Building Tomorrow's Society
Bâtir la Société de Demain

Fredericton, Canada
June 13 – June 16, 2018/ *Juin 13 – Juin 16, 2018*

DEVELOPING AND VALIDATING METRICS TO EVALUATE THE OCCUPATIONAL HEALTH AND SAFETY PERFORMANCE OF SUSTAINABLE BUILDING PROJECTS

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Abstract: The potentially lower occupational health and safety(OHS) performance of some sustainable building (SB) projects reinforces the need for tools and measures that would improve their performance through improving the maturity of the OHS practices implemented on them and addressing the risks that would undermine them. In this light, there is a need to move beyond traditional OHS performance assessment when assessing these buildings to high performance measures which can monitor the capacity of an organization to develop a SB project safely and drive performance towards continuous improvement. This paper presents the methods used to develop and validate a set of OHS performance metrics to evaluate the OHS performance of SB projects throughout their design and construction. The 35 OHS performance metrics proposed were categorized per safety maturity driver and developed based on a detailed literature review and an identification of the key best practices involved in the management of the OHS of these projects. By engaging the expert judgment of OHS researchers and experts through a questionnaire survey, the performance metrics were validated against the criteria of analytic soundness, practicality and predictability as recommended from the literature. It was found that 25 of the performance metrics received positive validation while the remaining 10 performance metrics received negative validation. The research is part of an ongoing research initiative led by the Construction Engineering and Management Group at the University of Manitoba and aiming to evaluate the OHS performance of these projects using performance indicators.

1 INTRODUCTION

Sustainable building (SB) projects have often considered issues related to energy, water and indoor environmental quality much more compared to occupational health and safety (OHS) issues. (Rajendran et al. 2009, Hinze et al. 2013, Chen 2010, Greg 2012). Little has been done to evaluate the OHS of SB projects despite it being a fundamental component of social sustainability and directly linked to economic sustainability because of its financial implications (Tom 2014). A review of the literature reveals that some SB have more complex design elements than non-SB, and may therefore be riskier to build from a OHS perspective compare to non-SB (Annie and Brian 2013, Rajendran et al. 2009, Fortunato et al. 2012 and Dewlaney et al. 2012). This is because tools developed to evaluate the sustainability of building projects such as the Leadership in Energy and Environmental Design (LEED) Rating System do not adequately address OHS. It has also been shown that several LEED credits may impact construction OHS negatively and have been associated with increased severity and frequency of work-related injuries (Fortunato et al. 2012, Fortunato et al. 2012, Dewlaney et al. 2012). Relatedly, a statistical analysis of 86 construction projects found that the recordable injury rate (RIR) of 38 LEED SB projects was 48% higher than that of 48 non-LEED SB projects (Rajendran et al. 2009). This is because SB technologies associated with rooftop energy generation, on-site water recovery, treatment, and reuse have been shown to sometimes pose significant public and OHS risks (Annie and Brian 2013, Ali and Gambatese 2017, Dewlaney and Hallowell 2012). Therefore, although SB projects offer the potential for improved environmental and energy performance, they are ultimately unsustainable if they do not consider the OHS performance of the projects (Rajendran et al. 2009, Hinze et al. 2013, Gambatese et al. 2007, Reyes et al. 2014, Fortunato et al. 2011). Given the unique OHS risks associated with some SB projects, there is a need to move from mere compliance with existing prescriptive OHS requirements to high OHS performance as is the case with other SB aspects such as water and energy use. There is also a need to move from the traditional approach of measuring OHS performance of SB to high level performance metrics that can monitor the capacity of an organization to perform a SB project safely. The traditional approach to evaluating OHS performance of SB has been through measurements of incident-related data such as recordable injury rate (RIR). These measures have focused on post-accident analysis and measuring system failures without revealing cause and effect relationships that would drive system improvement (Carder and Ragan 2003). Against this background, the Sustainable health and Safety Maturity Model (SHSMM) was developed to evaluate the maturity of the OHS practices of SB projects (Orogun and Mohamed 2017). The SHSMM consists of three different health and safety (H&S) dimensions of people, process and building which are organized by 22 safety maturity drivers (SMD). Each SMD contains a number of critical to safety practices (CTSP) which reflect current best OHS practices. Because the defined CTSP are not measurable, the research involved developing measurable proxies for the CTSP under each SMD which enabled the development of the OHS performance metrics to evaluate the OHS performance of SB projects. This paper reports on the methods used to develop and validate the OHS performance metrics to evaluate the performance of SB projects throughout their design and construction.

