing maintenance	X	X	Rail
Unauthorized personnel passing at rail	X	X	Rail

Table 7. Evaluation of threats identified in lumber yard with respect to type of pedestrian and type of threat continued

Threat	ME Threat	Pedestrian Threat	Type of Pedestrian Involved
Pedestrian in yard from public (e.g., walking trails)		X	Unauthorized
During an evacuation (e.g., fire, other emergency), all personnel would be leaving at nearest exit into the yard		X	All personnel onsite
Pedestrian activity at mobile shop, pre-and post-shift, fueling, mechanics, inspections, steam cleaning, tire deliveries, adjacent parking lot		X	Mobile shop pedestrians
Wash bay area (blowdown activities) involving forklifts and all ME	X	X	Personnel in wash bay area
Internal Company Authorized Site Visitors		X	Visitor
External Authorized Site Visitors for Tour (e.g., Aon, WorkSafeBC, vendors)		X	Visitor
Forklift conducting activities (e.g., pulling load) and causes upset condition (e.g., knocks over load) and pedestrian (e.g., in bay area) is in area	X		Yard
Personnel could have medical emergency/be in medical distress and could have runaway ME	X		Could affect anyone who operates ME onsite
Employee parking lots: snow clearing, sanding, chip trucks - could be main access to finished yard	X	X	All personnel onsite
ME performing other tasks outside of routine/normal operating areas (intermittent/non-routine activities) (e.g., snow clearing, sanding, graders, deliveries, water trucks for dust mitigation)	X	X	All personnel onsite (since these are activities that take place across site)
Mechanical malfunction (brake failure, driveshaft, e.g.) and that causes a runaway forklift	X		Could affect anyone onsite
Pedestrian crossing to walk from one area to another in designated walkway (from parking lot to planar)		X	Could affect anyone onsite

Table 7. Evaluation of threats identified in lumber yard with respect to type of pedestrian and type of threat continued

Threat	ME Threat	Pedestrian Threat	Type of Pedestrian Involved
Residual trucks driving through yard	X		Yard
Lumber or consumable storage indoors/sheds - pedestrians inside performing activities (e.g., transferring wrap, kiln strips, tallying)		X	Indoors
Small forklifts inside building	X		Indoors
High rough or finished inventories reduces visibility and maneuverability in yards	X	X	Yard

3.5 Summary of areas for improvement identified during workshop

This section summarizes other findings from the workshop including identified challenges and areas for improvement that were identified by workshop team. There were several potential areas for improvement to improve risk reduction that were discussed during the workshop. Areas for consideration include:

- At the mobile shop, reconfigure areas to have designated walkways.
- Create more room to have parking along wall, as well as away from pedestrian areas.
- Re-organize aspects of the site to make it easier to establish eye contact and facilitate more predictable behaviour.
- Move less frequently used equipment (such as spares) and create priority parking; optimize and prioritize the space for use.
- Look at opportunities to redesign and re-engineer to reduce mobile equipment and pedestrian interaction.
- Consider where muster stations (mobile equipment parking areas) are located to help reduce risk.
- Consider the use of a photo-eye system that illuminates a light path on the floor indoors.

Other general considerations and areas that could be examined to improve include:

- For designated parking areas, they should be examined to ensure they are level and flat.

- An evaluation to avoid a given area if a truck is in the vicinity should be completed.
- For the threat “Residual truck drivers (sawdust, chips) becoming pedestrians when performing tasks,” and barrier “SWPs: driver in designated area or remain in truck (depending on company policy),” consider ways to address challenges associated with the degradation factor “Drivers can show up onsite unannounced to pick up, can be companies unfamiliar with sites. Buyer of chips coordinates drivers, and not communicated with plant.” Additionally, confirm what the driver should do during loading and determine if the SWP either allows them to be on ground or in cab.
- Consider changing procedure for wearing of high-visibility apparel; a potential option is that all PPE is required beyond a certain point, which would include having to wear it in designated walkways.
- Consider decreasing or updating the posted speed limit to be more appropriate for high traffic areas (e.g., less than 20km/hr).
- For the threat “Mechanical malfunction (e.g., brake failure, driveshaft) that causes a runaway forklift,” a potential barrier for consideration is “Hydraulic lockout (on some equipment) if available.”

