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Project Report

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Integrating Inherently Safer Design into Mobile Equipment Risk Reduction

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EXECUTIVE SUMMARY

This report describes the work completed under the project titled "Integrating Inherently Safer Design into Mobile Equipment Risk Reduction" funded by WorkSafeBC through an Applied Innovation grant. This project was completed in collaboration with WorkSafeBC, Dalhousie University, BC Forest Safety Council (BCFSC), and Obex Risk Ltd. (K. Rayner Brown, MASc, P.Eng., Principal Investigator)

The scope of this project was the development of a framework for incorporating inherently safer design (ISD) within risk management for mobile equipment (ME). Bow-tie analysis workshops were undertaken to evaluate the ME hazard and systematically identify potential applications of the ISD principles. These workshops provided opportunities for peer-to-peer learning for participants, who represented subject matter expertise across safety relating to mobile equipment operation, procurement, servicing and maintenance, and traffic management.

A questionnaire was developed to facilitate a survey of workshop participants on the current usage of ISD. The questionnaire and workshops identified numerous areas where ISD should be prioritized and where there are challenges and opportunities for improvement, including equipment and facility procurement and management of change. The workshops indicated that the questionnaire served well as the basis for an analysis framework. This questionnaire was subsequently expanded on to form of a self-assessment worksheet. This self-assessment worksheet was developed to identify gaps and create corrective action plans. This self-assessment worksheet is designed to be completed by a multi-disciplinary team with managers, supervisors, safety specialists, procurement/purchases, frontline workers (e.g., operators, maintenance staff), and joint occupational health and safety committee (JOHSC) members.

ISD review questions were developed as another ISD integration tool, which can be used to help identify ways that ISD can be practically implemented. These questions can be incorporated by end-users in a variety of settings, including incident investigations and corrective action planning, management of change, risk assessments, traffic management plan development, and procurement of equipment and facilities.

This research also included the creation of resource collection, from both archival as well as publicly available sources, that includes safety resources from regulators, equipment manufacturers and suppliers, and researchers. These resources will help enhance safety and the awareness of ISD by providing further resources relating to facility and equipment design, equipment safety features, and safety culture.

The research project was communicated in a workshop participant outreach factsheet, two articles in Forest Safety News (BCFSC), and a webinar in the BCFSC Different Voices series. Further efforts for the dissemination of the research will include a webinar hosted

by BCFSC to summarize the findings of the research project, introduce the ISD integration tools, demonstrate how the integration tools work and how they can be used, and additional ways that BCFSC can provide support.

LIST OF ABBREVIATIONS USED

BCFSC	British Columbia Forest Safety Council
ISD	Inherently Safer Design
JOHSC	Joint Occupational Health and Safety Committee
MOC	Management of Change
PPE	Personal Protective Equipment
SOP	Standard Operating Procedure
SWP	Safe Work Procedure
WSBC	WorkSafeBC (Workers' Compensation Board of British Columbia)

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Thank you to Rob Moonen (BCFSC) for supporting the project, as well as Tammy Carruthers (BCFSC) and Michele Fry (BCFSC) for support with communications and Knowledge Transfer and Exchange (KTE) initiatives.

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1 INTRODUCTION

This report details the work conducted on the integration of inherently safer design (ISD) principles into risk reduction approaches for mobile equipment (ME) hazards in industrial settings, specifically within warehouses and sawmills.

The introduction of the report provides an overview of mobile equipment issues that were the focus of the research, which were struck-by incidents involving pedestrians, and musculoskeletal injuries (MSI). This introduction includes a summary of the motivation, scope and objectives of the research project.

The second section of the report provides background into work previously completed on within sawmills on the mobile equipment risk reduction, the fundamentals of inherently safer design, and the challenges this research was aiming to address.

The third section of the report describes the data collected through a series of workshops that included hazard analyses and a questionnaire.

The fourth section describes the research and development outcomes that form the basis of an ISD integration tool. These results include a collection of resources to enhance the awareness and provide guidance related to ISD and ME, the development of ISD review questions, and the creation of an ISD for SMS self-assessment worksheet.

The fifth section summarizes knowledge, transfer and exchange activities undertaken and planned to disseminate the research outcomes, and the report closes with concluding remarks.

1.1 Industrial Mobile Equipment and Associated Risks

Industries in BC and abroad rely on ME to carry out tasks inherent to sectors, facilities, and types of goods or materials being handled. The two sectors that were the focus of the project were sawmilling and general warehousing; this research is also relevant to other industries that uses mobile equipment, including wood pellet production, mining and construction.

ME poses a significant workplace risk. Some injuries associated with ME are acute, including struck-by incidents (i.e., pedestrian impacted by ME), as well as slips, trips, and falls. As outlined in the recent WorkSafeBC publication, there have been more than 550 struck-by incidents in BC within the last 10 years (WorkSafeBC, 2021). This means there is approximately one struck-by incident per week. Injuries associated with ME may also be chronic, including musculoskeletal injuries (MSI) due to repetitive movements and equipment design. ISO (2010) provides examples of hazards that are presented by machinery. Vibration hazards may be presented by ME and can lead to consequences such as low-back morbidity, osteo-articular disorder, and trauma of the spine. Ergonomic hazards can originate from access, effort, posture, repetitive activity, and visibility and can cause MSI, fatigue, and stress. ME and MSI were hazards included in the 2021-2023 Manufacturing High Risk Strategy (HRS) (WorkSafeBC, 2022).

Work was previous completed by project partners, Obex Risk Ltd. and British Columbia Forest Safety Council (BCFSC), focusing on the risk assessment of the mobile equipment-pedestrian interface (ME-PI) in sawmills. During this work, it was determined that most of the barriers that are currently being used to control the ME-PI hazard are administrative controls (least preferred and least effective). There is a knowledge gap of how to explicitly consider the four principles of inherently safer design (ISD) (minimization, substitution, moderation, simplification) to treat hazards at the source associated with specific types of ME.

1.2 Hierarchy of Controls and Inherently Safer Design

ISD the approach to risk management that focusses on eliminating hazards, rather than only relying on add-on equipment and procedures. ISD is the most preferred and effective risk management strategy (Kletz and Amyotte, 2010); however, effective risk reduction involves the use of ISD in conjunction with other types of controls, namely passive engineered equipment, active engineered equipment, and administrative measures (Amyotte and Khan, 2020). The preferred order of risk reduction measures is referred to as the hierarchy of controls, which is shown in Figure 1.

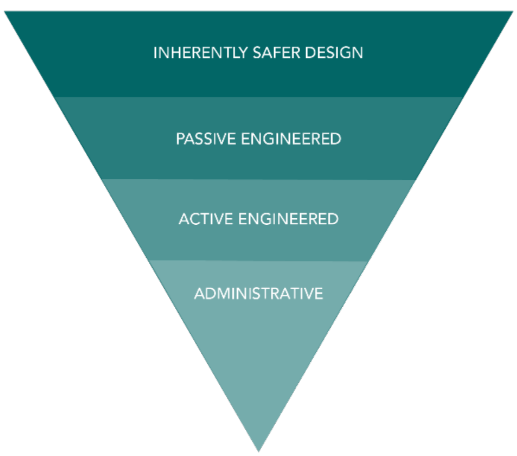

Figure 1. Hierarchy of controls (Credit: Obex Risk Ltd. 2024).

1.3 Research Scope

The scope of the research is development of a framework for the incorporation of the four principles into mobile equipment risk reduction for struck-by incidents and MSIs. The research was completed in collaboration with the wood products manufacturing industry and warehousing sector, but also provides outcomes that can be referenced by other sectors that involve heavy machinery including construction, oil and gas, and mining.

1.4 Research Motivation

There is currently a heavy reliance on administrative controls to reduce ME risk, which are the least reliable, making them least preferred. There is a need to enhance the understanding and awareness of ISD and develop tools so the principles can be explicitly incorporated into facilities and organizations as part of business decisions and within safety management system (SMS) elements, such as management of change (MOC), incident investigation, safety culture, and hazard analysis.

1.5 Research Objectives

The objectives of the research were to:

- Conduct bow-tie analyses to evaluate the ME hazards,
- Undertake ISD workshops to identify hazard-specific opportunities to consider ISD,
- Explore the current understanding and adoption of ISD through consultation and survey of stakeholders,
- Create tools to incorporate ISD explicitly in organizations through the safety management system (SMS),
- Share the research outcomes, along with practical and hands-on resources, to ensure ease of access and use to industry.