2. LITERATURE REVIEW

This section presents a review of the safety performance metrics and research validation approaches in construction safety research.

2.1 Safety Performance Metrics

Safety performance has been defined as the overall performance of an organization's OHS management system and its ability to achieve safe operation (Wu et al. 2015). Safety performance management has often depended on the systematic anticipation, controlling, monitoring and development of organizational performance (Reiman and Pietkäinen 2012). Rohleder (2006) submitted that effectively identifying and addressing changes in safety conditions can improve safety performance of any organization. The regular measurement of safety performance enables the identification and resolution of issues which provides the information needed to make proactive safety decisions, assess the effectiveness of safety practices and drive continuous improvement (Lingard et al. 2017). The root of the term, metric, is often substituted for indicator, measure, or index and used not only to describe activities, but also conditions, process or events (Grabowski et al. 2007). Harms-Ringdal (2009) defines safety metrics as observable measures that provide insights into the concept of safety. Kjellén (2009) defines safety performance measures as the metric[s] or indicator[s] used to measure an organisation's ability to control the risk of accidents. The concept of the safety performance metrics sometimes appear ambiguous and confusing with regard to the definition and indicated phenomenon (Lingard et al. 2017). For example, National Occupational Health and Safety Commission submitted that safety performance metrics can measure both outcomes and safety processes. Different sets of metrics tend to measure different things, including quality of the safety process, positive safety actions, safety system, individual behaviors and the effectiveness of safety management tasks (Lingard et al. 2017).

2.1.1 Inadequacy of Traditional Metrics of Safety Performance

The traditional approach to evaluating OHS performance has been through measurements and statistical analysis of incident-related data (e.g. recordable injury rate, lost time injury rate and severity rates). Traditionally, construction organizations have relied on standardized measures of frequency with which undesirable safety incidents have occurred as an objective measure of performance (Lingard et al. 2017). These metrics/measures are still the most widely used because they are easy to collect, easy to use in benchmarking and useful in the identification of trends over time (Lingard et al 2017). However, the use of safety incident rates have often been criticized as inadequate because of a number of issues and therefore alternative measures of OHS performance are increasingly favoured (Lingard et al 2017). First, these safety incident rates have been shown to have a statistically low probability of occurrence over short time frames, they are usually not stable when measured at a single construction project (Hopkins 2009). Hopkins (2009) described it as the zoom effect, because in very large construction projects, the frequency of incidents is not enough to calculate a meaningful rate and that even a stable safety system will produce a variable number of incidents (Stricoff 2000). Therefore the absence of incidents does not imply that a site is safer than another site in which an incidents has occurred in the same period (Cadieux et al. 2006). Secondly, these safety incident rates are often referred to as retrospective or lagging metrics capturing things that have already gone wrong (Lingard et al 2017). These metrics measure the absence of safety, rather than the presence of safety and therefore cannot be relied upon as a direct measure of the safety condition within a work system (Arezes and Miguel 2003). These metrics focus on post-accident analysis and measuring system failures without revealing cause and effect relationships that would drive system improvement (Carder and Ragan 2003, Cooper and Phillips 2004). Thirdly, the use of safety incident rates is influenced by incentive (Lingard et al. 2017). It has been shown that tying rewards and incentives to incident rates encourages underreporting of safety incidents (Cadieux et al. 2006). It was also found that workers with low levels of job security were less likely to report incidents which makes erroneous conclusions on the OHS performance (Probst et al. 2013). As a result of these limitations, there has been a move away from the exclusive use of retrospective incident data for the measurement of safety performance to alternative measures of OHS performance related activity. Over the last two decades, ongoing efforts have been made to develop metrics for construction safety management. Different ways and forms to quantify the state of safety, irrespective of the occurrence of incidents have been developed. For example, Hallowell et al. (2013) identified over 50 metrics on the basis of case studies, content analysis of award winning projects, and focused discussions among construction safety experts. Salas and Hallowell (2016) used leading indicators to develop a predictive model for providing early warning signs of changes in a construction contractor's safety management performance. Guo et al. (2015) developed a conceptual framework for developing leading safety indicators for the construction industry and proposed 32 leading safety indicators to monitor and evaluate safety conditions onsite. Wu et al. (2015) developed a systematic structural equation modeling based approach for prospective safety performance evaluation using questionnaires to reveal how well a company is performing. They classified safety performance measurement into five different levels, namely I (Very poor), II (Poor), III (Fair), IV (Good), and IV (Good). The choice of metrics used to measure safety is complex and ultimately the decision about what should be measured will rely on one's perspective and beliefs about what constitutes and explains safety (Lingard et al. 2017).