Potential barriers and additional controls that could be explored and considered were documented are summarized in Table 9 to 12 which are organized with respect to the hierarchy of controls. Potential barriers outlined in Table 9 to 12 that were identified include ISD, passive engineered, active engineered, and administrative controls. It is

recommended that operations consider ISD options first, followed by passive engineered, active engineered, and administrative.

Potential ISD barriers that were identified in the workshop are outlined in Table 9 with respect to the ISD principle.

Table 9. Potential ISD options identified in ME-PI bow tie workshop

Barrier	ISD Principle
Consider self-shading windshields - sunlight/photo sensitive to darken	Substitution
Engineering to redesign and re-route to re-locate pedestrian activity at mobile shop, mill entrances, as well at wash bay area performing blowdown activities	Moderation or minimization depending on approach/implementation
Pedestrian activity at mobile shop; designated walkway for pedestrians - more space would allow for a redesign so pedestrians can go directly to equipment	Moderation
Complete inventory check and remove unnecessary equipment that is not needed	Minimization
Examine relocation of loading wall to create physical distance between ME and pedestrians	Moderation

Potential passive engineered barriers that were identified in the workshop are outlined in Table 10.

Table 10. Potential passive engineered controls identified in ME-PI bow tie workshop

Barrier	Comment
Consider adding speed bumps in area to slow down ME	
Consider designing an area on equipment to keep or store wheel chocks so wheel chocks are available for use to prevent runaway equipment should there be a mechanical failure.	Note: The use of wheel chocks is administrative (requires human action)

Table 10. Potential passive engineered controls identified in ME-PI bow tie workshop continued

Barrier	Comment
Use of protective physical barriers to shield and separate pedestrians from ME and alert ME operators of personnel in area. For example, consider a physical barrier for truck on wall.	(Note: these passive engineered physical barriers are different than barriers like sandwich boards or pylons that are placed as needed by personnel, which are administrative. These protective physical barriers are added-on and may regarded as permanent – e.g., wall, cement blocks - and do not require human input beyond installation).

Potential active engineered barriers that were identified in the workshop are outlined in Table 11.

Table 11. Potential active engineered controls identified in ME-PI bow tie workshop

Barrier	Comment
Automatic gates and lights	This is a degradation factor control for the barrier "Gates (and maybe add-on activated lights" for the threat "Pedestrian crossing to walk from one area to another in designated walkway (from parking lot to planar)"
Speed governors applied to some equipment	This is a degradation factor control for the barrier "Designated crossing area (people are told to cross there)" for the threat "Pedestrian crossing to walk from one area to another in designated walkway (from parking lot to planar)"

Potential administrative barriers that were identified in the workshop are outlined in Table 12.

Table 12. Potential administrative controls identified in ME-PI bow tie workshop

Barrier	Threat or Consequence	Comment
Consider photo eye system - automatic light or sound activated	This is a degradation factor control for the barrier "Gates (and maybe add-on activated lights" for the threat "Pedestrian crossing to walk from one area to another in designated walkway (from parking lot to planar)"	This is an administrative control as the photo eye system does not stop pedestrians or forklifts – the system may increase driver awareness, but aversive operator action is required.
Install flashing speed detector/radar display	This is a degradation factor control for the barrier "Designated crossing area (people are told to cross there)" for the threat "Pedestrian crossing to walk from one area to another in designated walkway (from parking lot to planar)"	This is an administrative control as the system does not stop pedestrians or forklifts – the system may increase awareness, but human action is required.
Include in SWP to remove vehicle key but keep running light	Pedestrian in yard performing duties during upset conditions (e.g., millwright, cleanup, spilled load, electrician, heavy duty mechanic, maintenance, pipefitter, etc.)	This is a degradation factor control for the barrier "Park pick-up truck or forklift with strobe light flashing in bay where task being performed"