2 BACKGROUND

This section provides background information for the project, including bow-tie analysis and ISD as the conceptual foundations of the research, work previously completed in the sawmilling industry on ME risk reduction, and current challenges identified in this area.

2.1 Bow-Tie Analysis of Mobile Equipment-Pedestrian Interface in Sawmills

In Q1 2022, work was undertaken by Obex Risk Ltd. and the BCFSC Manufacturing Advisory Group (MAG) to conduct a bow-tie analysis on the ME-PI in sawmills to assess this hazard. The bow-tie analysis allowed for the identification of scenarios that could lead to struck-by incidents, as well as the controls that are in place to prevent them from occurring. The controls (including degradation factor controls) were quantitatively analyzed with respect to the hierarchy of controls to determine which types of safety measures were most frequently used; the result of this analysis was 851 barriers were administrative, 2 were active engineered, 7 were passive engineered, and 1 was ISD (Obex Risk Ltd., 2022). During the bow-tie workshop, numerous barriers related to ISD were identified for further consideration, including:

- 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.

These ISD options are promising as they present the opportunity to eliminate or significantly reduce pedestrian interactions with ME.

Further discussions with occupational health and safety practitioners emphasized the significant issue of MSIs involved with ME and hence should also be targeted for evaluation with respect to ISD for risk reduction. Preliminary research identified a strong influence of equipment design on the risk of MSIs, including those associated with full-body vibration, repetitive strain from body rotation, and entering/exiting equipment. Literature focusing on MSI arising from ME was identified that explicitly referred to applying the hierarchy of controls for risk reduction. NIOSH (2018) describes assessments of forklift drivers in two manufacturing facilities. The report references the hierarchy of controls for implementing measures to reduce neck and back pain from driving in reverse, beginning with recommendations to reduce or remove ergonomic hazards, followed by engineering controls (e.g., swivel seat forklifts), and administrative controls (e.g., rotating operators to reduce total exposure time).

2.2 Hierarchy of Controls and Inherently Safer Design

In order to demonstrate the overlap of the hierarchy of controls referred to in this work comprised of ISD, passive engineered, active engineered, and administrative controls, and the conventional hierarchy of controls used in occupational health and safety applications, Figure 2 provides a mapping of these two frameworks. ISD encompasses elimination and substitution, along with simplification and moderation. Passive engineering controls are add-on features that do not require detection and actuation – for example, barricades separating pedestrians and ME. Active engineering controls require detection and actuation – for example, pedestrian detection and interlocked speed reduction. Personal protective equipment (PPE) is a policy-based control, so it can be considered an administrative or procedural control.

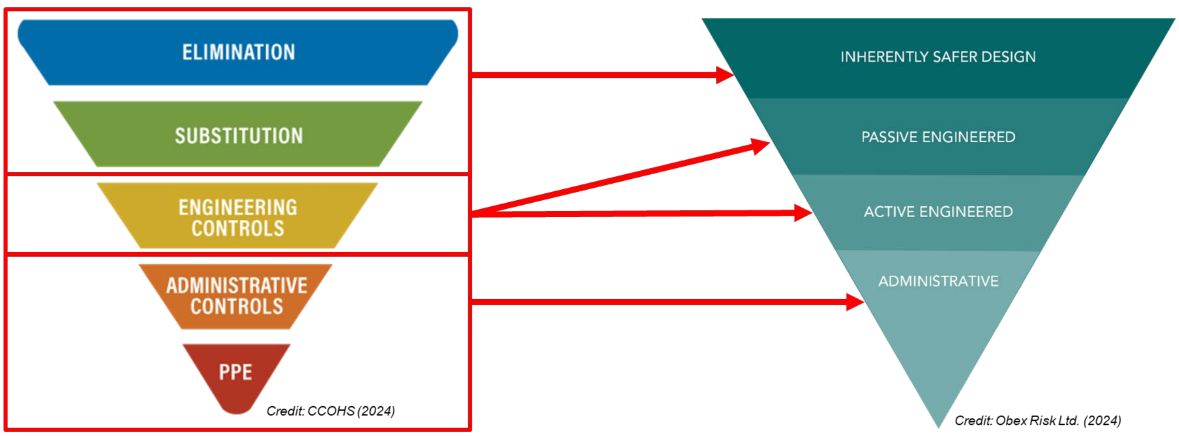

Figure 2. Mapping of conventional hierarchy of controls with ISD hierarchy of controls.

Larsson et al. (2003) reference the hierarchy of controls for traffic engineering interventions and includes recommendations such as reducing pinch points to create more separation between ME and pedestrians, which is aligned with the ISD principle of moderation.

2.3 Literature Review and Current Status and Challenges

Literature review of ME risk management has identified little use of ISD as an approach for eliminating or reducing mobile equipment hazards. ISO 12100:2010 – *Safety of machinery* explicitly uses inherent safety within the risk management framework for machinery design. This standard identifies ISD as a protective measure to reduce risk by modifying the design or operating features of the machine instead of the addition of guards or protective devices.

Larsson et al. (2003) references the hierarchy of controls for traffic engineering interventions and includes recommendations such as reducing pinch points to create more separation between ME and pedestrians, which is aligned with the ISD principle of moderation.

Options for engineered and administrative safety measures are frequently discussed in literature; however, there is evidence of a growing emphasis on safety by design. These resources are later provided in Section 4. Wilbanks et al. (2022) focusses on motion warning devices on forklifts, which are active engineered safety features that involve operator response (an administrative control). Guenther and Salow (2012) outline an operator assistant system, which consists of active engineered features and administrative controls as it requires action on the part of the ME operator. The operator assistant system includes collision avoidance, guidance for road departure, reversing and path following. The system outlined uses audible warnings for the operator to trigger a reaction. Michael and Gorucu (2020) discuss injuries caused by powered industrial trucks (PITs), which includes pallet jacks and forklifts. While training and safe work procedures (administrative controls) are identified as important measures, an emphasis is placed on improved layout planning for sites (which is aligned with the principles of ISD).

3 BOW-TIE ANALYSIS AND INHERENTLY SAFER DESIGN WORKSHOPS

This section describes the results of the bow-tie analysis and ISD workshops, including bow-tie analysis cut-out diagrams to highlight the assessments and the development of an ISD questionnaire.

3.1 Workshop Overview and Outcomes

The workshops took place in October 2023 and were successful cross-industry initiatives that focussed on improving ME risk, sharing of practices and challenges, as well as ways to enhance ISD adoption. The workshops were led by K. Rayner Brown (at the time Obex Risk Ltd., now Jensen Hughes) as facilitator and scribe. Workshop assistance was provided by B. Laturnus (BCFSC Senior Safety Advisor, Manufacturing).

The bow-tie analysis for MSI was completed online over two half-day workshop sessions which were attended by approximately 10 individuals, including health and safety resources, supervisors, managers, equipment suppliers and equipment maintenance providers.

The bow-tie analysis workshop for ME-PI was completed in conjunction with the ISD workshop, in order to optimize the workflow and emphasize the target of ISD. These workshops consisted of two full-day in-person workshops and were attended by 17 participants.

Numerous ISD options were successfully identified, and participants placed a key focus on discussing and exploring how ISD principles could be considered. Various types of active and passive engineered equipment were also shared across the workshop attendees.

Cut-out diagrams of the MSI and MEPI bow-tie analysis are provided in Figures 3 to 10, respectively. The outcomes from the bow-tie analyses and workshop findings underwent evaluation to inform the development of the integration tools, which are discussed and provided in Section 4.