2.2 Research Validation and Revision

Validation involves determining the extent to which the developed performance metrics can provide a reliable measure of onsite safety condition and performance. Because of the complexity of safety phenomena and the possible inappropriateness of the proposed OHS performance metrics developed to conceptualize safety conditions and safety performance, it is important that the performance metrics be validated. Two methods can be used for performance metrics validation. First, performance metrics can be validated through comparison with measured safety data from real projects so that consistencies or inconsistencies can be investigated and analyzed (Bockstaller and Girardin 2003). Secondly, they can be validated based on the judgment of experts (Guo et al. 2015, Kleinert and Kearns 1999). This involves submitting the OHS performance metrics to a panel of OHS experts with experience in the use of metrics, who will assess the scientific and managerial attributes of the performance metrics. Revision and refinement of the performance metrics will then be based on expert judgment. Expert judgement has been used in construction safety research validation, For example, Huang et al. (2015) developed an operational excellence model designed to evaluate and improve safety performance and validated the model using expert judgement. Guo et al. (2015) proposed 32 leading safety metrics to monitor and evaluate safety conditions onsite and validated them based on qualitative interviews and experts judgments.

3 METHODOLOGY

This section provides an overview of the safety maturity drivers (SMD) and how they generated the OHS performance metrics and were validated and revised.

3.1 Performance Metrics Development

In developing the OHS performance metrics, there is a need to determine the causal relationships between contributing elements of safety which are the Critical to Safety Practices (CTSP) which constitute the SMD that influence safety outcomes. The process used to develop these metrics is shown in Figure 1. The SMDs which are shown in Table 1 were defined from the Sustainable Health and Safety Maturity Model(SHSMM) after a detailed literature review. The CTSP were then defined from each SMD after a detailed literature review. Due to the fact that the defined SMDs in the SHSMM are not measurable, the research involved developing measurable proxies for the CTSPs defined for each SMD. The measurable proxies enabled the generation of the performance metrics for each SMD as presented in Table 1. The generation of the metrics were also guided based on existing metrics in the literature. These metrics had to be analytically sound, scientifically credible and causally linked with safety outcomes (Guo et al. 2015).