Table 12. Potential administrative controls identified in ME-PI bow tie workshop continued

Barrier	Threat or Consequence	Comment
Consider using technology that can indicate the operator is out of the machine and send notice to other operators in the area at the push of a button	This is a degradation factor control for the barrier "Ensure that forklift operator calls other ME operators on radio to inform they are out of their machine doing work" for the threat "Forklift operators become pedestrians when getting out of forklift to perform duties, like blocking, setting up the load, dropped board pick up)"	
Use an audible indication manually activated by pedestrian that would send sound to forklift operator	Pedestrian crossing to walk from one area to another in designated walkway (from parking lot to planar)	This is a degradation factor control for the barrier "Designated crossing area (people are told to cross there)"
Use of wheel chocks and/or pylons	Pedestrian in yard performing duties during upset conditions (e.g., millwright, cleanup, spilled load, electrician, heavy duty mechanic, maintenance, pipefitter, etc.)	This is a degradation factor control for the barrier "Park pick-up truck or forklift with strobe light flashing in bay where task being performed"
Add annual orientation responsibilities to person responsible for lumber trucks	Lumber truck drivers becoming pedestrians (during lumber truck loading, tarping)	This is a degradation factor control for the barrier "Annual orientations"

Table 12. Potential administrative controls identified in ME-PI bow tie workshop continued

Barrier	Threat or Consequence	Comment
Add annual tour to SMS calendar	Harm to personnel: Injury or death of personnel	This is a degradation factor control for the barrier "First Responders routinely visit site to become familiar (regulated at least annually)"
Consider additional communications, like sandwich board, that indicates pedestrian is on ground	Lumber truck drivers becoming pedestrians (during lumber truck loading, tarping)	
Consider use of sandwich boards (e.g., high-visibility signage to communicate personnel are in area and can be easily relocated as activities shift position in yard)	A number of threats involving contractor activities, upset conditions, kiln spotter activities, pedestrians performing tasks like transferring wrap, kiln strips, tallying.	
Consider add-on strobe light	A number of threats involving contractor activities, upset conditions, kiln spotter activities, pedestrians performing tasks like transferring wrap, kiln strips, tallying.	This is a degradation factor control for the barrier "Close off sections of the yard (using barriers - beams, piping on stands, pickups, sandwich boards) to perform that task and indicate that someone is working there"
Develop alternate check in location for service providers (mill stores)	Service providers/vendors ME (e.g., delivery to mobile shop, fuel, custodians, parts)	This is a degradation factor control for the barrier "Escorted by personnel that are responsible for contractor. Increased interaction and examination prior to coming onsite"

Table 12. Potential administrative controls identified in ME-PI bow tie workshop continued

Barrier	Threat or Consequence	Comment
Consider add-on display boards or technology that could be used to populate messages (inside forklift cabin) (e.g., man on ground in specific shipping area). This would ensure everyone is getting same message. Could be acknowledged and cleared and updated when work is complete. (e.g., storyboards)	A number of threats involving contractor activities, upset conditions, kiln spotter activities, pedestrians performing tasks like transferring wrap, kiln strips, tallying.	This is a degradation factor control for the barrier "Close off inside storage (using barriers - beams, piping on stands, pickups, sandwich boards) to perform that task and indicate that someone is working there"
Consider covered waiting area instead; lumber truck drivers enter secured area while their truck is being loaded	Lumber truck drivers becoming pedestrians (during lumber truck loading, tarping)	This is a degradation factor control for the barrier "Additional communications, like sandwich board, that indicates pedestrian is on ground"
Consider if cell phones could be strategically used to enhance communication; while cell phone use is prohibited, examine if they could be leveraged (with proper training and use guidelines)	A number of threats involving contractor activities, upset conditions, kiln spotter activities, pedestrians performing tasks like transferring wrap, kiln strips, tallying.	This is a degradation factor control for the barrier "Close off inside storage (using barriers - beams, piping on stands, pickups, sandwich boards) to perform that task and indicate that someone is working there"
Consider limiting forklift to have right of way to specific areas of yard. Give workers right of way in crosswalks.	A number of threats involving contractor activities, upset conditions, kiln spotter activities, pedestrians performing tasks like transferring wrap, kiln strips, tallying.	This is a degradation factor control for the barrier "Coaching and direction to communicate ongoing work by ME in area and communication with ME"