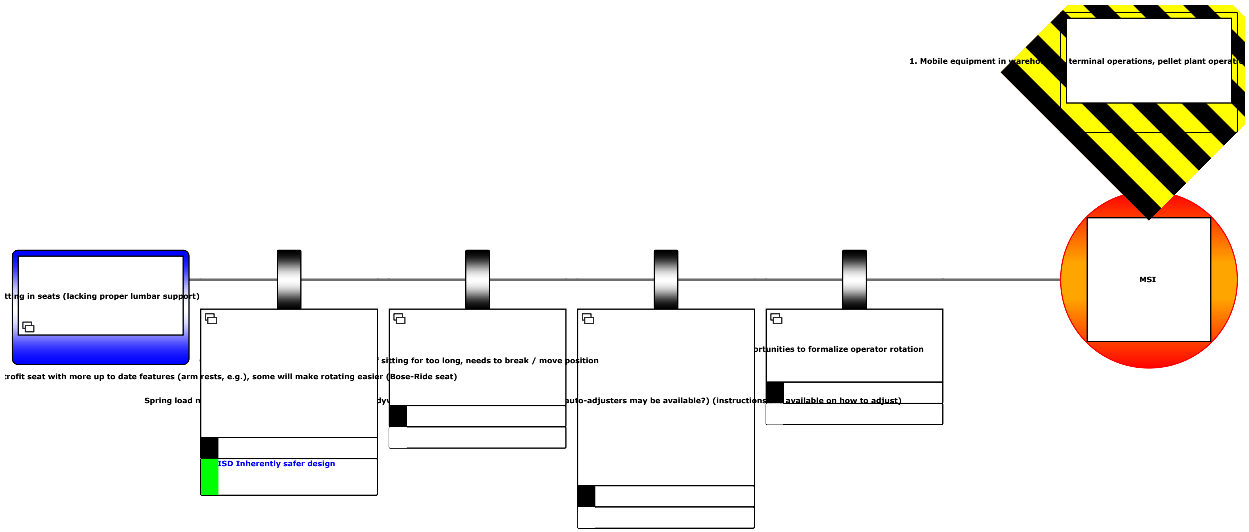

Figure 3. MSI BTA cut-out diagram (extended periods of time sitting)

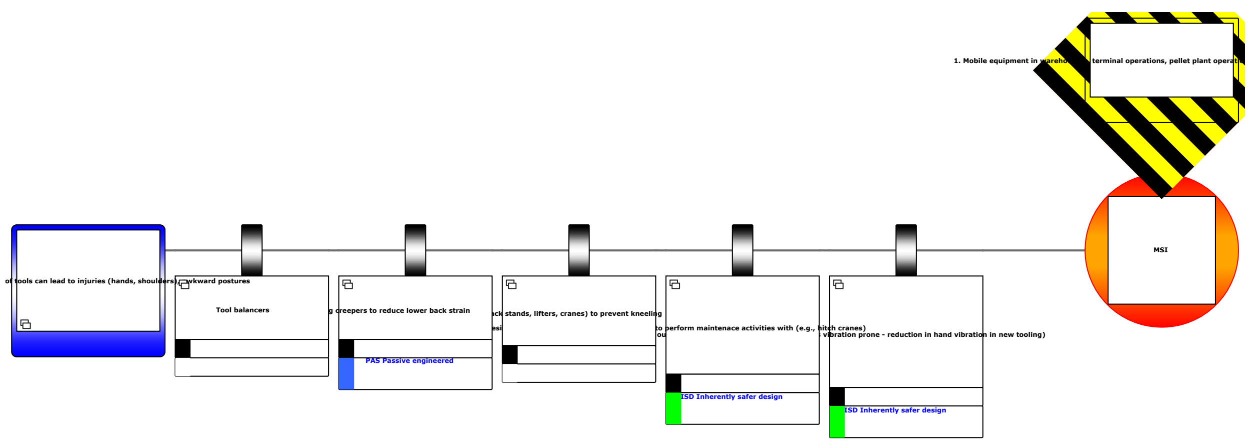

Figure 4. MSI BTA cut-out diagram (repetitive activities)

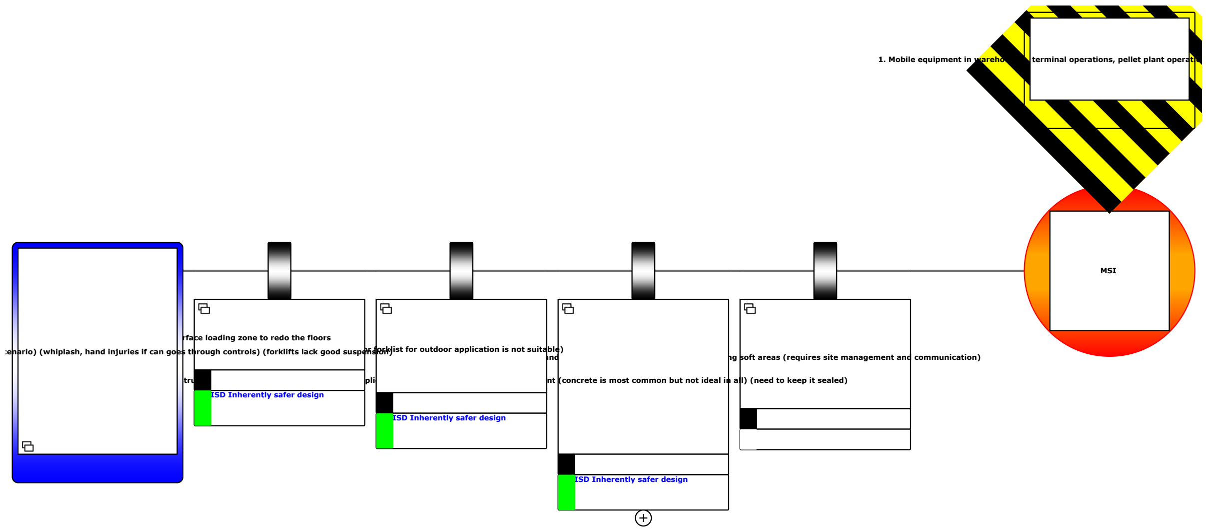

Figure 5. MSI BTA cut-out diagram (impacts from driving surface)

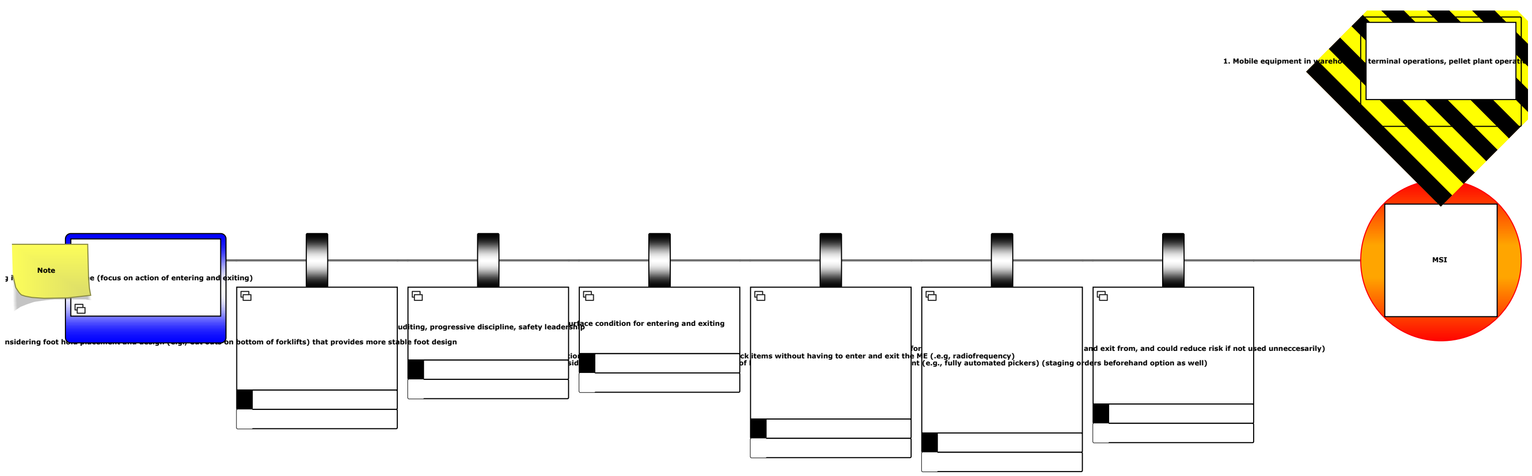

Figure 6. MSI BTA cut-out diagram (entering/exiting machine)

