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RESEARCH ARTICLE

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Integrating process safety management into Canadian wood pellet facilities that generate combustible wood dust

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Abstract

Wood pellets, which are manufactured from sawmill and forest residues, are sold in bulk for biomass power generation or in bags for residential heating. Wood pellet production involves combustible dust, which presents the risk of fires and explosions. Process safety management (PSM) is a framework for preventing and mitigating process-related incidents. While PSM has historically been integrated within the chemical process industries, there is a need to systematically manage process-related hazards in other sectors, including wood pellet and wood product manufacturing. However, there is a need to identify an approach to PSM implementation that is reasonable and achievable based on the relative complexity of the production process, as well as onsite resources. The scope of this project was to develop an integration tool for wood pellet production to serve as the foundation for a long-term strategy and implementation plan led by industry. This research resulted in a PSM integration tool consisting of a PSM survey for gap analysis, self-assessment worksheets that include numerous PSM best practices, factsheets, and an implementation strategy. Using the CSA Z767 *Process Safety Management* standard as the basis, the research included the development of a phased approach to integrating PSM elements to help improve feasibility. The selection of PSM element phases was informed by surveys of operations and subject matter experts. This research recognizes that, while PSM is currently mostly voluntary in Canada, some organizations have adopted the CSA Z767 standard into regulations and proactively implementing a PSM framework will position companies well should regulations change.

KEYWORDS

combustible dust, process safety, process safety management, wood pellets

1 | INTRODUCTION

Process safety management (PSM) is the use of management principles and systems to identify, understand, avoid, and control process hazards to prevent, mitigate, prepare for, respond to, and recover from process-related incidents. There are several PSM frameworks that have been developed globally, including the CSA Z767 Process Safety Management Standard which builds on the work of the Canadian Society for Chemical Engineering (CSChE). In Canada, PSM is largely voluntary best practice; however, CSA Z767 has been adopted by some regulators, including the BC Energy Regulator and the Technical Standards and Safety Authority. While the implementation of PSM is most commonly associated with chemical process industry facilities, such as oil and gas refineries, there is now a focus on incorporating best practices for PSM into other high-hazard, non-chemical process industry applications to manage process hazards such as combustible dust.

Industries handling combustible dust include those involved with food processing, grain, pharmaceuticals, and wood products manufacturing. Wood products manufacturing includes wood pellet facilities, medium density fibreboard (MDF) plants, wood component manufacturing, and sawmills. There is current interest in integrating PSM within wood products manufacturing, namely the Canadian wood pellet industry. This sector has previously focused its efforts on occupational health and safety improvements, along with fire prevention programs. An explicit focus on PSM will provide a proactive, systematic approach to preventing and mitigating combustible dust incidents. Additionally, wood pellet storage also presents numerous hazards, including formation of toxic off-gases and combustible gas, fires, and deflagrations.

There are currently 45 wood pellet plants across Canada (12 in British Columbia) with production capacities up to 400,00 tonnes annually.[1] Wood pellets are sold in bulk for biomass power generation or bags for residential heating. Conventional wood pellet production begins with the cleaning and screening of wood fibre to remove foreign material (e.g., rocks and tramp metal). The fibre undergoes size reduction in a hammer mill before or after the drying process to achieve an ideal particle size. The dryer removes moisture from the wood fibre in preparation for the pelletizers (an extruding process). The pelletizers press the fine wood fibre through small holes in a metal ring dye to form wood pellets. The pellets (which are hot and moist) next enter a cooler to cool and harden. Pellets may be stored in bulk in silos or bagged for residential customers. Wood pellets produced in Canada are sold domestically, as well as internationally to the United Kingdom, the Netherlands, Belgium, Denmark, Japan, and South Korea.

Pellet plants are commonly operated by a relatively small number of frontline staff (e.g., plant operators, maintenance technicians, electricians, and mobile equipment drivers) and generally do not have dedicated roles for process safety. A key focus for implementing PSM in wood products manufacturing is therefore identifying modes of integrating PSM elements that are practical and feasible for these operations that are not managing exceedingly complex hazards (such as reactive chemistry) and do not typically have process safety specialists on staff.

The scope of the current research was the integration of PSM within wood pellet production. Conventional wood pellets were the primary focus of the research; pellets containing additives and torrefied pellets were outside of the scope of the research. It should be noted that, while different pellet production processes and finished products present different hazards, PSM also applies. The motivation was to support the adoption of PSM within the industry to help prevent and mitigate losses due to combustible dust hazards. The objective of the research was to develop a PSM integration tool for wood pellet facilities that can aid in the design of an implementation plan and resources to support implementation in the near future. This tool establishes an initial roadmap and strategy that is scalable for wood products manufacturing, and other small-to-medium enterprises more generally. This research was carried out with the Wood Pellet Association of Canada (WPAC) and the BC Forest Safety Council (BCFSC). WPAC is the national industry association for wood pellet producers and affiliated sectors, including equipment suppliers, consultants, and insurance. BCFSC is the health and safety association for WPAC (which includes both wood pellet production, as well as MDF), who supports WPAC's Safety Committee activities and initiatives.

This paper begins with describing the development of a PSM survey to perform a gap analysis, identification of key PSM element priorities, and the design of a phased approach to PSM implementation. Next, the collection of good practices and resources for each of the elements in the CSA Z767 framework is outlined. Based on the phased implementation approach and PSM resources, the development of the PSM integration tool and strategy is then discussed. Lastly, recommendations for future work are provided. The outcome of this work is a PSM integration tool consisting of a PSM survey and self-assessment worksheets to identify gaps, a collection of numerous PSM best practices, a series of PSM factsheets, and an implementation strategy.

2 | PSM SURVEY AND GAP ANALYSIS

To understand the current status of PSM within wood plants, a survey serving as a gap analysis was conducted. The objective was to identify instances where PSM may be present but may perhaps be informal or a part of another aspect of the organization's safety management system. Existing PSM frameworks were reviewed and considered for the basis of the survey. PSM systems have been developed and disseminated by (among others) the (i) Canadian Standards Association (CSA),[2] building on the work of the CSChE,[3] (ii) Center for Chemical Process Safety (CCPS), American Institute of Chemical Engineers,[4] and (iii) Energy Institute, United Kingdom.[5] To develop the desired PSM integration tool, it was determined that it would be most efficient to base the research efforts on a single, established PSM standard, which would allow a gap analysis to be completed against that standard. The CSA Z767 standard presented several benefits to the survey development, and the broader project as a whole, including:

- A Canadian standard would be used for a Canada-based project.
- The CSA standard was developed based on expertise and previous work of the CSChE, with which the current authors are familiar.
- The development of the CSA standard involved expertise from a range of industries, presenting the opportunity to leverage best practices from other high-hazard industries, such as oil and gas, to the wood pellet industry.

CSA Z767 was therefore selected as the PSM framework for this project to guide the integration of PSM concepts, beginning with the development of the PSM survey.