Table 12. Potential administrative controls identified in ME-PI bow tie workshop continued

Barrier	Threat or Consequence	Comment
Consider providing a "cheat sheet" to new hires that explains what the terminology means	A number of threats involving contractor activities, upset conditions, kiln spotter activities, pedestrians performing tasks like transferring wrap, kiln strips, tallying.	This is a degradation factor control for the barrier "Ensuring that proper radio contact is used and established; call in"
Consider providing site map to new hires and visitors to help educate regarding zones and areas and key information needed and ensure personnel are using same language	A number of threats involving contractor activities, upset conditions, kiln spotter activities, pedestrians performing tasks like transferring wrap, kiln strips, tallying.	This is a degradation factor control for the barrier "Ensuring that proper radio contact is used and established; call in"
Consider providing radio training in orientation	A number of threats involving contractor activities, upset conditions, kiln spotter activities, pedestrians performing tasks like transferring wrap, kiln strips, tallying.	This is a degradation factor control for the barrier "Ensuring that proper radio contact is used and established; call in"
Plan a tour/drive-around when beginning shift. Gain situational awareness - tour yard, complete observations to examine what is currently happening and understand current status.	A number of threats involving contractor activities, upset conditions, kiln spotter activities, pedestrians performing tasks like transferring wrap, kiln strips, tallying.	This is a degradation factor control for the barrier "Close off sections of the yard (using barriers - beams, piping on stands, pickups, sandwich boards) to perform that task and indicate that someone is working there"

Table 12. Potential administrative controls identified in ME-PI bow tie workshop continued

Barrier	Threat or Consequence	Comment
Improve lighting	Kiln spotter conducting kiln activities	This is a degradation factor control for the barrier "Spotter conducts work while in forklift"
Improve signage directing drivers	Residual trucks driving through yard	This is a degradation factor control for the barrier "Maps"
Enhance pre-shift communication. Sign off for next shift (including if there are any upset conditions).	A number of threats involving contractor activities, upset conditions, kiln spotter activities, pedestrians performing tasks like transferring wrap, kiln strips, tallying.	This is a degradation factor control for the barrier "Close off sections of the yard (using barriers - beams, piping on stands, pickups, sandwich boards) to perform that task and indicate that someone is working there"
Review of barrier availability and ensure there is redundancy, and purchase more if needed. Consider adding this item to the monthly inspection form to check.	Pedestrians in car loading area (finished lumber onto railcars) (e.g., scanning, strapping, tallyman)	This is a degradation factor control for the barrier "Close off sections of the yard (using barriers - beams, piping on stands, pickups, sandwich boards) to perform that task and indicate that someone is working there"
Consider adding signage stating and reminding that ME has right of way in a given area	Pedestrian activity at mobile shop, pre-and post-shift, fueling, mechanics, inspections, steam cleaning, tire deliveries, adjacent parking lot	This is a degradation factor control for the barrier "Designated walkway for pedestrians"

Table 12. Potential administrative controls identified in ME-PI bow tie workshop continued

Barrier	Threat or Consequence	Comment
Consider developing a safety video including drone footage; provide in shipping office, beforehand on tablet, or online. Provided if new driver.	A number of threats including: - External Authorized Site Visitors for Tour (e.g., Aon, WorkSafeBC, vendors), - Residual trucks driving through yard, and - Lumber truck drivers becoming pedestrians (during lumber truck loading, tarping	This is a degradation factor control for the barrier "Safe work procedures (SWPs)"
Consider updating snow removal procedures to indicate where snow piles be placed	ME performing other tasks outside of routine/normal operating areas (intermittent/non-routine activities) (e.g., snow clearing, sanding, graders, deliveries, water trucks for dust mitigation)	