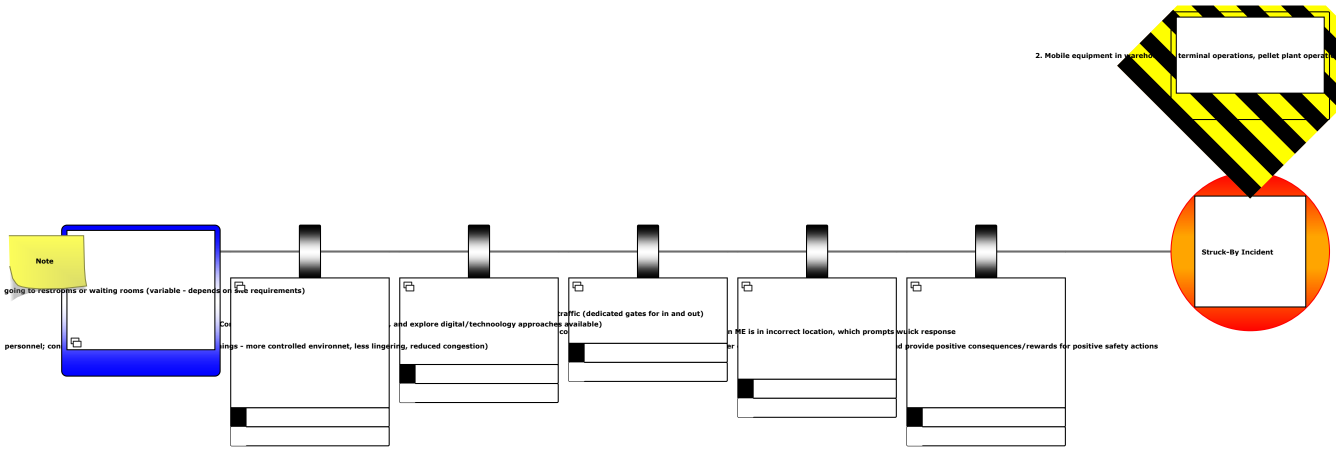

Figure 7. MEPI BTA cut-out diagram (third-party personnel)

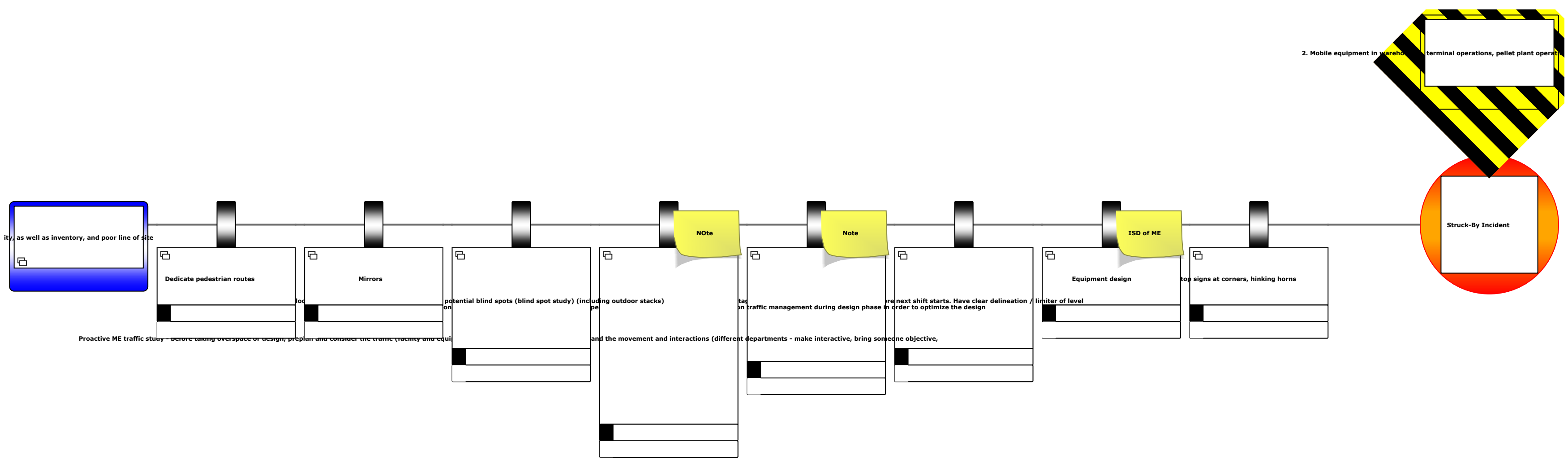

Figure 8. MEPI BTA cut-out diagram (blind corners)

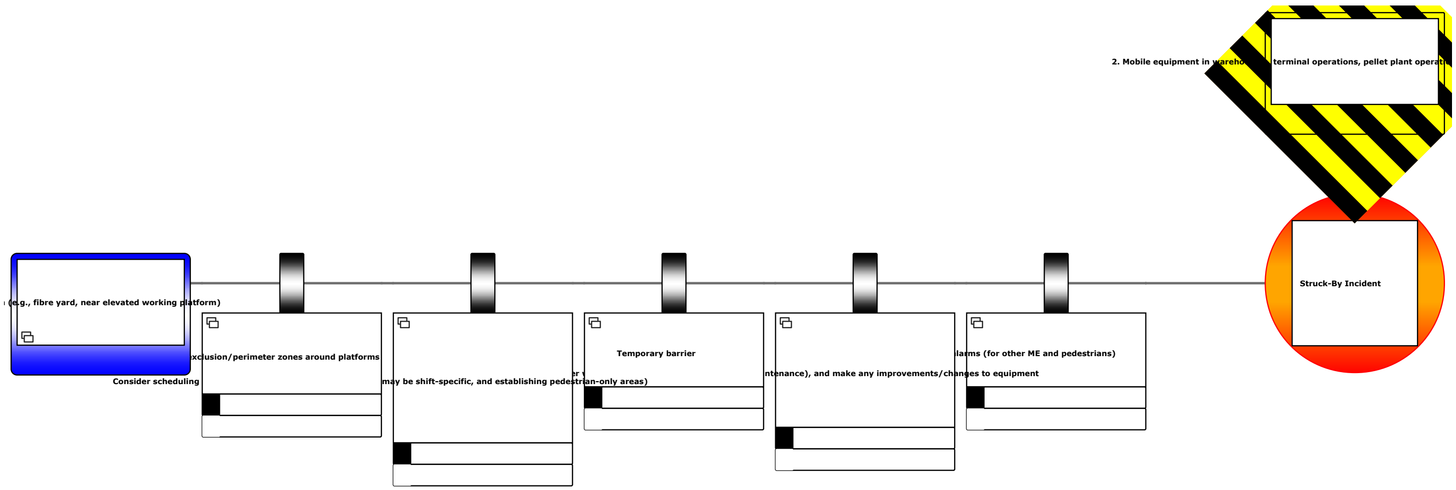

Figure 9. MEPI BTA cut-out diagram (personnel in high-traffic areas)

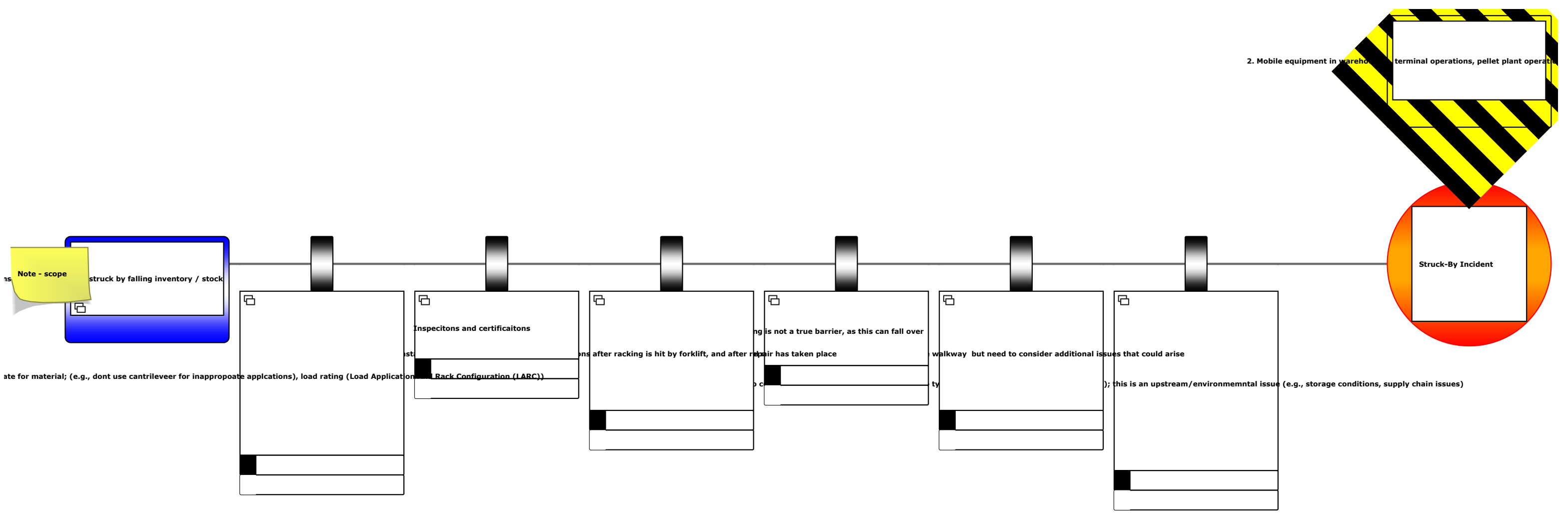

Figure 10. MEPI BTA cut-out diagram (personnel struck by falling stock)