2.1 | PSM survey development, results, and discussion

Survey questions were developed by examining each of the clauses of the CSA Z767 standard and re-wording the clauses to pose them as questions in an attempt to understand the extent of application in a given company. This includes evaluating how informal (undocumented) and formalized (documented) the elements are, which is an approach outlined by CCPS.[6] Resources developed by the CSChE, including a PSM audit protocol and workbook, and site self-assessment tool[7,8] were also used to help guide the structure and approach to developing the survey questions. As an example, an excerpt of survey questions for the PSM element, management of change (MOC) follows:

- Is a management of change (MOC) program in place?
  - Yes (formalized)
  - Yes (informal)
  - No
  - Unsure
- Does the MOC system manage risks associated with the following changes? Select all that apply:
  - Design changes
  - Equipment changes
  - Procedural changes
  - Organizational changes
  - Not applicable
- If an MOC system is present, does it consider the following aspects? Select all that apply:
  - States what a change is.
  - States what type a given change is (emergency or temporary).
  - States what replacement-in-kind (RIK) is (which is not included in MOC).
  - Considers changes in operating procedures or safe operating limits.
  - Considers changes in the structure of the organization and staffing.
  - Includes a process for reviewing and approving changes.
  - Includes a risk assessment of the change.
  - Includes the communication of the change with relevant stakeholders before the change is made.
  - Includes any necessary training of relevant stakeholders before the change is made.
  - Includes a procedure for implementing an emergency change, as well as communicating with relevant personnel in a timely manner.
  - States the documentation needed for a change, including:
    - Explanation of proposed change
    - Change authorization
    - Training requirements
    - Up-to-date drawings
    - Confirmation that change was implemented as design intended
    - Not applicable

The full survey can be found in the project report on the PSM webpage of the Wood Pellet Association of Canada (WPAC).[9] The survey was distributed using Survey Monkey, which allowed for it to be easily shared and for respondents to participate anonymously. The survey was completed in a self-reported manner, not an audit that required proof or documents. The survey was developed to be completed by personnel who have involvement and knowledge in management system development; this includes plant managers, production supervisors, program coordinators, site safety resources, and project managers.

The survey results were used to:

- Identify which PSM elements should be prioritized first for implementation, and
- Understand the most common PSM elements, or parts of elements (CSA clauses), that have gaps in implementation. This helped inform the development of element-specific guidance to align with CSA Z767.

A pilot was first undertaken to engage stakeholders with the development of the survey and gather their feedback to improve its quality. The survey was then distributed to WPAC members that operate wood pellet and MDF plants. Two responses were collected for the survey pilot and six responses were collected during distribution to WPAC producing members, for a total of eight responses collected. Many of these were provided by personnel at companies that have more than one facility in Canada, which broadens the number of plants that are captured and represented by the survey responses. The survey responses were evaluated qualitatively via a single-analyst approach to identify key PSM elements to target for prioritization of improvement and implementation.

Figure 1 highlights survey respondent perspectives on which PSM elements should be targeted with prioritization for implementation and improvement. Figure 1 shows that process safety culture, process risk assessment and risk reduction, and key performance indicators (KPIs) are of primary interest of the surveyed operations. Figure 1 also illustrates that there is interest in implementing or improving almost all of the other PSM elements.

Figure 2 displays the degree of formalization (documentation) of the PSM elements and concepts at responding operations. The responses indicate that informal systems are being used for many of the PSM elements, which highlights that there is an opportunity to build on existing management system frameworks and improve these elements through explicit documentation, plans and programs. For example, Figure 2 shows that the element *investigation* is largely formalized (as explained by the regulatory requirement to investigate incidents), in contrast to *management of change* which has both informal and formal implementation. *Accountability* is also identified as an element that would benefit from formalization; this is viewed as a high-priority item given that process safety leadership is key for PSM implementation. Overall, these results demonstrate a strong interest among respondents to explicitly incorporate the PSM elements that are described by the CSA Z767 standard.

As a validation exercise, the survey was also distributed to personnel in other industries handling combustible dust. These industries included food production, panel board manufacturing, grain handling, engineered flooring, chemicals, and oil and gas. Eight participants were involved with the validation activity, all of which were outside of Canada. The purpose of this research activity was to support data gathering and complete a benchmark of the survey results from the wood pellet industry with other industries handling combustible dust. Validation involved examining other industries to understand the prioritization of other PSM elements for further exploration.

The validation activity also included virtual meetings with the subject matter experts (SMEs) who completed the survey to gather expert opinion on practices and implementation tools used to integrate the PSM elements. The follow-up interviews involved discussing approaches with the respondents regarding how organizations can integrate, progress, and maintain PSM. The interviews aimed to gather recommendations on key elements for emphasis and areas for prioritization. Numerous experts agreed that an explicit focus on enhancing risk assessments means taking proactive steps to improve risk reduction and prevent incidents from occurring. On the other hand, a focus on improving investigation means learning reactively from incidents to address gaps in risk reduction, which also contributes to incident prevention. Lastly, a focus on improving process safety culture facilitates the behaviours and approaches needed to implement systemic changes to prevent incidents.

2.2 | Design of phased approach for implementing PSM elements

Through the analysis of the survey data, expert opinions gathered from the validation interviews, and expert input from the project team, the research suggests that the following CSA Z767 PSM elements should be prioritized first:

- Accountability
- Process safety culture
- Process risk assessment and risk reduction
- Management of change (MOC)
- Investigation
- Key performance indicators

Next, the importance of training, along with avoiding human error, was also identified. The survey also found

