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cshs Center for Safety & Health Sustainability

Best Practice Guide for Leading Health Metrics in Occupational Health and Safety Programs

Guidance Document

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CSHS was launched in 2011 and represents over 100,000 OEHS professionals in over 70 countries. The "Center" has a vision "For all organizations to consider the safety, health and well-being of workers, customers and the community as part of their sustainable business practice".

Founded in 1939, AIHA is a nonprofit organization serving professionals dedicated to the anticipation, recognition, evaluation, control, and confirmation of environmental stressors in or arising from the workplace that may result in injury, illness, impairment, or affect the well-being of workers and members of the community.

The contributors to this document hope that the resources, example metrics, and discussion on analysis of metrics presented herein will continue the dialogue in anticipating and preventing ill health conditions before they occur. We welcome the opportunity to contribute to the growing body of knowledge on this important subject.

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Introduction

Occupational and Environmental Health and Safety (OEHS) Professionals help organizations meet their goal of preventing harm to workers arising from hazards in their workplace. Their larger goal is to send each worker home at the end of the day healthier than when he or she arrived. Tools to assess success in meeting these goals can be found in metrics that either measure what has happened in the past or may serve as an indicator of future performance.

Traditionally, the most commonly used tools to identify health concerns and hazards, prevent exposure, and control risks that lead to injury and illness are lagging indicators of health and safety in the workplace. Lagging metrics, sometimes referred to as retrospective indicators, measure after-the-fact occurrences, such as injury and illness rates and prevalence or risk of illness or disease.

Unfortunately, lagging metrics are not preventive, as worker health has already been impacted. Because of the lag time between exposure and adverse health effects, such metrics can give false reassurance when the physical manifestation from an adverse exposure is not yet present. Furthermore, an absence of documented illness or disease does not necessarily equate to an absence of hazardous exposures in the work environment or inherent in the work. Also, lagging metrics do not generally drive actions or behavior changes that can reduce workplace risk.

Alternatively, leading metrics can assist with prediction of and influence on health and safety performance related to occupational illness and worker health. Many common leading metrics currently in use focus on safety-related injuries and outcomes. Leading health metrics—those that focus on disease prevention and health preservation—are not as prevalent, often due to the complexities related to human health. However, leading health metrics could be extremely useful and important in promoting behaviors and actions shown to correlate with improved worker health.

Highlights to This Guidance Document

- Resource list for further information on leading health metrics (Appendix C)
- Examples of leading occupational health metrics (Table 1)
- Inclusion of metrics aligned with Total Worker Health
- Focus on developing a correlated and balanced "set" of leading health metrics
- A guide to estimating exposure performance metrics (Appendix D)

To fill the gap caused by few leading health metrics, the Center for Safety and Health Sustainability (CSHS) initiated a project to identify leading health metrics for the broad community of OEHS professionals. AIHA, a founding member of the CSHS, assumed the lead role in this project. AIHA convened a broad group of occupational health, safety and environmental professionals, including representatives of industry, government, and professional occupational health and safety societies, to develop a guide to leading health metrics for OEHS programs. In addition, to help make leading metrics more valuable, an approach to developing a set of balanced leading metrics is presented.

The resulting document, Best Practice Guide for Leading Health Metrics in Occupational Health and Safety Programs, is intended for use by both practitioners and managers in the broad occupational health community, including industrial hygiene, occupational medicine, occupational health nursing, engineering, and human resources. The information in this guide applies to all industry sectors and business categories, including but not limited to manufacturing, distribution, healthcare, nongovernmental organizations (NGOs), consulting, and government.

In addition to addressing the needs of OEHS professionals at large organizations, the guide is also applicable to small and medium-sized enterprises. It may not be feasible for small organizations to meet all the recommendations, but the document can serve as guidance for best practice.

Scope and Approach

To meet the charge established by CSHS, a core working team was convened under the leadership of AIHA. This team met primarily via conference calls, with two face-to-face meetings in the spring and fall of 2019. At the initial meetings, approaches to the project were finalized. An early decision by the core team was to define leading health metrics and limit the scope of health issues the metrics would address. Thus, metrics related to safety and injury and community health were determined to be outside the scope of this project.