3.2 ISD Workshop: Prioritization Framework

Building off the ISD workshop approach described by Edwards et al. (2015), a new tool was developed for ISD workshops in collaboration with BCFSC, which helps with the assessment and prioritization of potential ISD options; this approach is provided in Table 1. It was found in the workshop that the bow-tie analysis provided a simpler way to identify ISD options with respect to specific hazards; however, the tool in Table 1 can help guide discussions and action plans.

Table 1. ISD option worksheet

Area	
Threats/Hazardous Scenarios: What is dangerous? Why is it dangerous? - Primary equipment/mechanical performance - Environmental influence - Operational issues	
Reason for Change Examples: Order, Opportunity for Improvement, Audit, Management of Change (MOC), Investigation, Near Miss, Hazard Analysis	
Possible ISD Improvement (PI) (Is there a safer way?) ISD Examples: Eliminate/reduce hazards Alternate equipment or process to eliminate or reduce hazard Separate people and processes, reduce likelihood or severity Simple, reliable equipment and processes	
Type of Control: ISD PAS (Passive Engineered) ACT (Active Engineered) ADM (Administrative)	
Benefits / Pros	
Challenges / Cons (e.g., inventory, personnel, other hazards)	
Cost - Low - Moderate - High	
Impact of Design Feature on Safety - Significant benefit / highly inherently safe - Marginal benefit - Neutral (equal pros and cons) - Marginal degradation - Significant degradation - change design, poor ISD (new hazards added)	
Score (1 - 5) 5: Very feasible 4: Feasible 3: Neutral 2: Significant challenges 1: Not feasible	
Priority: H: High M: Medium L: Low	
Action	
Action Owner	
Assessment of Results: ISD Implementation Success/Failure H: High M: Medium L: Low	

3.3 ISD Workshop: Survey Development and Questionnaire

When formulating the data collection approach, a quantitative analysis to identify gaps in ISD usage with a survey was proposed; however, during the workshops gaps and opportunities for improvement were able to be identified qualitatively in discussions with the workshop attendees using a questionnaire. It was deemed more beneficial for the survey and questions to bee discussed as a group to help facilitate brainstorming. Through initial discussions, as well as the outcomes of the workshop sessions, it was identified that explicitly considering ISD for ME risk reduction is in the early stages, and there is awareness and understanding to support. Rather than distributing the questions in a survey format and answered by individuals, they were discussed to facilitate brainstorming, and further sharing of information and perspectives across the participants. The questions were based on the topics of senior leadership, risk assessment, management of change, incident investigation, and equipment procurement.

Senior Leadership

- Are they knowledgeable in the hierarchy of controls? Or when it is the best time to consider ISD?
- Are the safety resources included in the project design phase? Are they knowledge able / equipped with knowledge as well?
- Does senior leadership direct decision-makers related to design to consider ISD?
- Are there arrangements in place for communicating mobile equipment safety information to staff?
- What kind of resources do we need to develop to help leadership be aware of ISD?

Risk Assessment

- Are engineered controls generally regarded as preferred over administrative/procedural controls?
- Is the hierarchy of controls and ISD considered when identifying and selecting control measures from a risk assessment?
- Have you identified critical controls? How are you ensuring reliability? Have you identified responsibilities and accountabilities at all levels of your organization?

Management of Change (MOC)

- Are engineered controls generally regarded as preferred over administrative/procedural controls?
- Is the hierarchy of controls and ISD options considered during management of change?
- Are operators involved or consulted when work processes are developed, when new mobile equipment is introduced, new materials being handled, facility changes (layout, traffic flow, temporary building)?

- How are changes being handled with respect to seasonality, inventory, shipping changes?
- How are temporary obstructions to lines of sight managed?
- Are potential ME risks considered when proposing changes onsite, including new manufacturing processes, new building construction, new material handling considerations (unit sizes, shipping frequency)?

Incident Investigation

- Is the hierarchy of controls and ISD options considered when developing corrective action plans?
- Do all operators understand the reporting procedures for incidents, near misses, damage & emergencies?
-

Equipment Procurement

- This is one of the areas identified as a priority for further research – how can we help operations more effectively select ISD equipment?
- What is the lifecycle of the forklift? Who is leasing, who is buying?
- What innovations and technology changes are occurring with equipment to help with MSIs and MEPI? How can the awareness of this be raised? How does an industry or region encourage equipment manufacturers to innovate?

The discussions guided by the questionnaire highlighted:

- The need to increase the awareness of the hierarchy of controls,
- The need to formalize management of change (MOC) processes,
- Safety culture, as well as equipment and facilities procurement, are significant drivers for ME risk reduction, and
- Resources and communication tools are needed to help with understanding and integration within organizations.

This series of questions was identified as one of the integration tools; following the workshop, subsequent work was undertaken to expand the questionnaire and add additional questions to create an ISD self-assessment. This tool is described Section 4.3.

4 ISD INTEGRATION TOOL

This chapter describes resulting ISD integration tools, namely a collection of literature and resources, ISD review questions and an ISD self-assessment worksheet.

4.1 ISD Integration Literature and Resources

Literature and resources were collected from archival as well as grey literature sources (e.g., informational booklets, brochures, and factsheets from government, trade associations, ME manufacturers). These resources and good practice guidelines are publicly available and can be accessed to those readers in industrial and commercial organizations. The resources are provided in Table 2, and also include tools such as examples of site surveys and traffic management plans.

Table 2. ISD and ME safety resources from archival and grey literature

Reference/Good Practice and Link
British Standards (2011). Safety of machinery – General principles for design – Risk assessment and risk reduction (ISO 12100:2010).
Crown Equipment (2024). An Integrated Approach to Forklift Safety.
A. Cantini, F. De Carlo, M. Tucci. (2020). Towards Forklift Safety in a Warehouse: An Approach Based on the Automatic Analysis of Resource Flows. Sustainability, 12 (21), 8949.
M. Feno and A. Savescu (2024). Safe workplace layout design by joint analysis of workers and material flows. *Procedia Computer Science*, 232, 3074-3082.
T. Horberry (2011). Safe design of mobile equipment traffic management systems. *International Journal of Industrial Ergonomics*, 41 (5), 551-560.
T. Larsson, T. Horberry, T. Brennan, J. Lambert, I. Johnston. (2003). A Guidebook of Industrial Traffic Management and Forklift Safety.
T. Horberry. (2004). Forklift safety, traffic engineering and intelligent transport systems: a case study. *Applied Ergonomics*, 25 (6), 575-581.
L. Miller and C. Gariepy (2023). Heavy Mobile Equipment - Ergonomics and the Prevention of Musculoskeletal Injuries.
Mitsubishi Forklift Trucks (2024a). Site Survey.
Mitsubishi Forklift Briefing (2024b). Why operators could be feeling the impact of Whole-Body Vibration.
Mitsubishi Forklift Trucks (2024c). Musculoskeletal disorders: How well-designed handling equipment can help
Mitsubishi Forklift Trucks (2024d). Safer Apart: Why it's vital to separate forklifts and pedestrians
NIOSH (National Institute for Occupational Safety and Health). (2018). Health Hazard Evaluation Report 2012-0182-0208-3300. Evaluation of Forklift Operators' Risk of Musculoskeletal Disorders at Two Manufacturing Plant.