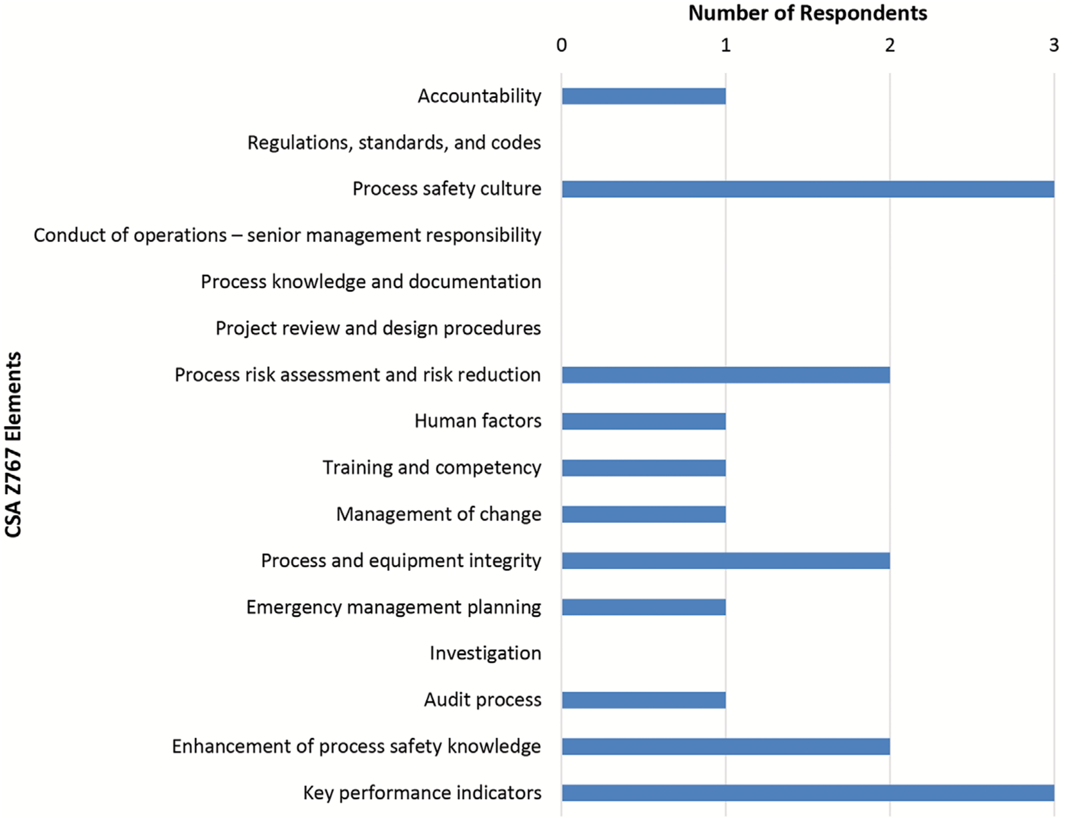


FIGURE 1 Results of a wood pellet production facilities survey on the preferred prioritization of Canadian Standards Association (CSA) Z767 process safety management (PSM) elements for implementation and improvement.

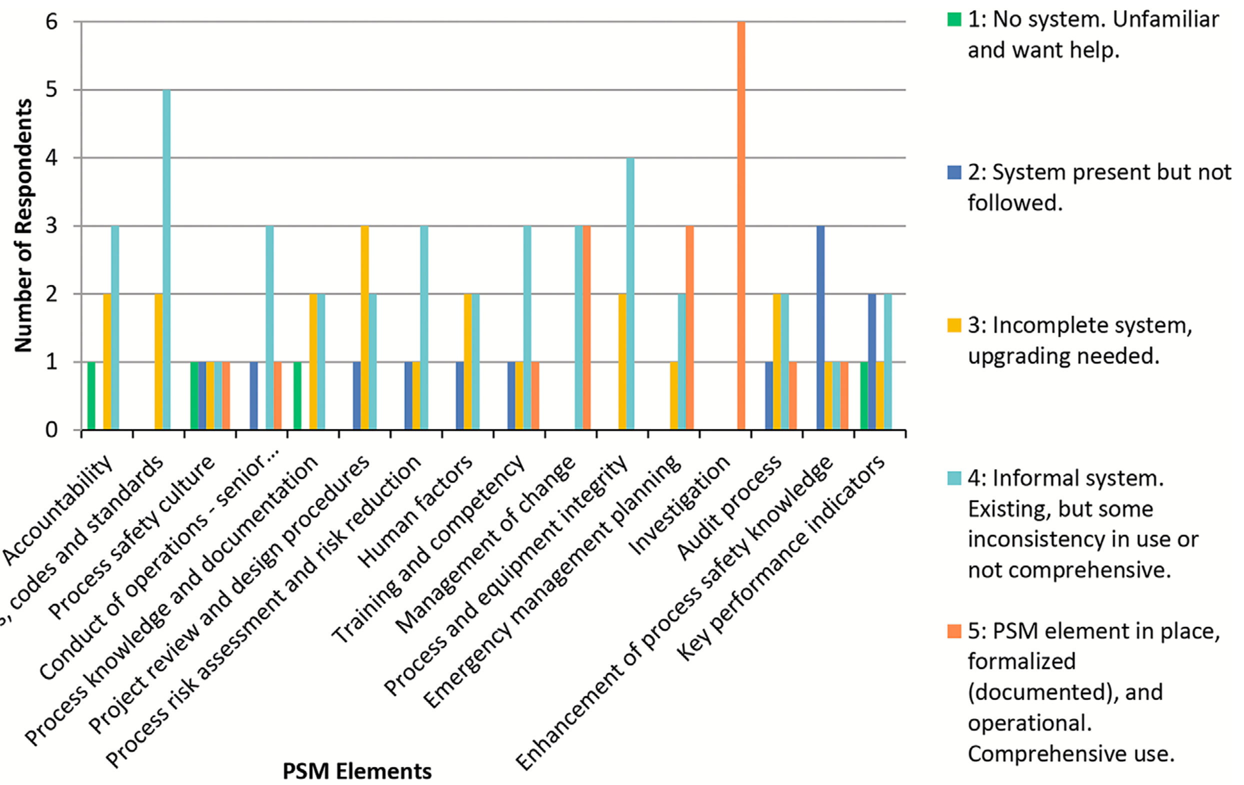


FIGURE 2 Results of a survey of wood pellet production facilities investigating the formalization of Canadian Standards Association (CSA) Z767 process safety management (PSM) elements.

there are opportunities to improve the effectiveness of training programs. Additionally, the importance of preventative maintenance and equipment reliability has been an ongoing focus for industry, including through the previously completed critical control management project. Based on the survey, it was observed that measures, such as implementing a formal pre-startup safety review (PSSR), will enhance the process and equipment integrity PSM element. As with the importance of accountability discussed previously, senior management responsibility for conduct of operations was also recognized by respondents. These results imply a second phase of PSM elements that would be comprised of:

- Training and competency
- Process and equipment integrity
- Human factors
- Conduct of operations–senior management responsibility
- Process knowledge and documentation

Lastly, while the survey indicated there are opportunities to formalize aspects of emergency management planning, this element was not as high of a priority as the other PSM elements listed above. While 'Project review and design procedures' was identified in Figure 2 as an element of interest for upgrading, the survey used only one self-assessment question for this element, which did not broadly identify any issues. For 'Enhancement of process safety knowledge', as well as 'Regulations, codes, and standards', the survey did not identify as many gaps, and again, as shown in Figure 2, were not selected as high priority. Finally, the audit process would be used once a PSM framework has been implemented, so this element resulted in a lower priority. Due to these findings, the elements that are proposed to be focussed on within a third phase are:

- Emergency management planning
- Project review and design procedures
- Audits process
- Regulations, codes, and standards
- Enhancement of process safety knowledge

While the PSM elements have been organized with respect to suggested implementation phases, this serves as a starting point for a given facility. An important consideration for implementation will be site-specific judgements and priorities on a case-by-case basis. Different sites may require different prioritization schemes based on current status of PSM use, gaps in their use, and degree of formalization. This will clearly require a flexible approach. For example, while survey responses indicated the element of investigation was formalized and had a correspondingly low preference for prioritization, it is a key element and an emphasis on investigation will help any operations that do have gaps in their program.