Table 12. Potential administrative controls identified in ME-PI bow tie workshop continued

Barrier	Threat or Consequence	Comment
Review and consider SWPs: directions for driver to stay in front of truck in designated area (could be rest area) or remain in truck (depending on company policy)	Lumber truck drivers becoming pedestrians (during lumber truck loading, tarping)	
Use alternate barrier (e.g., brow logs, lumber packages w/ spray painted "barrier")	A number of threats involving contractor activities, upset conditions, kiln spotter activities, pedestrians performing tasks like transferring wrap, kiln strips, tallying.	This is a degradation factor control for the barrier "Close off sections of the yard (using barriers - beams, piping on stands, pickups, sandwich boards) to perform that task and indicate that someone is working there"
Consider wearing of high-visibility apparel	Pedestrian activity at mobile shop, pre-and post-shift, fueling, mechanics, inspections, steam cleaning, tire deliveries, adjacent parking lot	This is a degradation factor control for the barrier "Designated walkway for pedestrians"
Use QR (quick response) codes for onboarding and site visits	Residual truck drivers (sawdust, chips) becoming pedestrians when performing tasks	This is a degradation factor control for the barrier "SWPs: driver in designated area or remain in truck (depending on company policy)"
Seek capital to re-route pedestrians to a more practical crossing point. Seek 3rd party or outside set of eyes to help identify better route for through traffic	Pedestrian in yard performing duties during upset conditions	These are degradation factor controls for the barriers "Consider alternate routes, if possible, particularly during peak traffic times" and "Minimize traffic through parking lots (do not use parking areas for through traffic"

Potential administrative barriers with ISD overtones that were identified in the workshop are outlined in Table 13.

Table 13. Potential administrative barriers with ISD overtones identified in ME-PI bow tie workshop

Barrier	Comment
Consider looking for different crossing point that has less traffic; elevate or relocate.	If it was elevated and the potential for ME-pedestrian interaction was eliminated, would be ISD (minimization).
Consider improved electronic maintenance tracking system and automation of process for pre-trip inspections to prevent mechanical malfunction of ME. An improved tracking system may address current challenges with interface of machine and in-house program.	This is considering the principle of simplification and reducing human error by improving maintenance system.
Consider add-on display boards or technology that could be used to populate messages (inside forklift cabin) (e.g., man on ground in specific shipping area). This would ensure everyone is getting same message; could be acknowledged, cleared, and updated when work is complete, similar to storyboards.	This is considering the principle of simplification and reducing human error by improving communication interfaces.

Following the workshop, there were areas identified that require some additional input from industry including:

- Analysis of the threat “Unauthorized personnel passing at rail,”
- Additional input on the barrier “Trucks escorted to loading area” to identify if and how this barrier is relevant for the threat “Lumber truck drivers becoming

pedestrians (during lumber truck loading, tarping) “; describe the barrier and how it prevents drivers from becoming pedestrians, and

- Due to time constraints, the mitigation barriers for the consequences were not analyzed with respect to degradation factors and controls; based on previous bow tie analyses completed by the wood pellet industry, examples of potential degradation factors and controls were added (by B. Laturnus). Additional input is needed from the sawmill stakeholders to complete the analysis of the mitigation barriers.

4 LITERATURE REVIEW OF ME-PI HAZARDS IN OTHER INDUSTRIES

A literature review on mobile equipment and pedestrians in industrial settings was completed to learn about how other industries are addressing and managing the ME-PI risk and identify any potential approaches for risk reduction in the sawmill application. Using Google Scholar, “industrial mobile equipment pedestrian safety” was searched and publications from 2000 to present were included.