Table 2. ISD and ME safety resources from archival and grey literature continued

Reference/Good Practice and Link
SafeWork Australia (n.d.). Traffic hazard checklist
SafeWork Australia (2021). Traffic management: Guide for warehousing
S. Schwartz. (2021). Minimizing Severe Injury and Fatality Risk in Warehouse Operations.
UK Material Handling Association (2024). 2020 Pedestrian Impact.
WorkSafe Queensland (2021). Workplace traffic management – general guide.
WorkSafe Queensland (n.d.). Onsite traffic management self-assessment tool.
WorkSafeBC (2023). Layer risk controls to help prevent workers from being struck by mobile equipment
WorkSafe New Zealand. (2020a). Safe reversing and spotting practices.
WorkSafe New Zealand. (2020b). Managing work site traffic.
WorkSafe New Zealand. (2021a). Safe stacking of sawn timber and board materials.
WorkSafe New Zealand (2021b). Whole body vibration – information for workers.
WorkSafe New Zealand (2021c). Working safely with pallet racking systems.
Y. ZandMiralavand. (2018). Thesis: Designing the warehouse and improving the layout of JAMK Bio-Economy Campus

Appendix A is an ME safety culture exercise that can be used in a toolbox talk or workshop setting. Appendix B is an ISD quick reference sheet that can be used as a communication tool to help with the understanding and application of ISD.

4.2 ISD Review Questions

Horberry (2011) describes a series of 50 questions that were developed to aid in the design of a safer mobile equipment traffic management system. These questions were structured with respect to the work environment, work tasks, equipment and policies, and people at work. Horberry (2011) outlines an approach to surveying and workshops to assess risk and identify potential approaches for risk reduction. This approach, along with the ISD review approach described in CCPS (2019), was used to develop ISD review questions for ME. The ISD review questions in Table 4 can be used to guide brainstorming and discussion. The potential solutions will be site-specific and may not be feasible during the operational lifecycle stage, but they should be explored and noted should companies be selecting new sites for new leases or moving to new sites during expansions. As noted in Larsson et al. (2003), it is much easier and beneficial to incorporate ISD during site selection and integrate design features during initial site configuration.

Table 3. ISD review questions for mobile equipment

Guideword	Review Question

Minimize	Can the hazardous equipment or activity be eliminated or minimized?
	Can the number of mobile equipment or pedestrians involved in a given activity or task be minimized?
	Can pedestrians and bystanders be eliminated from loading/unloading processes?
	Are all materials or mobile equipment onsite removed when they are no longer needed to reduce congestion?
	Can the storage of raw or finished product inventory be reduced or improved to enhance traffic flow and visibility? For example, improve production scheduling, sales forecasting, or communication with transporters/material handlers.
	Can the distance that mobile equipment needs to travel be minimized?
	Can the distance that pedestrians need to travel be minimized?
	Can the number of pedestrian-ME intersections/crossings be reduced?
	Can blind corners for pedestrians and ME operators be minimized?
	Can elevated walkways be designed and constructed that separate pedestrians from mobile equipment and eliminate potential interactions?
	Can pinch points be minimized by removing obstructions from aisles, roadways and intersections?
	Can the site be reconfigured to reduce backing-up/reversing of heavy-duty vehicles?
	Can low overhead clearances that could be impacted by a raised or partially raised mast be redesigned or removed?
Substitute	Can alternate processes or workflows that are less hazardous be substituted?
	Is alternate equipment that eliminates or substantially reduces the hazard available?
	Can electric hand pallet movers or conveyor belts be used instead of forklifts?
	Can alternate equipment be used that has better line of site for operators?
	Can alternate lighting configurations or types be used at entrances/exits of buildings to avoid drastic changes in light levels that are difficult for personnel's vision to quickly adjust to?
	Can alternate locations be designated for lunch and worker breaks that minimizes potential exposure to ME risk?

	Can vehicles be parked alongside buildings instead of across roadway / ME driveway / path, which means that pedestrians entering the building need to cross the roadway?
Moderate	Can potential hazards be reduced by less severe operating conditions of equipment? For example, speeds and maneuvers.
	Are all hazardous processes and equipment stored as far away as possible to eliminate disruption or possible harm to people and property in the event of an incident?
	Can the worksite be re-arranged to have more separation and distance between pedestrians and mobile equipment?
	Can high-traffic areas for mobile equipment and pedestrians be re-configured to reduce congestion?
	Can separate entrances, exits and paths be designed or reconfigured to be dedicated for each pedestrians and mobile equipment?
	Can aisles, roadways and intersections be widened to design more separation between pedestrians and ME?
	Can heavy-duty mobile equipment (e.g., loaders, forklifts, tractors) be separated from light-duty vehicles (e.g., cars, pickup trucks, carts)?
	Can the conditions of the roads and paths be modified or improved (e.g., fixing potholes, uneven surfaces, slippery surfaces) to ensure the stability of ME and loads to reduce the likelihood of upset conditions (e.g., spilled loads, slips, trips and falls, sudden and unexpected maneuvers or deviation from designated safe areas)?
Simplify	Is the workplace designed for consideration of human factors (i.e., is the workplace ergonomically designed for different physical conditions of personnel, including eyesight, age, mobility and walking speed)?
	Can the site be re-configured to make it easy for pedestrians and ME operators to distinguish restricted/designated zones (i.e., ME-only and pedestrian only)?
	Can the worksite be configured to make it less desirable for pedestrians to walk in undesignated paths (shortcuts)?
	Can pedestrian paths be configured and located to be free of any potential hazards (e.g., falling of objects from overhead, environmental conditions) that could make them less desirable for pedestrians to use?
	Are dedicated pedestrian paths intuitive and easy to understand?
	Can equipment or work processes be designed such that it is difficult or impossible to create a potential hazardous situation due to an operating error or maintenance issue?

	Are there any ways operations and processes involving hazardous mobile equipment can be simplified to reduce risk?
	Can safety devices and features be engineered to make tamper-proof (as per OHSR 19.36 Control Systems)?
	Can the line of sight in road and building design be reconsidered and improved?
	Can plant layout or equipment be improved to consider hazards associated with mobile equipment that do not generate a lot of noise (e.g., electric or battery-operated equipment)?
	Is the right-of-way easily understandable for all personnel onsite?
	Can the site be reconfigured to use one-way roads to simplify traffic flow and direction?
	Can signage be updated (including style, font, colouring) to be consistent and aligned with standards that personnel would expect and be familiar with?
	Can access ways be redesigned and resized to easily accommodate loads being transported? This includes loads being moved by personnel – if loads do not easily fit through pedestrian-dedicated access points, pedestrians may choose to use those meant for ME, which increases the potential for struck-bys.
	Can there be designated parking areas for all vehicles onsite, with appropriate spots dedicated for large vehicles (e.g., heavy-duty vehicles parked away from high pedestrian-traffic areas)?
	Can maintenance be completed in optimized, dedicated locations to minimize potential disruptions to traffic flow and potential hazards posed by maintenance activities (e.g., tools, fluids) and to protect mechanics working around vehicles?
	Can the efficiency of pedestrian, ME and load movements be reviewed and made more optimal through planning and automation?
	Can pedestrian calming measures (e.g., chicane, inward opening self-closing gate) be used to prevent personnel from entering ME paths?

4.3 ISD Self-Assessment Worksheet

Safety management systems (SMS) provide frameworks to manage workplace risk. ISO 45001 is an international standard that describes requirements for an occupational health and safety (OH&S) management system (ISO, 2024). OSHA (2024) and WorkSafeBC (2024) provide guidelines for the core elements; those from OHSA (2024) are:

- Management Leadership
- Worker Participation
- Hazard Identification and Assessment

- Hazard Prevention and Control
- Education and Training
- Program Evaluation and Improvement
- Communication and Coordination for Host Employers, Contractors, and Staffing Agencies

An ISD self-assessment worksheet has been developed that reflects these elements; this self-assessment is provided in Appendix C. The self-assessment provides a mechanism to incorporate ISD within a given organization’s SMS, and therefore explicitly consider ISD for ME risk reduction. The self-assessment has been created with reference to self-evaluation tools provided by WorkSafeBC (2023) and Rayner Brown et al. (2024).

5 KNOWLEDGE TRANSFER AND EXCHANGE

Numerous knowledge transfer and exchange (KTE) initiatives have been completed during the course of the project and are planned to follow the completion of the research project. To reach audiences at wood products manufacturing, avenues including Forest Safety News, have included articles on the research project.