Based on the outcomes of the PSM survey activities, a prioritization of elements has thus been identified and a staged approach to PSM element implementation has been developed. Prioritization can also be adapted based on the operation's judgement through considering the outcomes of self-assessment, anticipated effort, and perceived risk. The staged approach is outlined in Table 1. While it is recognized that each of the PSM elements are ultimately necessary, this prioritized subset provides an approach for implementing PSM systematically and increases the feasibility for organizations who may be beginning the process of building process safety programs.

3 | COLLECTION OF PSM IMPLEMENTATION GOOD PRACTICES AND RESOURCES

As previously described, this research project is ultimately focused on PSM integration tool development,

TABLE 1 Staged approach to PSM element implementation with respect to CSA Z767 (2017).

Stage	Element
1	Accountability
	Process safety culture
	Process risk assessment and risk reduction
	Investigation
	Management of change
	Key performance indicators
2	Training and competency
	Process and equipment integrity
	Human factors
	Conduct of operations–senior management responsibility
	Process knowledge and documentation
3	Emergency management planning
	Project review and design procedures
	Audits process
	Regulations, codes, and standards
	Enhancement of process safety knowledge

Abbreviations: CSA, Canadian Standards Association; PSM, Process safety management.

which would be used to support subsequent industry implementation through a long-term strategy. A review of key resources that can be incorporated within a given implementation approach was therefore conducted. Resources that provide guidance on PSM implementation with a particular focus on small businesses and non-chemical process industries were identified through a comprehensive literature review as shown in Table 2. These resources were collected from various online searches of academic literature and white papers using process safety-related keywords.

3.1 | Resources for CSA Z767 PSM elements

Good practices identified for the integration of PSM elements were collected and organized with respect to each of the 16 CSA Z767 standard elements. The resources identified in Tables 3–18 serve as examples for protocols that can be customized and tailored for the wood products manufacturing industry. These resources are further discussed in Section 4 with respect to their inclusion in PSM self-assessments as part of the PSM integration tool.

TABLE 2 Process safety management (PSM) program documentation examples and guidance.

References	Resource description
HNI risk advisors[10]	Example of a PSM plan based on OSHA standard 29 CFR 1910.119, process safety management of highly hazardous substances (PSM)
Newington energy LLC[11]	Example of PSM plan
Pennsylvania State University[12]	Pennsylvania State University has implemented PSM to manage hazardous operations. Examples of written procedures for each of the PSM elements are provided.
Nevada division of environmental protection[13]	The Nevada Division of Environmental Protection Chemical Accident Prevention Program (CAPP) regulates facilities handling highly hazardous substances. Guidance and checklists for process safety elements are provided.
Rio Tinto[14]	Rio Tinto process safety standard
Gulf Petrochemicals & Chemicals Association[15]	Process safety code
PSM Egypt[16]	PSM implementation guidelines

TABLE 3 Best practices and resources for accountability.

References	Resource description
Health and safety executive[17]	Process safety leadership guiding principles
OECD[18]	Corporate governance for process safety: Self-assessment questionnaire for senior leaders
Levovnik et al.[19]	Article exploring how different leadership types relate to facilitating managers' commitment to safety.
Travers[20]	Practical leadership for process safety management
Control of Major Hazards (COMAH)[21]	Managing risk—the hazards that can destroy your business. A guide to leadership in process safety.
Control of Major Hazards (COMAH)[22]	Major Hazard leadership intervention tool
CalOSHA (California Occupational Safety and Health)[23]	Identifying measurable safety goals
Process Safety Forum[24]	Resources (leadership principles, safety leadership charter, lessons learned)
Center for Chemical Process Safety[25]	Process safety leadership from the boardroom to the frontline

4 | PSM INTEGRATION TOOL DEVELOPMENT

This section explains the industry resources and PSM implementation strategy that comprise the PSM integration tool. One of the industry resources is a set of self-assessment worksheets, which are fillable documents that can be used by operations to identify gaps in their existing programs. Another industry resource are factsheets which are brief two-page communication tools to highlight key messages about PSM. Potential KPIs for monitoring both PSM implementation, as well as process safety metrics specific to wood pellet production, have also been developed. The implementation strategy consists of 10 high-level activities, and serves as a guide for an industry-driven process.

4.1 | Industry resources

PSM self-assessment worksheets to perform a qualitative gap analysis against the PSM standard (in this case, the CSA Z767 standard) were also identified as an initial step in implementation. This allows operations to identify where changes to programs and policies need to be made.

TABLE 4 Best practices and resources for process safety culture.

References	Resource description
WorkSafe Queensland[26]	Safety climate and safety culture videos, assessment guidance, factsheet (safety culture, climate and leadership), factsheet (getting the most out of your safety climate survey)
Transport Canada[27]	Example safety culture policy statement
Manufacturing Safety Alliance of British Columbia[28]	Safety culture: A guide to effective measurement and improvement
Energy Institute[29]	Hearts and minds safety culture toolkit
Contra Costa County Health Services[30]	Safety culture assessments overview and survey example (baker panel report)
Contra Costa County Health Services[31]	Safety culture assessments guidance
DuPont[32]	Safety culture survey example: DuPont safety perception survey
Center for Chemical Process Safety[33]	Building process safety culture tool kit: Tools to enhance process safety performance
WorkSafeBC[34]	Enhancing health & safety culture & performance
Health and Safety Executive[35]	Organizational culture: Guidance
Health and Safety Executive[36]	Extract from inspectors' human factors toolkit: Safety culture questions
Arendt and Manton[37]	How to ensure sustainable process safety performance–Strategies for managing, maintaining, and improving PSM systems

Abbreviation: PSM, process safety management.

Using the PSM gap analysis survey discussed in Section 2, PSM self-assessment worksheets for Accountability, and the high priority elements of Process Safety Culture, Management of Change, and KPIs were produced. These self-assessments include sections for developing corrective action plans, as well as the resources and good practices that can be used to close the identified gaps. As future work, the self-assessment worksheets for the remaining PSM elements will be developed during the early stage of industry implementation, which are:

- Process risk assessment and risk reduction
- Investigation
- Training and competency

TABLE 5 Best practices and resources for process risk assessment and risk reduction.

References	Resource description
Gulf Petrochemicals and Chemicals Association[15]	Process safety code: Process risk management
Wood Pellet Association of Canada[38]	Critical control management resource
WorkSafeBC[39]	Barrier-focused approaches to risk analysis–Introduction to bow tie analysis
Technical Standards and Safety Authority[40]	Path 2 RSMP guidelines for operating engineers safety program–Appendix B: Detailed guidance & references on process safety risk assessment

TABLE 6 Best practices and resources for management of change.