Subteams were created to accomplish specific tasks, including outreach, data collection, data review, data analysis, and document editing. The outreach and data collection teams were charged with contacting organizations where leading health metrics have been developed and are in use. The subteams also conducted a literature review.

All members of the core team assisted with the review of literature, the relevant results of which are presented in Appendix C as an annotated bibliography of resources. The data review and analysis teams focused on defining and developing leading health metrics and drafting the guide text, including presentation of examples.

A stakeholder group of leading OEHS professionals provided additional input to the core team in the process of developing this guide. They had opportunities to provide general as well as specific guidance to document drafts.

The task force first developed a definition of a leading health metric and associated criteria. These are presented in the section What is a Leading Health Metric?

Examples of leading heath metrics and concepts are provided in the next section of the guide. These demonstrate the broad range of potential metrics that can be used prospectively to assess the work environment and work design factors that may impact worker health and well-being.

Guidance on the development of leading health metrics is given in the section How to Develop a Balanced Set of Leading Health Metrics. The guide focuses on developing a balanced set of metrics because there is not generally one overriding measure that can predict or influence a health outcome. A set of metrics that are interrelated may give a more balanced picture of factors that, taken together, better monitor and affect health and well-being. In addition, overall risks and potential risk management actions can then be assessed prior to the onset of illness.

Rounding out the guide are four appendices of useful reference information. They include a glossary of terms, a description of Total Worker Health® (TWH), an annotated bibliography of resources, and a guide to estimating exposure performance metrics. Leading health metrics in OEHS programs ideally are consistent with TWH approaches to worker safety, health, and well-being, as defined by the National Institute for Occupational Safety and Health (NIOSH).

In summary, the approach to leading health metrics, as presented in this guide, represents strategies and measurements currently in use by leaders in the

OEHS field. Metrics, and especially a balanced set of metrics, are relevant for all organizations. These leading health metrics represent standards of performance that are accepted and understood by organizations proactively managing the safety, health, and well-being of their workers.

What is a Leading Health Metric?

Leading metrics are prospective: they measure some exposure, factor, risk, program or control that occurs or exists prior to an unwanted health outcome. Although many of the publications on OEHS leading metrics focus on safety and resultant injuries, this document focuses on metrics that are related to worker health and well-being, as resulting from occupational exposures in the workplace.

There are many variations in the definition of a leading health metric. Frequent commonalities include attributes that are proactive, preventive, and predictive; measures that identify, evaluate, and control risks; and measures that correlate to lagging indicators of safety and health. Based on a review of the literature, the AIHA task force developed a common definition.

CSHS/AIHA Definition of a Leading Health Metric

A measurable, meaningful, actionable, evidence-based indicator that can be used to monitor, predict, influence or manage exposures, hazards, actions and conditions of work that may impact worker health and well-being.

Health outcomes addressed by metrics can be acute, such as eye irritation, dermatitis, or metal fume fever—or they can be chronic, such as elevated blood pressure, hearing loss, or cancer. Whereas OEHS programs traditionally focused on adverse health outcomes, health metrics can also address positive outcomes, such as reduced obesity or increased satisfaction in the workforce.

Leading health metrics are by definition quantitative, generally involving counts or percentages of people, behaviors, conditions, or other discrete actions or events. However, metrics may be based on either quantitative or qualitative data. Metrics that result from quantitative analysis of somewhat qualitative data can also be useful and are referred to as *semi-qualitative*.

What is Worker Health and Well-being?

The World Health Organization defines health as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (WHO, 2020).

The National Institute for Occupational Safety and Health (NIOSH) defines worker well-being as an integrative concept that characterizes quality of life with respect to an individual's health and work-related environmental, organizational, and psychosocial factors. Well-being is the experience of positive perceptions and the presence of constructive conditions at work and beyond that enables workers to thrive and achieve their full potential (Chari et al., 2018; Appendix B).