Table 4. Summary of knowledge transfer and exchange (KTE) initiatives

KTE Deliverable	Date	Target Audience and End-Users	Stakeholder Engagement	Information Sharing Strategies	Reference
Article: "Applied Innovation Grant from WorkSafeBC Awarded for Research Project Focussing on Inherently Safer Design (ISD) in Mobile Equipment Risk Reduction in BC Sawmills and Warehouse Operations," Forest Safety News (FSN)	June 2023	Sawmills, wood pellets, manufacturers, trucking	Advertising on LinkedIn and other social media channels, website, email	Industry trade publication	BCFSC (2023).
Article: "New Developments in Research Project Focussing on Inherently Safer Design (ISD) in Mobile Equipment (ME) Risk Reduction in BC Sawmills and Warehouse Operations," Forest Safety News (FSN)	March 2024	Sawmills, wood pellets, manufacturers, trucking	Advertising on LinkedIn and other social media channels, website, email	Industry trade publication	BCFSC (2024a).
ISD in ME project profile for prospective workshop participants	April 2023	Sawmills, wood pellets, warehousing, trucking	Personal correspondence and stakeholder outreach	Written document	Appendix XX

Table 5. Summary of knowledge transfer and exchange (KTE) initiatives continued

KTE Deliverable	Date	Target Audience and End-Users	Stakeholder Engagement	Information Sharing Strategies	Reference
Different Voices - Mobile Equipment Pedestrian Interface	June 2024	Sawmills, wood pellets, manufacturers, trucking	Advertising on LinkedIn and other social media channels, website, email	Webinar	BCFSC (2024b)
Planned Webinar with BCFSC: "Safer Through Design: How to Integrate Inherently Safer Design to Reduce Mobile Equipment Risk"	Q4 2024 – Q1 2025 (upon final delivery of project to WSBC).	Sawmills, wood pellets, manufacturers, trucking, construction, mining, food manufacturing	Advertising on LinkedIn and other social media channels, website, email	Webinar	N/A
Article in Forest Safety News and outreach to other industry groups and publications	Q4 2024 – Q1 2025 (upon final delivery of project to WSBC).	Sawmills, wood pellets, manufacturers, trucking, construction, mining, food manufacturing	Advertising on LinkedIn and other social media channels, website, email, personal outreach	Article, personal correspondence	N/A

6 CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the outcome of this research provides a foundation to improve the integration of ISD for ME risk reduction. A collection of relevant resources, the creation of ISD review questions, and the development of an ISD self-assessment for safety management systems provide numerous avenues for operations to explore opportunities to implement ISD.

Bow-tie analyses were conducted, which provided a systematic assessment of ME hazards as well as the identification of potential ISD options. The workshop participants benefitted from collaboration with others, sharing challenges and different perspectives. It is recommended that additional workshops, or a working group, be formed to help support this collaboration. Networking and communication help companies overcome challenges – even intermittent meetings quarterly could be beneficial. This is validated by additional work undertaken in Q1 2024 with the Wood Pellet Association of Canada (WPAC) focussing on bow-tie analysis of ME risk. A finding of the workshop team is a recommendation to form an industry working group on ME safety. The objectives of the working group would be to discuss shared concerns and trending issues, consolidate approaches and design features that are well-suited for sector-specific application, as well as connect with equipment manufacturers and suppliers to try to address and overcome these issues.

It is also suggested that user-friendly factsheets be developed as communication tools with the goal of enhancing the understanding of ISD, how to consider it within facilities and raise awareness of the principles of ISD to become more established as a risk reduction approach for mobile equipment. One factsheet designed for frontline workers and another factsheet for supervisors and management are suggested. Next steps include the communication of research project results to operations, which will include a webinar to highlight key findings and resources.

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APPENDIX A: MOBILE EQUIPMENT SAFETY CULTURE ACTIVITY

WOOD PELLET ASSOCIATION OF CANADA | BC Forest Safety | WorkSafeBC | MEDIA SPONSOR CANADIAN BIOMASS

Wood Pellet and Bioenergy Safety Summit, Prince George, BC (November 15 & 16, 2023)

Breakout Session: Handling Uncomfortable Safety Situations—Safety Culture Case Study 3 (Loose Leadership)

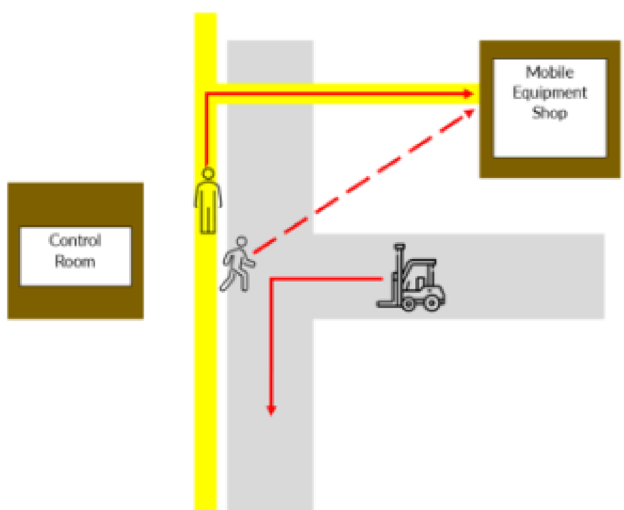
Senior leadership at a wood products facility determined they could expand their material handling services if they offered additional loaders and forklifts to be used at construction sites and other locations very close by on evenings and weekends, in addition to the normal daily business hours.

To accommodate these expanded hours at the lowest cost, they brought in mobile equipment operators from an outside company rather than hiring additional loader and forklift operators.

The lead mobile equipment operator voiced their objection to the decision, stating that outside operators would still require training on the configuration of the site and use of the mobile equipment at the facility. Additionally, the written procedures would need to be reviewed, and they would need to be supervised to ensure they were competent. Given numerous different operators could be provided by the service on a rotating basis, this would make it difficult to ensure they receive adequate training and supervision. Leadership indicated that the outside company would be responsible for training and that the lead operator would provide short written descriptions of the protocols and the latest available version of the site plan.

After three weeks of onboarding the outside company, the maintenance team reported an increase in broken headlights, disabled back-up alarms, and missing pre-trip inspections.

The lead mobile equipment operator contacted a manager to arrange a meeting in the shop to discuss and review the state of the mobile equipment. They met outside near the entrance of the control room. The manager, without a high-visibility vest, immediately walked briskly in the direction of the shop straight ahead, while the lead operator paused, as they were preparing to walk adjacent to the roadway in a designated walkway. A forklift carrying scrap metal came down the roadway and turned left but the driver braked suddenly when surprised to see a pedestrian in their periphery.



They narrowly avoided a struck-by incident but spilled the load of scrap metal. The manager blamed the forklift driver for the event and fired them.

UNRESTRICTED

Discuss

1. What are some indicators of a weak safety culture in this scenario?
2. What are some ideas on how this situation could have been prevented?
3. What are some actions and behaviours that could have reinforced a strong safety culture?
4. For the following, share an idea of what you would like to improve when you return to your operation:
    a. Reporting
    b. Leadership accountability
    c. Maintaining a sense of vulnerability and having a questioning attitude
    d. Safety communication (including management of change)

Developed by K. Rayner Brown (Obex Risk Ltd.) Adapted from International Atomic Energy Agency (IAEA) "Radiation Safety Culture Trait Talks" Last accessed October 31, 2023 from https://www.iaea.org/sites/default/files/21/01/radiation-safety-culture-trait-talks.pdf

APPENDIX B: ISD QUICK REFERENCE SHEET

April 2023 (R1)

INHERENTLY SAFER DESIGN (ISD)

OVERVIEW

BC Forest Safety
Safety is good business

OBEXRISK

INHERENTLY SAFER DESIGN (ISD) AND HIERARCHY OF CONTROLS

ISD reduces hazards through the system or process design, rather than relying solely on add-on measures. ISD is the most effective and preferred in the hierarchy of controls.