References	Resource description
Safety Advisory Foundation for Education and Research[41]	Combustible dust management assessment handout
Occupational Health and Safety Administration[42]	MOC guidelines
Center for Chemical Process Safety[43]	Golden rules for combustible dust
PSM Egypt[44]	Management of change guideline
Canadian Society for Chemical Engineering[45]	Managing the health and safety impacts of organizational change
National Fire Protection Association (NFPA) 652[46]	Standard on the fundamentals of combustible dust
National Fire Protection Association (NFPA) 664[47]	Standard for the prevention of fires and explosions in wood processing and woodworking facilities
Pennsylvania State University[48]	Process safety management: management of change form

Abbreviation: MOC, management of change.

- Process and equipment integrity
- Human factors
- Conduct of operations—senior management responsibility
- Process knowledge and documentation
- Emergency management planning
- Project review and design procedures
- Audits process
- Regulations, codes, and standards
- Enhancement of process safety knowledge

TABLE 7 Best practices and resources for investigation.

References	Resource description
Center for Chemical Process Safety[49]	Introduction to incident investigation
Health and Safety Executive[50]	Investigating accidents and incidents: A workbook for employers, unions, safety representatives and safety professionals
Pennsylvania State University[51]	Compliance guidelines for incident investigation
Pennsylvania State University[52]	Process safety incident report form

TABLE 8 Best practices and resources for key performance indicators (KPIs) for process safety.

References	Resource description
Health and Safety Executive[53]	Developing process safety indicators: A step-by-step guide for chemical and major hazard industries
Fanelli[54]	Process safety performance indicators for a fuel storage site: A worked example
Chemical Business Association[55]	Safety performance leading indicators
Center for Chemical Process Safety[56]	Process safety metrics guide for leading and lagging indicators (Version 4.1)

TABLE 9 Best practices and resources for conduct of operations.

References	Resource description
Center for Chemical Process Safety[57]	Introduction to conduct of operations
Center for Chemical Process Safety[58]	Key principles of process safety for operational readiness
Klein and Thompson[59]	Audit process safety for compliance and performance, chemical engineering progress (CEP)

TABLE 10 Best practices and resources for process knowledge and documentation.

References	Resource description
Nevada Division of Environmental Protection Chemical Accident Prevention Program[60]	Process safety information program
Inland Star Distribution[61]	Process safety information procedure
Environmental Protection Agency[62]	Presentation: Prevention program safety requirements for program level 3 processes

TABLE 11 Best practices and resources for human factors.

References	Resource description
Health and Safety Executive[63]	Reducing error and influencing behaviour
WorkSafeBC[64]	Human factors overview and resources
Energy Safety Canada[65]	Video: Human and organizational performance–The 5 principles in action
Gambetti et al.[66]	The human factor in process safety management
Contra Costa County Health Services[67]	Process Hazard analysis human factors checklist
State of Western Australia (Department of Mines, Industry Regulation and Safety)[68]	Human factors self-assessment guide and tool for safety management systems at petroleum and major Hazard facility operations
Center for Chemical Process Safety[69]	Guidelines for preventing human error in process safety

TABLE 12 Best practices and resources for training and competency.

References	Resource description
Hitachi[70]	HSE training matrix
Hitachi[71]	HSE requirements for contractors
Leach and Wright[72]	A guide to enhancing process safety and plant efficiency through the competence of control room operators (CROs)

Abbreviation: HSE, health and safety executive.

The use of factsheets to communicate key messages to operations is based on the leading best practice set by the CCPS Process Safety Beacon.[104] The Process Safety Beacon is designed to primarily target process safety messages to plant operators, maintenance personnel, and production staff. Factsheets have also been created and developed as part of the current research to support the understanding of PSM elements and to explicitly integrate these PSM concepts within wood products manufacturing. Factsheets that provide an overview of PSM, Accountability, and the high priority elements of Process Safety Culture, Management of Change, and KPIs were created as part of the current work. Additional factsheet and WPAC website resources are being developed as part of the

TABLE 13 Best practices and resources for process and equipment integrity.

References	Resource description
Honeywell[73]	Alarm management primer
Health and safety executive[74]	Alarm handling checklist
Health and safety executive[75]	Better alarm handling information sheet
ABB[76]	Alarm management–A practical guide
Hydrocarbon processing[77]	Alarm management: A pillar of process safety management
Marsh[78]	Risk engineering position paper: Pre-start-up safety review

TABLE 14 Best practices and resources for regulations, codes, and standards.

References	Resource description
Center for Chemical Process Safety[79]	Introduction to compliance with standards
Canadian Standards Association[2]	CSA Z767 process safety management standard

Abbreviation: CSA, Canadian Standards Association.

TABLE 15 Best practices and resources for project review and design procedures.

References	Resource description
Contra Costa County Health Services[80]	Process Hazard analysis facility siting checklist
Environmental Protection Agency Ohio[81]	Facility siting checklist
Bridges and Tew[82]	Controlling risk during major capital projects

TABLE 16 Best practices and resources for emergency management planning.

References	Resource description
Occupational Safety and Health Administration[83]	Firefighting precautions at facilities with combustible dust
BC Energy Regulator[84]	Emergency management manual
Nova Chemical[85]	Pipeline operations emergency response plan
Arc Resources Ltd.[86]	Emergency management program
Arc Resources Ltd.[87]	Northeast BC emergency response program
Fortis BC[88]	Corporate emergency response plan
Persson[89]	Silo fires: Fire extinguishing and preventive and preparatory measures

TABLE 17 Best practices and resources for audit process.

References	Resource description
Occupational Safety and Health Administration[90]	PSM auditing checklist
Georgia Tech Occupational Safety and Health Program[91]	PSM program review checklist
Canadian Society for Chemical Engineering[7]	Process safety management standard audit protocol
Canadian Society for Chemical Engineering[8]	Process safety management audit protocol workbook
Canadian Society for Chemical Engineering/Major Industrial Accidents Council of Canada (MIACC)[92]	Site self-assessment tool
Nevada Division of Environmental Protection[93]	Process safety element audit checklist

Abbreviation: PSM, process safety management.

aforementioned industry implementation initiative. Figure 3 is an example of the two-page factsheet developed; Process Safety Culture is the topic of this factsheet.

As a key objective of the current research is ensuring effective integration of PSM into operations, the development of KPIs is critical. Effective integration refers to the measurement of PSM performance via safety metrics and the assurance of a robust safety culture. Effective integration requires the identification of appropriate leading/lagging indicators and safety culture components.

There are three categories of KPIs of interest for this research. The first is KPIs for PSM implementation which can monitor and track the progress of integrating PSM elements. The second is site-specific process safety KPIs, focusing on leading indicators such as inspections and training, and lagging indicators, including fires and deflagrations. The third is process safety KPIs for industry benchmarking to monitor industry-wide PSM performance.