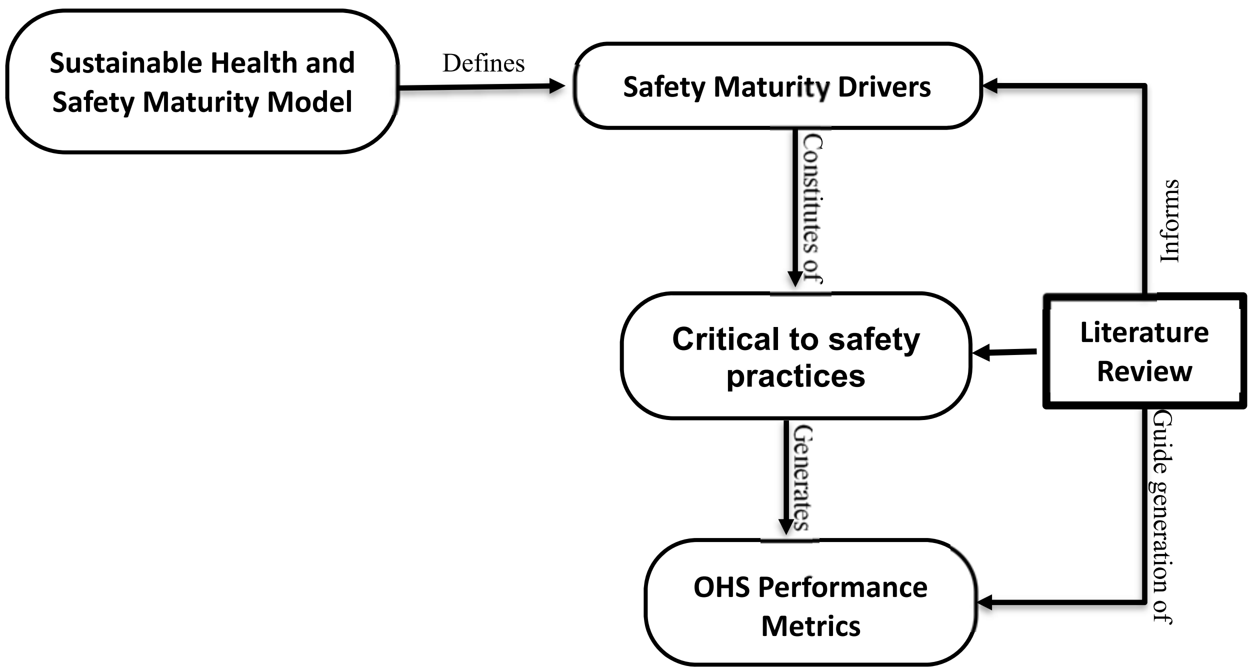

Figure 1: Performance metrics development guide

3.2 Performances Metrics Validation and Revision

The OHS performance metrics validation was done by expert judgement as suggested by Bockstaller and Girardin (2003) and it addressed the conceptual, output, and end use dimensions of the performance metrics. Because the performance metrics were developed from the SMD of the SHSMM, their conceptual validity logically depends on the validation of the SMD. The SMD and CTSP were determined based on a detailed literature review and therefore provided a solid theoretical basis for developing the OHS performance metrics. The criteria for the validation were analytical soundness, practicality and predictability as recommended by (Rajendran 2013, Guo et al. 2015). Analytic soundness which addressed the conceptuality of the performance metrics aimed to determine the ease with which the performance metrics could be quantified on a per week, per month or per year basis. The criteria of predictability and practicality which addressed end use and output dimensions of the performance metrics aimed to determine whether the proposed performance metrics could provide valid, meaningful, and reliable information about a SB OHS performance. Practicality refers to the extent to which each metric is compatible with practical OHS management (Guo et al. 2015). Predictability refers to the sensitivity of each metric to changes in onsite safety condition (Guo et al. 2015). Eight OHS experts and five OHS researchers were recruited to conduct the validation of the performance metrics using a five-point Likert-scale. These experts were identified using convenience and snowball sampling (Bryant and Charmaz 2010). The eight OHS experts were provided with questionnaire validation worksheets and requested to give ratings based on the extent to which they agreed that the practicality and predictability of each performance metric were met. The five OHS researchers were requested to give ratings on the extent to which they agreed that the analytic soundness criteria for each performance metrics was met. The average rating based on the response of the participants for each criteria considered was computed as the final score for each performance metrics as shown in Table 3. Following the completion of the validation, the performance metrics were revised based on the results of the validation. Any performance metric that received an average rating for any of the criteria below 3.5 will not be taken to account in the performance metrics implementation.