Implicit in these definitions of health is the concept of quality of life, not merely the absence of disease, but the ability to be productive at work, at home and in retirement.

- Quantitative data are objective, numerical values to determine the what, who, when, and where of health-related events (Wang, 2013). Examples of quantitative data that may be measured by a leading health metric include chemical or noise exposure levels, number of personal monitoring samples collected, ventilation rate, age, weight, and blood pressure.

- Qualitative data can include almost any categorical data. Qualitative data generally use words to describe a rating. The rater can be an expert (e.g., an industrial hygienist) or a representative of the worker population being studied. Examples of qualitative data that may be measured by a leading health metric include perception questionnaire response (agree, disagree, neutral); measurements of organizational change or culture; measures of leadership in implementing evidence-based practices; and employee experience of their psychosocial environment (National Safety Council [NSC], 2019).

Leading metrics are most effective when they are part of a comprehensive safety and health management system. This approach integrates worker health with business objectives and may reveal potential actions leaders can take to improve future performance. Leading indicators can help organizations correct potential weakness without waiting for demonstrated failures. Well-designed leading metrics can drive preventive or corrective action and improve health and safety culture through awareness and accountability.

Many organizations address health in a comprehensive manner that includes both occupational and nonoccupational components of health affecting workers' ability to perform their job duties. Metrics that help identify and address health risks are often included in programs that aim to improve TWH.

Leading indicators can evolve as an organization matures in its journey from more compliance-based to prevention- and promotion-based approaches.

Examples of Leading Health Metrics

Leading health metrics are an important component of health and safety management systems. They assist in assessing programs and predict, influence, or prevent adverse health outcomes. Table 1 presents examples of published metrics drawn from the resources in Appendix C that may be useful to assess health programs and outcomes.

The metrics are organized by broad categories of health protection and health promotion. Health protection metrics are further grouped by program, exposure, and control activities that organizations undertake in managing of risks in the workplace.

Worker health and well-being metrics address promotion and integration of health and safety programs at organizational, occupational, and personal levels. Worker health, safety, and productivity are enhanced through on-the-job health protections and promotions. Thus, in Table 1, health promotion metrics are grouped by management and on-the-job activities.

These examples from the literature are intended to show the types of measures that can be identified and tracked as leading health metrics. There are many more measures that could be developed as leading health metrics. The resources in Appendix C provide additional examples. To be most effective, however, the measures should reflect the specific potential risks (health outcomes) identified for a specific workplace and its operations.

In addition to the metric data, ancillary demographic and employee data may be collected for analysis, depending on how the metrics are defined.

Demographic or employee information for data analysis

- Gender
- Age
- Race/ethnic group
- Work status
- Job Title
- Educational status
- Zip code

Table 1 — Examples of Leading Health Metrics and Concepts

Category	Subcategory	Example health-related metrics/metric concepts	Reference (see Appendix C)
HEALTH PROTECTION			
Health program	Worker health support	Number of workers' compensations claims	ACOEM, 2019
	Worker health support	% employees with restrictions returned to work through structured return to work programs	ACOEM, 2019
	Worker health support	% employees with health insurance	NSC, 2019a
	Worker health support	Ratio of occupational safety and health professionals (e.g., board-certified occupational medicine physicians, nurses, industrial hygienists [IHs]) to employees	CSTE/NIOSH, 2018
	Worker health support	% eligible employees receiving employee assistance programs	ACOEM, 2019

Table 1 — Examples of Leading Health Metrics and Concepts (continued)