4.1.1 | PSM implementation KPIs

Using the self-assessment worksheets developed in this research and referring to the implementation indicators

TABLE 18 Best practices and resources for enhancement of process safety knowledge.

References	Resource description
International Association of Oil and Gas Producers[94]	Process safety fundamentals
Conoco Philips[95]	Process safety-Process safety summit
Energy Institute[96]	Toolbox webinar series (including learning from incidents, the role of leadership in accident investigations, learning from what goes right and others listed)
DustEx Research Ltd.[97]	Combustible dust incident database and reports
Gulf Petrochemicals and Chemicals Association[98]	Process safety code: Process risk management–Enhancing process safety knowledge
BC Forest Safety Council[99]	Combustible dust resources
US Chemical Safety Board (US CSB)[100]	Chemical safety (including combustible dust)
Hopkins[101]	Safety, culture, and risk
Institution of Chemical Engineers (IChemE)[102]	Safety lore
Klein and Vaughen[103]	Process safety: Key concepts and practical applications
Center for Chemical Process Safety[104]	CCPS process safety beacon
Occupational Safety and Health Administration[105]	Process safety management for small business
Canadian Society for Chemical Engineering[106]	Process safety management division
Mary Kay O'Connor Process Safety Center[107]	Education, research, resources
Major Accident Reporting System (MARS)[108]	Chemical accident report site
The ARIA Database[109]	Chemical accident report site
The Japanese Failure Knowledge Database[110]	Chemical accident report site
International Association of Oil & Gas Producers SafetyZone[111]	Resources and accident reports

Abbreviation: CCPS, center for chemical process safety.

outlined by the Technical Standards and Safety Authority,[40] potential PSM implementation KPIs include percent completion of:

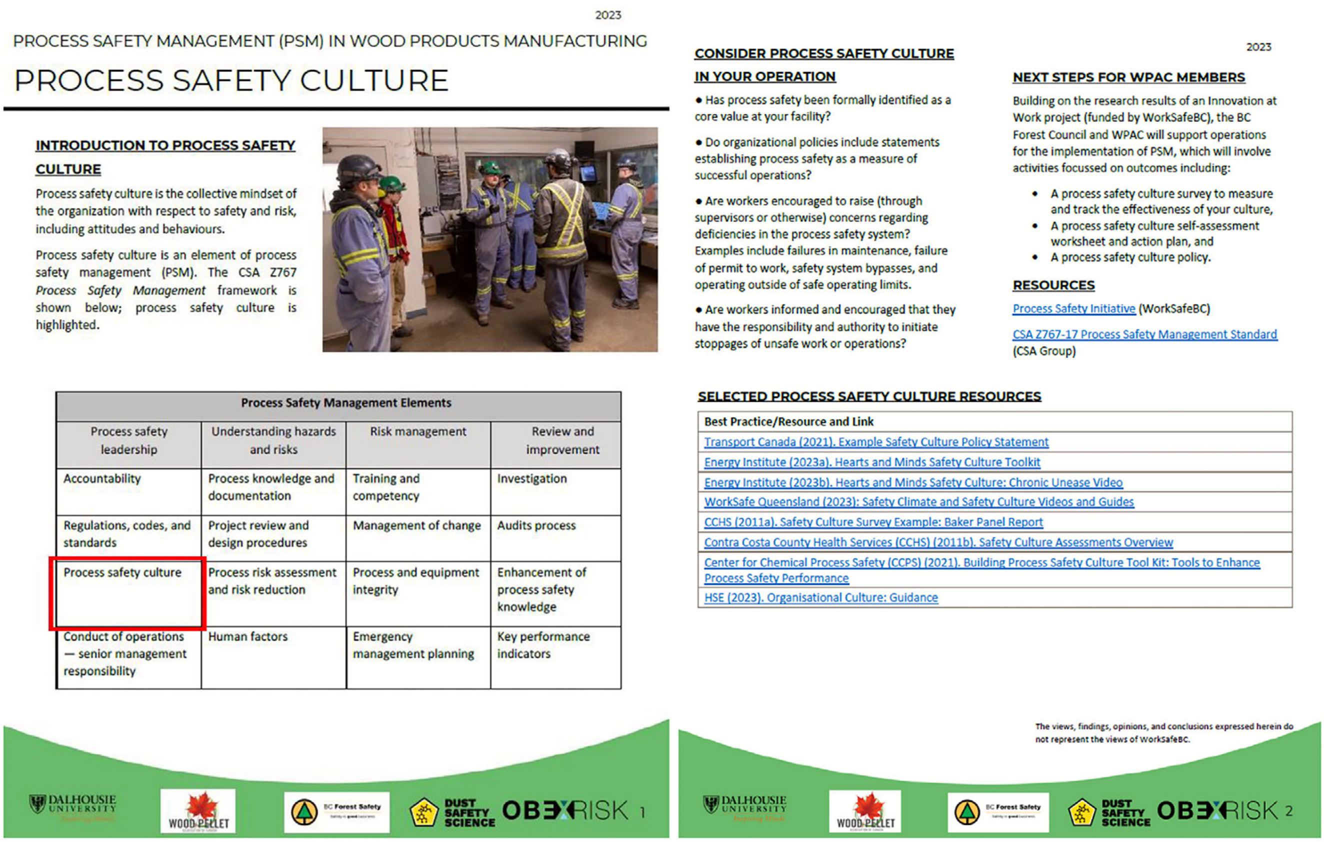
- PSM element self-assessment worksheets
- Corrective action plans identified in self-assessment worksheets
- PSM element policies development
- PSM element procedures development

Additionally, desired outcomes and target indicators of implementation (as given by the Technical Standards and Safety Authority)[40] include:

- Senior leadership knowledge of, and commitment to, the PSM framework
- Operating staff knowledge of, and commitment to, the PSM framework and its procedures and policies
- Staff training records
- Incident reporting and investigation records
- Accessible information system
- Testing, inspection, and maintenance records
- KPI tracking system
- Audit reports
- Corrective action plans for implementing recommendations from risk assessments
- Documented MOC program, including updating the PSM program based on plant changes, and completing risk assessments and approval logs on new projects and process changes

4.1.2 | Site-specific process safety and industry benchmarking KPIs

The UK Health and Safety Executive[53] provides a step-by-step approach that can be adapted for the wood pellet industry. Fanelli[54] describes a worked example of developing proposed KPIs for a fuel storage site following the method described by the Health and Safety Executive.[53] For wood pellet production, there are numerous leading metrics that could be chosen and monitored. The scope of the hazard is combustible dust ignition in raw fibre storage, hammer mills, dryers, baghouses, pelletizers, and finished pellet silo storage. The desired safety outcomes include elimination of fires and explosions, and fire detection and fire-fighting equipment being available and properly functioning. Based on hazard awareness



2023

PROCESS SAFETY MANAGEMENT (PSM) IN WOOD PRODUCTS MANUFACTURING

PROCESS SAFETY CULTURE

INTRODUCTION TO PROCESS SAFETY CULTURE

Process safety culture is the collective mindset of the organization with respect to safety and risk, including attitudes and behaviours.