Table 1 Proposed set of performance metrics

Safety Maturity Driver	**Proposed performance metrics**
Project health and safety planning	1. The percentage of the total number of construction activities where pre-task safety reviews were conducted.
	2. The percentage of submitted contractors OHS performance reports in which the owner reviewed and gave feedback.
Incident investigation, reporting and performance evaluation	3. The percentage of the total number of reported near misses and incidents that were investigated.
	4. The percentage of the total number of reported safety observation that were addressed with corrective actions.
	5. The percentage of total number of action items addressing near misses and incidents that were high priority action items
Safety communication	6. The percentage of the total number of safety meetings in which the contractors and subcontractors were updated with onsite safety information.
	7. The percentage of the total number of construction activities where workers were informed of the hazards before work commenced.
Risk and hazard management	8. The percentage of the total number of construction activities where job safety assessment was carried.
	9. The percentage of the total number of hazard abatement strategies in which verification of implementation was carried out.
Safety control	10. The percentage of the total number of safety observations where stop work authority were exercised.
	11. The percentage of the total number of construction activities which involved the use of a safe work permit.
Safety policy and standards implementation	12. The percentage of the total number of contractors who submitted their OHS policy before construction execution
Safety inspection	13. The percentage of the total number of identified safety violations that were discussed between workers.
Site safety audits	14. The percentage of the total number of jobsite safety audits which identified safety compliance to defined standards.
	15. The percentage of the total number of jobsite safety audits which was carried out by management.
Designing for safety	16. The percentage of integrated design team members who had OHS expertise.
Health and safety in contracts	17. The percentage of the total number of OHS requirements in the contract that the contractor complied with.
	18. The percentage of the total number of OHS requirements in the contract that the subcontractor complied with.

	19 The percentage of the total contract clauses in the contract which were OHS clauses.
Onsite health and safety professionals	20. The percentage of site supervisors who had site safe supervisor gold card
Management and project leadership commitment	21. The percentage of the total number of addressed critical safety incidents where management participated. 22. The percentage of the total workdays in which management spent with workers onsite. 23. The percentage of the total number of safety observations that were carried out by management. 24. The percentage of the total number of times, submitted OHS performance reports received feedback from management.
Safety meetings	25. The percentage of workers who attended safety meetings. 26. The percentage of the total number of safety meetings which were toolbox meetings.
Training, competence and education	27. The percentage of total number of safety training which were safety leadership trainings. 28. The percentage of workers who had stop-work authority.
Workers involvement	29. The percentage of total number of unsafe worker behaviour observations that were addressed.
Workers behavior management	30. The percentage of total number of success safety stories shared among workers.
Alcohol and drug evaluation	31. The percentage of the total number of random drug assessments that had lab confirmed positive result for impairment**.** 32 The percentage of workers who were assessed for alcohol and drug intake before construction work.
Industrial hygiene and site ergonomics management	33. The percentage of the total number of construction activities where ergonomic task analysis was carried out.
Project team selection	34. The percentage of subcontractors selected in part on the basis of satisfactory OHS performance.
Management of project execution resources	35. The percentage of tools and equipment that were in compliance with their maintenance plan.