Wilbanks et al. (2022) studied workers’ experience and perception of motion warning devices on forklifts. The study considered tonal backup alarms as well as blue safety lights. While there was no significant difference in workers’ satisfaction with these devices, it was found that having forward motion warning devices is also desired. The study also noted that broadband alarms should be further investigated, as they regarded as a superior alarm technology. The preference of broadband alarms over tonal alarms is also outlined in WorkSafeNB (2018). In the ME-PI bow tie workshop, the type of alarm was not specified (whether it is tonal or broadband). It is recommended that operations determine if the current ME alarms use tonal technology, and if so, investigating and considering broadband technology for this application. This is an administrative control; is it requires human input through the interpretation and reaction of the pedestrian.

Guenther and Salow (2012) outline an operator assistant system that includes collision avoidance, guidance for road departure, reversing and path following. The system outlined uses audible warnings for the operator to trigger a reaction. This is an administrative control as it requires action on the part of the ME operator.

Horberry et al. (2003) outline a number of traffic engineering changes that could be considered to address ME-PI risk. These measures have been categorized in Table 14 with respect to the hierarchy of controls.

Table 14. Traffic engineering approaches from Horberry et al. (2003) categorized with respect to the hierarchy of controls.

Control	Type of Control
Segregate and separate ME and pedestrians by closing off certain areas to either ME or pedestrians.	ISD or administrative (This depends on the manner by which areas are closed off – if it is achieved by designing areas so it is impossible for the ME to enter the pedestrian space and vice versa, it is ISD. If it is achieved by procedural means, it is administrative.)
Reduce pinch points, which would create more separation between ME and pedestrians (e.g., remove obstructions from aisles, widen roadways and intersections).	ISD (moderation)
Redesign pedestrian workspace to reduce ME traffic (e.g., replace forklift by adding hand pallet movers, have temporal separation where forklifts cannot enter when pedestrians are present).	ISD (substitution) and administrative (Replacing any ME with a pedestrian operated activity is substitution. Scheduling so ME and pedestrians are not in the workspace at the same time is administrative).
Implement grade separation (e.g., pedestrians use elevated paths and are separated from ME).	ISD (minimization)
Install barriers or guardrails between ME and pedestrians if the same route must be used.	Passive engineered
Clearly mark walkways and ensure unobstructed.	Administrative

HSE (2012) outlines a number of measures to incorporate, many of which were identified during the bow tie analysis workshop. This publication recommends mapping ME and

pedestrian movements and paths on a plan, which would clarify and visualize where pedestrians and ME interact. This may be a process that a facility may want to conduct, as it may help identify any opportunities to re-route traffic or improve site design.

Michael and Gorucu (2020) discuss injuries caused by powered industrial trucks (PITs), which includes pallet jacks and forklifts. While training and safe work procedures is identified as an important measure, an emphasis is placed on improved layout planning for sites.

5 RECOMMENDATIONS

Based on the evaluation completed within the scope of this overview report, additional areas for further work in ME-PI risk reduction include the following:

- Finish bow tie analysis of the log yard (hazard “Mobile equipment-pedestrian interface within log activities”).
- Complete a bow tie analysis on evaluating the hazard “Mobile equipment-pedestrian interface within production and storage indoors.”
- Evaluate the threat associated with high material inventory (“High rough or finished inventories reduces visibility and maneuverability in yards”) that was identified by a workshop participant.
- Consider the areas for improvement outlined in Section 3.5 and examine the implementation and feasibility of ISD options first, followed by passive engineered, active engineered, and administrative controls.
- Complete an ISD workshop to identify opportunities to incorporate ISD into facilities.
- Conduct research into best practices and approaches used in other sectors and industries (e.g., airports, construction, mining, trucking, and warehousing) where the ME-PI is very prevalent to identify lessons learned and any strategies that could be evaluated and/or adopted (FAA, 2002).

- Develop a site map of ME-PI risk, comparable to a dust accumulation diagram used in combustible dust hazard management. Use colour coding to indicate site areas that have minimal, moderate, and high ME-PI risk.