Process safety culture is an element of process safety management (PSM). The CSA Z767 *Process Safety Management* framework is shown below; process safety culture is highlighted.

Process Safety Management Elements			
Process safety leadership	Understanding hazards and risks	Risk management	Review and improvement
Accountability	Process knowledge and documentation	Training and competency	Investigation
Regulations, codes, and standards	Project review and design procedures	Management of change	Audits process
Process safety culture	Process risk assessment and risk reduction	Process and equipment integrity	Enhancement of process safety knowledge
Conduct of operations — senior management responsibility	Human factors	Emergency management planning	Key performance indicators

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CONSIDER PROCESS SAFETY CULTURE IN YOUR OPERATION

- Has process safety been formally identified as a core value at your facility?
- Do organizational policies include statements establishing process safety as a measure of successful operations?
- Are workers encouraged to raise (through supervisors or otherwise) concerns regarding deficiencies in the process safety system? Examples include failures in maintenance, failure of permit to work, safety system bypasses, and operating outside of safe operating limits.
- Are workers informed and encouraged that they have the responsibility and authority to initiate stoppages of unsafe work or operations?

NEXT STEPS FOR WPAC MEMBERS

Building on the research results of an Innovation at Work project (funded by WorkSafeBC), the BC Forest Council and WPAC will support operations for the implementation of PSM, which will involve activities focussed on outcomes including:

- A process safety culture survey to measure and track the effectiveness of your culture,
- A process safety culture self-assessment worksheet and action plan, and
- A process safety culture policy.

RESOURCES

Process Safety Initiative (WorkSafeBC)

CSA Z767-17 Process Safety Management Standard (CSA Group)

SELECTED PROCESS SAFETY CULTURE RESOURCES

Best Practice/Resource and Link
Transport Canada (2021). Example Safety Culture Policy Statement
Energy Institute (2023a). Hearts and Minds Safety Culture Toolkit
Energy Institute (2023b). Hearts and Minds Safety Culture: Chronic Unease Video
WorkSafe Queensland (2023): Safety Climate and Safety Culture Videos and Guides
CCHS (2011a). Safety Culture Survey Example: Baker Panel Report
Contra Costa County Health Services (CCHS) (2011b). Safety Culture Assessments Overview
Center for Chemical Process Safety (CCPS) (2021). Building Process Safety Culture Tool Kit: Tools to Enhance Process Safety Performance
HSE (2023). Organisational Culture: Guidance

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FIGURE 3 Process safety management (PSM) factsheet for process safety culture.

and operational experience, key upset conditions with a high likelihood of occurring or those with severe consequences were previously identified by the Safety Committee of the WPAC. These hazards were collated as part of an industry-wide initiative to develop an operator competency training program. Additionally, work was previously undertaken to use bow-tie analysis to assess combustible dust hazards associated with wood pellet production; the outcomes of these hazard analyses are described by Rayner Brown et al.[112]

Proposed metrics are for these types of upset conditions are given in Table 19. These are suggested for industry benchmarking, which would also be recorded as part of site-specific KPIs. These potential KPIs are unique for the wood pellet production process. When first entering the process, magnets and screens are used to remove rocks and metal. Prior to drying, the fibre is referred to as 'green' fibre. The induced draft (ID) fan draws air through dryers and removes combustible gas from the system. After being dried, fibre may be temporarily stored in a dry fibre silo prior to pelletizing to maintain infeed fibre supply. The dry fibre is extruded into pellets by the pelletizers. The cooler is used to cool down the pellets prior to packaging or loading into silos and bulk transportation. Material is transported between processes by different conveyance systems (e.g., bucket elevators, drag chain conveyors, belts). Numerous ignition sources are possible in the production process, including mechanical and electrical failure, hot work, or smouldering of material on hot surfaces. Pellet storage also presents a fire risk. In silos, flat warehouses, or bulk storage, pellets can self-heat due to biological activity, which is influenced by numerous factors including wood species, fibre size, moisture content, and ambient temperature.[113] Spark detection and deluge systems are commonly used for fire protection in the production process. Silo fires require alternate approaches for emergency response and fire extinguishment, namely nitrogen inerting, as described by Persson.[89] An operator in a control room oversees and runs the entire process through the human–machine interface (HMI) system.

It is also recommended that the metrics be tracked with respect to dates so annual/seasonal trending can be completed to analyze how seasonal fluctuations impact process safety; other factors, including species and feedstock, will also be relevant. Metrics should be selected that are practical to collect and report, and allow opportunities for improvement to be identified.

TABLE 19 Categories of incidents and near-misses as the basis for the development of leading and lagging indicators for site-specific and industry benchmarking metrics.

Incident detail	Category
Materials involved	Green (not dried) wood fibre, dry wood fibre, wood pellets, combustible gas (syn gas)
Equipment involved	Wood pellet: raw material/wood fibre storage, green hammer mill, dry hammer mill, dry fibre silo, dryer (direct-heated belt dryer, indirect heated belt dryer, drum dryer), dust collector (cyclone, baghouse), elevator/conveyor, pelletizer/extruder, cooler, pellet silo, mobile equipment. Medium-density fibreboard (MDF): raw material handling, drying, forming, dust collecting (production baghouse), finishing, pressing.
Ignition sources (if source was identified)	• Hot work and welding • Mechanical sparks • Electrical equipment • Smoulder spots • Self-heating/ignition • Hot surfaces • Static electricity • Friction • Propagation from upstream or downstream equipment
Incident type (lagging indicators)	• Fire (smoulder, incipient, fully developed) • Induced draft (ID) fan fire • Pellet silo fire • Pelletizer/extruder fire • Cooler fire • Ventilation pipe fire • Dry fibre silo fire • Conveyance fire • Hammer mill deflagration • Dryer deflagration • Deflagration (mobile equipment) • Deflagration (dust collector) • Deflagration propagation (multiple pieces of equipment impacted) • Deflagration/explosion (any other equipment/area as specified by facility)
Upset conditions—leading indicators (as these are not a top event or consequence, such as a fire or explosion)	Electrical: • Loss of power, and key process components affected by an electrical loss, including human–machine interface/programmable logic controller (HMI/PLC) communication, ID fans (loss of air flow), deluge system, electric fire pump, fire and explosion detection systems • Communication error between PLC and HMI or between electrical and computer communication • Auto deluge malfunctions • Motor failure Mechanical: • Cyclone plug-ups/clogs • Conveyor plug-ups and breakdowns • Dryer infeed conveyor failure • Dryer outfeed conveyor failure • Drag chain breakage • Hammer mill shutdowns • Belt breakage (dryer or conveyor) • Dryer high temperature shutdowns (due to losing power or due to losing feed) Weather: • Deluge system failure due to freezing • Dryers having trouble with fluctuating fibre moistures (inconsistent speeds) • Sparks caused by combustion air fluctuating with ambient air • Freeze-up in abort gates • Freeze-up in utilities/compressed air system • Operational issues with pneumatic sensing/differential pressure lines/flow sensor due to cold temperatures • Freezing of incline conveyors