Category	Subcategory	Example health-related metrics/metric concepts	Reference (see Appendix C)
HEALTH PROTECTION			
Health program	Perception surveys (health focus)	% positive/negative poll results	NSC, 2015a
	Perception surveys (health focus)	% staff perceptions of management commitment to health	Step Change in Safety, n.d.
	Leadership engagement/ commitment	Number of leadership reviews confirmed/scheduled	ACOEM, 2020
	Inspections/audits	% inspection action closed/closure time	Johnson, 2010
	Inspections/audits	Number of compliance program requirements met	NSC, 2019a
	Inspections/audits	% medical records reviewed that were compliant	ACOEM, 2020
	Inspections/audits	% facility health reviews completed as compared to planned facility health reviews	Johnson, 2010
	Inspections/audits	% completed health corrective actions by due date	NSC, 2019b
	Emergency response	Number of corrective actions/lessons learned from drills, table-top sessions and incidents	ACOEM, 2020
	Pandemic planning	% drills and assessments of readiness for pandemic plans	ACOEM, 2020
	Fitness for duty	% employees with completed required medical surveillance	ACOEM, 2020
	Fitness for duty	% required medical or qualified personnel involved in job assessments to establish functional requirements	ACOEM, 2020
	Hazard recognition	Number of comments for unsafe observations (health) that clarified the nature of the hazard	NSC, 2019b
	Hazard recognition	% permits to work reviewed and found to meet health requirements	Step Change in Safety, n.d.
	Hazard recognition	% safe observations	NSC, 2015a
	Healthy buildings	% buildings continuously commissioned to ensure optimal indoor air quality is maintained	Allen & Macomber, 2020
	Risk assessment	% health risk assessments completed as compared to health risk assessments planned	Step Change in Safety, n.d.
	Risk assessment	% identified risks mitigated or controlled	NSC, 2015a

Table 1 — Examples of Leading Health Metrics and Concepts (continued)

Category	Subcategory	Example health-related metrics/metric concepts	Reference (see Appendix C)
HEALTH PROTECTION			
Exposure/risk evaluation	Workplace hazard assessment	% of processes for which occupational health exposures have been completed (of number required)	Boyd, 2001
	Exposure assessments	% planned qualitative exposure assessments completed	Boyd, 2001
	SEGs	% of locations with defined SEGs	U.S. Navy, 2018
	Monitoring	% of locations with completed baseline monitoring (of locations requiring baseline monitoring)	U.S. Navy, 2018
	Monitoring	% of locations participating in IH monitoring activities	U.S. Navy, 2018
	Monitoring	% of personal monitoring samples completed against sample plan	U.S. Navy, 2018
	Monitoring	Number of results that exceed permissible exposure limits (of total number of workers monitored)	ACOEM, 2020
	Noise	Number of noise surveys completed (of total number of noise surveys planned)	U.S. DOE, 1996
	Noise	Number or % of workers exposed to hazardous noise	Boyd, 2001
	Noise	% Compliance with required audiometric testing	Boyd, 2001
	Musculoskeletal disorders	% of worksites that conduct ergonomic assessments for workspace design and equipment when problems are identified or anticipated	CDC 2019
	Indoor air quality	% indoor air quality complaints resolved	Boyd, 2001

Table 1 — Examples of Leading Health Metrics and Concepts (continued)

Category	Subcategory	Example health-related metrics/metric concepts	Reference (see Appendix C)
HEALTH PROTECTION			
Exposure/risk evaluation	Indoor air quality	% reduction in new indoor air quality complaints received	Boyd, 2001
	Medical surveillance	% medical surveillance completed as compared to health surveillance required (for position and/or OEHS monitoring triggers)	ACOEM, 2020
	Ergonomics	% workers with reported risk factors completing repetitive stress injury self-assessment and annual training	Chevron Health Metric, 2020
	Ergonomics	% risk factors reported by employees resolved	CDC, 2019
Controls	Engineering controls	% identified engineering controls for health hazards completed	Boyd, 2001
	Ventilation	% ventilation surveys completed (versus planned)	U.S. Navy, 2018
	Training	% positive post-training evaluations	ACOEM, 2020
	Training	% workers trained (by number of workers or by facility)	ACOEM, 2020
	PPE - hearing protection	% hearing protection fit tests completed versus those required	Boyd, 2001
	PPE - respiratory protection	% workers in a respiratory protection program with current qualifications to wear a respirator	Boyd, 2001
	PPE - respiratory protection	% workers in a respiratory protection program who have exposure assessment validating need for respirator	Boyd, 2001
	PPE - general	% reduction in the use of PPE (e.g., hearing protection, respiratory protection)	Boyd, 2001
	PPE - general	Number of assessments to determine the type of PPE training needed	NSC, 2019b