6 CONCLUSIONS

The mobile equipment pedestrian interface hazard in sawmills was examined using bow tie analysis. There were 28 different threats identified in the bow tie analysis for the lumber activities that involve a broad range of different pedestrians and mobile equipment operators. Most barriers currently being used to manage ME-PI risk are administrative controls; there is an opportunity to explore the other controls that are higher in the hierarchy of controls, namely ISD, active engineered and passive engineered. Frequently used barriers are administrative controls such as closing off sections of the yard while personnel are working in the area, procedures for the removal of hearing protection while working in the yard and wearing of high-visibility PPE. During the workshop, there were numerous areas for improvement that were identified and potential approaches to reduce ME-PI risk were discussed, including reconfiguring aspects of the site to improve movement paths for both pedestrians and mobile equipment. Recommendations for future work include completing bow tie analyses for log yard activities, as well as production and storage indoors.

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APPENDIX A: BARRIER TYPE COUNT REPORT

Table A-1. Barrier type count report from BowTieXP with barrier type based on the hierarchy of controls for the ME-PI bow tie analysis

ME-PI	<No Value Assigned>	Administrative	Active Engineered	Inherently Safer Design	Passive Engineered	Administrative with ISD Overtones	Potential Administrative	Potential Active Engineered	Potential Passive Engineered	Potential Inherently Safer Design	Potential Administrative w/ ISD overtones
Mobile equipment-pedestrian interface within lumber activities / Mobile equipment-pedestrian incident											
Threats											
Mechanical malfunction (brake failure, driveshaft, e.g.) and that causes a runaway forklift		42	2						1		1
Pedestrian crossing to walk from one area to another in designated walkway (from parking lot to planar)		57			5	7	6	4	1	2	10
Yard Pedestrian (e.g., in yard doing clean up, scanning loads, inventory, maintenance, kiln attendant, kiln spotting, strip machine) outside of designated area due		71				3	17		2		7

to performing tasks/duties											
Pedestrian in yard performing duties during upset conditions (e.g., millwright, cleanup, spilled load, electrician, HD mechanic, maintenance, pipefitter, etc.)		71				3	22		2		5
Pedestrian in yard from public (e.g., walking trails)					1			1			
Contractors (service contractors working on rail, mechanical, electrical, CN Rail, renovators)		40				2	11		2		2
Contractors for longer term capital projects		34				2	10		1		1
Service providers/vendors ME (e.g., delivery to mobile shop, fuel, custodians, parts)		37				1	1				1
Residual truck drivers (sawdust, chips) becoming pedestrians when performing tasks (e.g., tarping station, ropes, loading		27				2				1	2

at bins, discussions while entering office)											
Pedestrians in car loading area (finished lumber onto railcars) (e.g., scanning, strapping, tallyman)		13				1	8		1		1
Pedestrians near rails performing maintenance		14				1	7		1		1
Unauthorized personnel passing at rail		21				1	4				
Forklift operators become pedestrians when getting out of forklift to perform duties, like blocking, setting up the load, dropped board pick up)		26				1	5				
Lumber truck drivers becoming pedestrians (during lumber truck loading, tarping)		20				1	5				2
Residual trucks driving through yard		31				1	7				
During an evacuation (e.g., fire, other emergency), all personnel would be leaving at nearest exit into the yard		11				1					

ME performing other tasks outside of routine/normal operating areas (intermittent/non-routine activities) (e.g., snow clearing, sanding, graders, deliveries, water trucks for dust mitigation)		11					1				
Pedestrian activity at mobile shop, pre-and post-shift, fueling, mechanics, inspections, steam cleaning, tire deliveries, adjacent parking lot		46				6	4		2	2	5
Employee parking lots: snow clearing, sanding, chip trucks - could be main access to finished yard		6				1	2				
Wash bay area - blowdown activities - forklifts and all ME		15				3			1	1	
Internal Company Authorized Site Visitors		10					2				
External Authorized Site Visitors for Tour (e.g., AON, WSBC, vendors)		12					2				