(Continues)

TABLE 19 (Continued)

Incident detail	Category
	• Blower intake screens plugging due to hoar frost • Building dry valve systems breaking the drain systems due to frost • Excursions of high-speed bearing temperatures, including hammermills and fans, during hot ambient temperatures • Excursions of high pellet temperatures out of the coolers and into the rail cars during hot ambient temperatures • Issues with electrical drives, power distribution centres (PDCs), and motor control centres (MCCs) during hot ambient temperatures Operations: • Magnets filled with metal contaminants (not cleaned) • Rock traps full (not cleaned or emptied) • Worn hammers • Holes in hammer mill screens • Pelleter roll and dies worn or out of adjustment • Bridging of material in surge bins • Failing bin level indicators (bindicators) • Fibre too wet or too dry coming into pelletizers • Decks bridging off or running empty • Mixing bin bridging • Cooler bins plugging up • Manual deluge malfunction • Burner not relighting • Dryer startup/shutdown (procedure not followed)

4.2 | PSM implementation strategy

Establishing a PSM steering committee was also identified as a step to be taken by industry for effective PSM implementation. In addition to engaging operations and creating ownership, a steering committee provides oversight, communicates priorities and necessary resources, and creates short-term and long-term milestones. Resources for PSM steering committees include PSM Egypt[16] and Pennsylvania State University.[114] The following discussion highlights strategic next steps for PSM implementation in wood products manufacturing and other industrial sectors planning to implement PSM.

WPAC and BCFSC anticipate that PSM implementation in the Canadian wood pellet sector will take over 5–7 years to complete. Implementation will be guided and supported by WPAC and BCFSC but will be company-driven by establishing a PSM Steering Committee. Cross-industry collaboration facilitates the efficient development and sharing of resources and tools. With guidance from PSM implementation resources from PSM Egypt[16] and TSSA,[40] 10 activities that have been identified in the current research to support PSM implementation are given below:

1. Obtain leadership and stakeholder commitment to proceed with PSM implementation through initiative led by WPAC and BCFSC.
2. Establishment of a PSM Steering Committee with an appropriate scope and objectives. Development of a process by WPAC and BCFSC to provide ongoing support across the industry.
3. Development of implementation guide, workplan and milestones by the PSM Steering Committee. Proposal of timeline, milestones, and other processes to support implementation.
4. Development of self-assessment worksheets for each PSM element with support of the PSM Steering Committee.
5. Development of additional implementation resources by WPAC and BCFSC, such as workshops and webinars, to provide guidance on PSM elements and self-assessments.
6. Completion of gap analysis by companies against CSA Z767 standard using the self-assessment sheets.
7. Development of action plans by operations to address identified areas for improvement. Tools and approaches, such as value graphing (evaluating corrective actions with respect to effort and value), will be provided by WPAC and BCFSC to help manage priorities.
8. Creation of a library policies and procedures by WPAC and BCFSC to share with companies.
9. Development of KPIs for PSM implementation, along with site-specific and industry benchmarking process safety KPIs, so WPAC, BCFSC, and the Steering

Committee can regularly review, monitor, and report progress.

10. As part of the Plan-Do-Check-Act cycle, development of guidance by WPAC and BCFSC to support companies in determining the effectiveness of improvement actions and undertaking additional steps to close gaps.

5 | RECOMMENDATIONS AND FUTURE WORK

In the province of British Columbia, while PSM standards are not currently referenced in occupational health and safety legislation, there is significant potential for process safety amendments in the near future. Beginning the process of implementing PSM proactively will well-position industries, like wood products manufacturing, should regulations come into effect.

For the Canadian wood pellet sector, the early stages of industry-driven implementation are actively underway, which involves input from operations to transition from the currently described research project into an implementation plan. A workplan for implementation activities includes the formation of a PSM steering committee, rollout of self-assessment worksheets, developing action plans, and developing KPIs to track implementation progress. In addition to these broad implementation activities, a recommendation for future work includes the creation of webinars on safety culture and incident investigation, hosted within the WPAC learning platform. The development of site-specific, industry benchmarking, and PSM implementation KPIs is also an area for future work, including a pilot program for validation of the proposed leading and lagging indicators. It is also recommended that a PSM audit tool tailored for operations be developed by BCFSC and WPAC to support and sustain PSM performance.

6 | CONCLUSION

The outcomes of this research provide a PSM integration tool for wood products manufacturing, including a PSM survey for gap analysis, self-assessment worksheets supported by a collection of industry best practices, a series of informative factsheets, and an implementation strategy. The CSA Z767 framework was selected to guide PSM implementation. Using survey results and expert opinion, elements were prioritized, which informed the development of a staged or phased approach to PSM element implementation. This approach involves focussing on a selection of PSM elements to integrate at operations, followed by elements in subsequent stages. The strategy of PSM element phases helps make the PSM framework more feasible for adoption by wood products manufacturing and other small-and-medium enterprises.

Stage one PSM elements are Accountability, Process safety culture, Process risk assessment and risk reduction, Management of change, Investigation, and KPIs for process safety. Stage two elements are Conduct of operations, Process knowledge and documentation, Human factors, Training and competency, and Process and equipment integrity. Stage three elements are Emergency management planning, Project review and design procedures, Audit process, Regulations, standards, and codes, and Enhancement of process safety knowledge. The PSM implementation strategy, which includes 10 primary activities, serves as a roadmap to steer this phased approach.

This research project provides a foundation to improve the integration of process safety in operations and has enhanced the understanding of how the CSA Z767 can be used to meet the needs of the wood products manufacturing industry. A broad culture shift in the industry is being observed through the continued support of progressive process safety initiatives. Process safety has been embraced by WPAC leadership and this project has accelerated the awareness and understanding of PSM across the wood products manufacturing industry and others handling combustible dust.

AUTHOR CONTRIBUTIONS

Kayleigh Rayner Brown: Data curation; formal analysis; investigation; methodology; resources; visualization; writing – original draft; writing – review and editing. **Bill Laturnus:** Conceptualization; funding acquisition; investigation; methodology; writing – review and editing. **Gordon Murray:** Conceptualization; funding acquisition; supervision; writing – review and editing. **Fahimeh Yazdanpanah:** Conceptualization; funding acquisition; writing – review and editing. **Chris Cloney:** Conceptualization; funding acquisition; investigation; methodology; writing – review and editing. **Paul Amyotte:** Conceptualization; funding acquisition; investigation; project administration; writing – review and editing; resources; supervision; validation; methodology.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicting interests to declare.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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