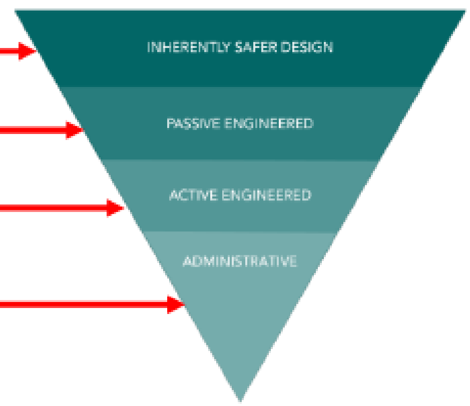
EXAMPLE OF HIERARCHY OF CONTROLS FOR MOBILE EQUIPMENT:

ISD (Minimization): Redesign of work areas to minimize the interaction of mobile equipment and pedestrians.

Passive Engineered: Installation of cement barriers.

Active Engineered: Installation of automatic gates activated when personnel detected.

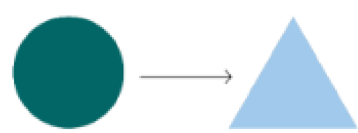
Administrative: Wearing of high-visibility personal protective equipment (PPE) by personnel.



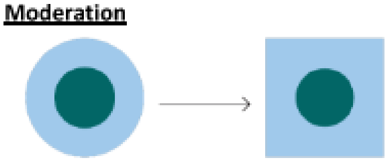
The principles of ISD are minimization, substitution, moderation, and simplification.

Minimization

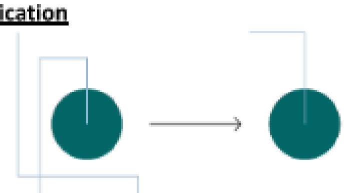
Substitution



Moderation



Simplification



UNRESTRICTED

SAMPLE OF ISD EXAMPLES

ISD Principle	Description
Minimization	Redesign processes, equipment or areas and worksites to minimize or eliminate the hazard
Substitution	Use alternate process methods or equipment that eliminates or minimizes the hazard
Moderation	Relocate hazardous activities involving away from personnel to reduce likelihood or severity of consequences
Simplification	Redesign processes and equipment to make it difficult or impossible to produce a hazardous scenario due to operating or maintenance error

SAMPLE OF ISD CHECKLIST QUESTIONS FOR MOBILE EQUIPMENT

ISD Principle	Question
Minimization	Can mobile equipment interactions with workers be minimized by removing either one from a hazardous area? Can the number of pedestrian-ME intersections and crossings be reduced? Can the distance that mobile equipment or pedestrians need to travel be minimized?
Substitution	Is alternate equipment or process available that eliminates or substantially reduces mobile equipment interactions with workers? Can alternate equipment be used that has better line of site for operators?
Moderation	Are all hazardous processes and mobile equipment as far away as possible to reduce possible impacts to personnel in the event of an incident? Can high-traffic areas for mobile equipment and pedestrians be re-configured to reduce congestion? Can aisles, roadways and intersections be widened to design more separation between pedestrians and ME?
Simplification	Can the line of sight in road and building design be improved? Can equipment be designed such that it is difficult or impossible to create a potential hazardous situation due to an operating or maintenance error? Are there any other alternatives for simplifying operations involving hazardous materials in this process?

Ask yourself: Have I considered ISD during management of change (MOC), incident investigation, inspections, or risk assessments?

APPENDIX C: ISD SELF-ASSESSMENT WORKSHEET

Inherently Safer Design (ISD) for Mobile Equipment Risk Reduction

Self-Assessment **D1 (2024)**

Mobile equipment (ME) poses a significant workplace risk, including the mobile equipment-pedestrian interface (ME-PI) (struck-by incidents) as well as ergonomics and MSI (musculoskeletal injuries).

Effective risk reduction involves the use of inherently safer design (ISD), passive engineered equipment, active engineered equipment, and administrative measures. ISD is the most preferred and effective risk management strategy as it addresses hazards at the source rather than relying on only add-on safety devices and procedures.

ISD Self-Assessment

Complete the ISD self-assessment and find opportunities for improvement. Identify ways to address issues and take action. Consider your proposed actions with respect to factors such as:

- Practicality,
- Benefits, and
- Anticipated effort and cost.

Additional Resources (Available on BCFSC Website)

- Full Research Report
- ISD Review Questionnaire
- June 2024 Webinar Recording

Senior Leadership
1. Are managers and supervisors knowledgeable in the hierarchy of controls and ISD? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
2. Are managers and supervisors knowledgeable of when it is the best time to consider ISD? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)

1 OBEXRISK BC Forest Safety DALHOUSIE UNIVERSITY WORKSAFEBC

3. Are onsite safety staff knowledgeable of the hierarchy of controls and ISD? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
4. Are onsite safety staff included in the design phase of projects? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
5. Does senior leadership direct decision-makers related to design, including procurement and purchasers, to consider ISD? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
6. Are there processes in place to communicate mobile equipment safety information to staff? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
7. What kind of resources do we need to develop to help leadership be aware of ISD?
Findings/Comments, Proposed Actions and Responsible Person(s)

Is safety information relating to ME easily accessible, shared and communicated? For example, new equipment being introduced onsite, incidents and near misses, key performance indicators (KPIs) and trends, schedules for audits and inspections. Examples may include notice boards, emails, meetings, newsletters, factsheets.
Findings/Comments, Proposed Actions and Responsible Person(s)
Risk Assessments
8. Are engineered controls and design-based controls (ISD) generally regarded as preferred over administrative/procedural controls? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
9. Is the hierarchy of controls and ISD considered when identifying and selecting control measures from a risk assessment? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
10. Have you identified critical controls, and do you have systems in place to ensure reliability, and assign responsibilities and accountabilities at all levels of your organization? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
Management of Change (MOC)

11. When implementing controls to reduce risk associated with changes, are engineered controls and design-based controls (ISD) generally regarded as preferred over administrative/procedural controls? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
12. Is the hierarchy of controls and ISD options considered during management of change? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
13. Are operators involved or consulted when work processes are developed, when new mobile equipment is introduced, new materials being handled, facility changes (layout, additional changes, temporary building)? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
14. Is there an effective process in place to address new risks associated with changes related to seasonality, inventory quantities, shipping and receiving frequencies, equipment, technology, and personnel? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
Incident Investigation
15. Are the hierarchy of controls and ISD options considered when developing corrective action plans arising from incidents and near-misses?

☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
16. Is there an effective process in place for operators to report near-misses, incidents, damage and emergencies, and do operators understand the reporting procedures? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
Mechanical Integrity: Equipment and Facilities Design and Procurement
17. Is there an effective process in place for personnel who make procurement decisions to be made aware of safety considerations (ISD or engineered) and the impacts of equipment and facilities design on risk? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
18. Is there is process in place for staff to stay updated with new innovations and technology to help with MSIs and struck-bys? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
19. In discussions with sellers and distributors, do staff involved with procuring equipment inquire about all safety features that are available and assess the benefits and limitations of such features? For example, "Are there certain models that have fewer blind spots, or are easier to maneuver and operate?"
Findings/Comments, Proposed Actions and Responsible Person(s)

20. Are staff that are involved with procuring equipment provided opportunities to enhance their knowledge regarding mobile equipment safety? This may include attending webinars and conferences, becoming involved with relevant committees or associations and collaborating with others in the same or similar industries? Examples of organizations include Safety Driven, Canadian Manufacturers and Exporters (CME), Canadian Materials Handling and Distribution Society (CMHDS), and Excellence in Manufacturing Consortium (EMC).
Findings/Comments, Proposed Actions and Responsible Person(s)
21. When developing business cases, is the hierarchy of controls considered with respect to initial investment and ongoing operating costs of different equipment or facility options? For example, the higher cost of an equipment model designed to reduce MSI risk compared with the cost of another equipment model with less optimal design (at a lower cost) with continuous need for ongoing training and procedural controls.
Findings/Comments, Proposed Actions and Responsible Person(s)
22. Is an approval process established for matters relating to maintenance and production? ☐ Yes (formalized) ☐ Yes (informal) ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)
23. Does the approval process for matters related to maintenance and production consider risks relating to the process? ☐ Yes (formalized) ☐ Yes (informal) ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)

Key Performance Indicators and Program Improvements
24. Is there an effective process in place for tracking of struck-by incidents and MSIs? Are trends relating before and after integrating new ISD or enginering measures monitored? ☐ Yes ☐No ☐Unsure
Findings/Comments, Proposed Actions and Responsible Person(s)

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