Small forklifts inside building											
Lumber or consumable storage indoors/sheds - pedestrians inside performing activities (e.g., transferring wrap, kiln strips, tallying)		12				3	7				1
Forklift conducting activities (e.g., pulling load) and causes upset condition (e.g., knocks over load) and pedestrian (e.g., in bay area) is in area		59				3	18		2		2
Kiln spotter conducting kiln activities		74				3	12		3		
Personnel could have medical emergency/be in medical distress and could have runaway ME		32				2	4		1		
High rough or finished inventories reduces visibility and maneuverability in yards											
Consequences											

Harm to personnel: Injury or death of personnel		26					1				
Business impacts: reputation, employee morale, employee retention, business interruption		26									
Mobile equipment-pedestrian interface within production and storage indoors / Mobile equipment-pedestrian incident											
Threats											
New Threat											
Mobile equipment-pedestrian interface within log activities / Mobile equipment-pedestrian incident											
Threats											
Log truck drivers getting out of truck and becoming pedestrians (e.g., pulling down stakes, trailer hoists, may be getting out while being loaded/unloading areas, dewrapping, banding stations,		4		1		1					

removing flags, walk around checks)											
Scaler and helper banding the load and log truck driving off											
Pedestrian activity at mobile shop, pre-and post-shift, fueling, mechanics, inspections, steam cleaning, tire deliveries, adjacent parking lot											
Sample yard (scalers, loaders and Letourneau(s)/Wagner (large loader)). Proximity in sample yard: spreading sample and pedestrian nearby skid											
Pedestrians coming into log yard (daily inspections, inventory, maintenance, supervisors doing observations)											
ME performing other tasks outside of routine/normal operating areas											

(intermittent/non-routine activities) (e.g., snow clearing, sanding, graders, deliveries, water trucks for dust mitigation, dump trucks, gravel trucks, low bed)											
Internal Company Authorized Site Visitors (incl. log buyers)											
External Authorized Site Visitors for Tour (e.g., AON, WSBC, vendors, log buyers)											
Loaders: ME becoming pedestrians - greasing, pull cables											
Log yard cleanup - drive around in trucks, but getting in and out of truck to pick up debris, log chunks											
Overflow inventory from lumber yard - ME less familiar with area driving through and may be less aware of activities in area											
Moving trucks in log yard (residual, log,											

civilians/public using scale)											
Service providers/vendors (e.g., delivery to mobile shop, fuel, custodians, parts,)											
In sample yard: spreading sample and pedestrian nearby skid											
Wash bay area - blowdown activities - logging trucks and other ME											
Mechanical malfunction (brake failure, driveshaft, e.g.) and that causes a runaway of any ME in yard											
Pedestrian crossing to walk from one area to another in designated walkway (from scale shack to sample yard)		3			1						
Pedestrian in yard from public (e.g., walking trails)											
Contractors (engineers, maintenance)											
Residual truck drivers (sawdust, chips)											

becoming pedestrians when performing tasks (e.g., rolling tarps)											
Pedestrians near rails performing maintenance or ME passing through line to go to mobile shop											
During an evacuation (e.g., fire, other emergency), log truck drivers could be leaving during emergency and there would be pedestrians in yard (either already there or could log yard could be safest egress)											
Employee parking lots: snow clearing, sanding, chip trucks - could be main access to finished yard											
Upset conditions in log area: dealing with spill/environmental issue, mud. Pedestrians could be managing these upset conditions											
Logging trucks other log truck driver											

Traffic congestion at two-way scale - log trucks in proximity to scalers											
Area in yard that personnel are allowed to pick discarded material (firewood)											
Inventory: start to new and must tag it - spray paint/tag rows - high stacker operator or scalers becomes pedestrian.											
		851	2	1	7	49	156	5	20	6	41
	Total	1138									

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