Table 2 Profile of OHS validation experts

Experts	Position	Experience in Health and Safety Field
1	District Health and Safety Manager	22 years
2	Senior District Health and Safety Manager	20 years
3	Health and Safety Administrator	10 years
4	Health and Safety Consultant	10 years
5	Senior Health and Safety Advisor	15 years
6	Health and Safety Advisor	8 year
7	Senior Health and Safety Manager	17 years
8	Health and Safety Consultant	18 years

4 RESULTS

Eight of the 22 OHS experts and five out of the 10 academic OHS researchers who were contacted responded to the performance metrics validation. The average validation score for each performance metrics based on the criteria of predictability and practicality as shown on Table 3, were determined based on the average rating given by the eight OHS experts. That of analytic soundness was determined based on the average rating given by the five OHS researchers.. The eight OHS experts involved in the performance metrics validation all had experience using performance metrics. Their profiles are presented in Table 2. The respective criteria evaluated for each performance metrics will be interpreted based on a five-point Likert scale (1 = lowest level; 5 = highest level), in which ratings of 1–1.99, 2.0-3.49, 3.5-4.0 and 4.01–5.0 were considered “highly invalid,” “invalid,” “valid,” and “highly valid,” respectively. In addition, the experts added a few comments which helped the authors revise the proposed performance metrics.

Table 3: Performance Metrics Validation

S/N	Proposed Performance Metrics	Average rating		
		Analytic soundness	Practicality	Predictability
1	The percentage of the total number of construction activities where pretask safety reviews were conducted.	4	4	3.75
2	The percentage of submitted contractors OHS performance reports in which the owner reviewed and gave feedback.	3.25	3.75	3.75
3	The percentage of the total number of reported near misses and incidents that were investigated.	4	3.75	3.75
4	The percentage of the total number of reported safety observation that were addressed with corrective action.	4.25	3.5	3.75
5	The percentage of total number of action items addressing near misses and incidents that were high priority action items.	3.5	3.75	3.75
6	The percentage of the total number of safety meetings in which the contractors and subcontractors were updated with onsite safety information.	3.5	4	3.5
7	The percentage of the total number of construction activities where workers were informed of the hazards before work commenced.	4	3.75	3.5
8	The percentage of the total number of construction activities where job safety assessment was carried.	4.25	3.5	3.5
9	The percentage of the total number of hazard abatement strategies in which verification of implementation was carried out.	3.75	3.75	3.5
10	The percentage of the total number of safety observations where stop work authority were exercised.	4.25	3.25	3.25
11	The percentage of the total number of construction activities which involved the use of a safe work permit.	4.25	4	3.25
12	The percentage of the total number of contractors who submitted their OHS policy before construction execution.	4.25	3.5	4
13	The percentage of the total number of identified safety violations that were discussed between workers.	4	4	4
14	The percentage of the total number of jobsite safety audits which identified safety compliance to defined standards.	4.5	3.75	3.25
15	The percentage of the total number of jobsite safety audits which was carried out by management.	4.25	4.25	4.25
16	The percentage of integrated design team members who had OHS expertise.	3.5	3.75	3.5
17	The percentage of the total number of OHS requirements in the contract that the contractor	3.5	3.5	3.75

	complied with.			
18	The percentage of the total number of OHS requirements in the contract that the subcontractor complied with.	3.75	3.75	3.5
19	The percentage of the total contract clauses in the contract which were OHS clauses.	4.5	3.5	3.5
20	The percentage of site supervisors who had site safe supervisor gold card	4.5	3.5	3.5
21	The percentage of the total number of addressed critical safety incidents where management participated.	2.75	3.75	3.75
22	The percentage of the total workdays in which management spent with workers onsite.	3.5	4	4
23	The percentage of the total number of safety observations that were carried out by management.	3.5	3.75	3.5
24	The percentage of the total number of times, submitted OHS performance reports received feedback from management.	4	4	3.5
25	The percentage of workers who attended safety meetings.	4	3.75	3.5
26	The percentage of the total number of safety meetings which were toolbox meetings.	4	3.75	3
27	The percentage of total number of safety training which were safety leadership trainings.	4.5	3.5	3
28	The percentage of workers who had stop-work authority.	4.5	3.75	4
29	The percentage of total number of unsafe worker behaviour observations that were addressed	3.75	4	3.75
30	The percentage of total number of success safety stories shared among project workers.	3.25	4	4
31	The percentage of the total number of random drug assessments that had confirmed positive result for impairment.	4.75	4	3.67
32	The percentage of workers who were assessed for alcohol and drug intake before construction work.	4.75	3.67	3.33
33	The percentage of the total number of construction activities where ergonomic task analysis was carried out.	3.5	3.5	3.25
34	The percentage of subcontractors selected in part on the basis of satisfactory OHS performance.	4.5	3.5	3.75
35	The percentage of tools and equipment that were in compliance with their maintenance plan.	3.25	3.25	3.5

5. DISCUSSIONS

For the full set of performance metrics, the average scores for analytic soundness, practicality and predictability were 4.0, 3.6 and 3.6 (out of 5), respectively, suggesting that the performance metrics have a valid scientific and conceptual basis and, from the experts perspectives can provide timely information of the OHS performance of the project. In addition, with regard to analytic soundness, 14 of the total 35 performance metrics were rated highly valid, 18 were rated valid and the remaining three were rated invalid. For practicability, six of the total 35 performance metrics were rated highly valid and 22 were rated valid, seven were rated invalid. For predictability, 10 of the total 35 performance metrics were rated highly valid, 23 were rated valid, two were rated invalid**.** Minor revisions were made based on the expert's comments, for instance, it was suggested that the quantity of OHS defined in the contract in metrics 17 and 18 should be deemphasized but rather the quality of OHS is more important. In addition, a few performance metrics were suggested by one of the participating expert, out of which three of the performance metrics were selected such as the percentage of the total number of corrective actions identified through the inspection process which were successfully implemented. The percentage of the total number of stand down meetings held as a result of an incident. The percentage of total safety training spot checks that were not in compliance. This metrics were suggested from the safety inspection, safety meetings and training development and education SMDs. The average rating for analytic soundness of 4.0 for the set of performance metrics suggest the metrics can be easily quantified. However the average rating for predictability and practicality of 3.6 and 3.6 respectively suggest a borderline acceptability of the metrics. For assessing the invalid metrics, it was determined that for each performance metric, any of the three criteria assessed, in which the performance metric received a rating of less than 3.5 will be eliminated. The total invalid metrics was 10 which represented 28% of the 35 performance metrics. This means 72%, which represents 25 of the 35 safety performance metrics developed had a positive valid result for the three criteria. The 25 positively validated performance metrics will be collected for SB and non-SB projects. The specific data to determine the performance metrics will be collected for a one year period for projects executed within the last two years to enable the calculation of these metrics. Once collected, the metrics will be analyzed and interpreted over time, in relation to one another and in relation to the SMDs they evaluate. They will also be analyzed in relation to the specific project and category of projects (i.e. SB versus non-SB) they evaluate.

6 CONCLUSIONS

In addressing the existing and emerging OHS risks of SB projects and the inadequacy of OHS requirements implemented on SB project which has resulted in some SB been potentially more risky to build compared to non-SB projects. It is important to move beyond inadequate traditional systems of measuring OHS performance which measures the absence of safety to dynamic systems that measures the presence of safety. This movement requires performance metrics that can monitor the capacity of an organization to perform a project safely and drive the safety management system to continuous improvement. Against this background, a set of 35 OHS performance metrics as guided by the literature was developed from the SHSMM using the concept of measurable proxies of the CTSP defined in each of the SMD constituting the SHSMM. These performance metrics were then validated by five academic OHS researchers and eight industry OHS experts based on the criteria of analytic soundness, practicality and predictability respectively as recommended from the literature. It was found that 25 of the performance metrics received positive validation based on the defined threshold of acceptable validation while the remaining 10 performance metrics received negative validation and thus will not be used to collect data when evaluating the SB and non SB projects OHS performance. It is expected that the data to determine the metrics would be collected for each project that would be evaluated. The research is part of an ongoing research initiative led by the Construction Engineering and Management Group at the University of Manitoba and aiming to evaluate the OHS performance of these projects.

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