Table 1 — Examples of Leading Health Metrics and Concepts (continued)

Category	Subcategory	Example health-related metrics/metric concepts	Reference (see Appendix C)
HEALTH PROMOTION (WELLNESS)			
Health program	Healthy building designs	Reduction of health risks at design stage by including standards (e.g., noise, low VOC building materials, exercise facilities)	NSC, 2019a
	Employee assistance programs	Number/% of employee assistance programs offered, per year	ACOEM, 2020
	Sponsored health screenings	Number/% of employees participating in health screenings	ACOEM, 2020
	Health promotion/ wellness activities	Does organization have a strategic plan that includes goals and measurable organizational objectives for the health promotions/wellness activities? (for large companies, could be number of organizations that provide)	Chevron Health Metric, 2020
	Health promotion/ wellness activities	% of health programs, or other interventions, to optimize return on investment for health, attendance, and productivity (e.g., weight loss, health clubs)	ACOEM, 2020; NSC, 2019a
	Health promotion/ wellness activities	% locations offering health promotion and wellness activities	NSC, 2019a
	Health promotion/ wellness activities	% workers who participate in health promotion and wellness activities	ACOEM, 2020
	Health promotion/ wellness activities	% employees surveyed satisfied with health promotions and wellness activities	NSC, 2019a
	Fatigue management	% locations that have mitigation plans in place to address fatigue risk and/or provide fatigue counter-measures	Chevron Health Metric, 2020
	Fatigue management	% managers completing training to improve understanding of safety and health risks associated with poor sleep	CDC, 2019
On the job	Tobacco environment	Number of workers that stop smoking as result of smoking cessation program	NSC, 2019a
	Tobacco environment	% of locations that provide incentives for not being a tobacco user or for being enrolled in a tobacco cessation program	Chevron Health Metric, 2020

Table 1 — Examples of Leading Health Metrics and Concepts (continued)

Category	Subcategory	Example health-related metrics/metric concepts	Reference (see Appendix C)
HEALTH PROMOTION (WELLNESS)			
On the job	Tobacco environment	% smoke free workplaces	ACOEM, 2019
	Food environment	% locations that subsidize or provide discounts on healthier food items in cafes and snack bars	Chevron Health Metric, 2020
	Food environment	% healthy food options provided through catering/ vending	ACOEM, 2019
	Food environment	% of worksites that provide visible nutritional information for the food and beverages available at the worksite	CDC, 2019
	Psychosocial factors	% workers reporting being exposed to these at their workplace in the last 12 months: bullying, undesired sexual attention, feeling that work drains so much energy that it has a negative effect on private life; employees unable to express their views and feelings; feeling of lacking any influence on what they do at work	Forsknings Center, 2007
	Psychosocial factors	% worksites that provide free or subsidized clinical assessments for depression by a provider, followed by directed feedback and clinical referral when appropriate	CDC, 2014
	Psychosocial factors	% worksites that provide educational materials on stress management	CDC, 2014
	Exercise support	% sites with gym/other environmental supports for recreation or physical activity	CDC, 2014
	Vaccinations	Number of vaccinations (e.g., influenza, hepatitis A) coverage among workers (e.g., healthcare, food handlers)	CSTE, 2018
Note: Chevron Health Metrics are provided courtesy of Chevron as examples – reference is not available.			

How to Develop a Balanced Set of Leading Health Metrics

A balanced set of metrics measures both a balance (identification, evaluation, and control) and a complementary set of leading and lagging metrics. It provides a concise but comprehensive view of performance that is used to monitor, predict, influence, or manage exposures, hazards, actions and conditions, thereby providing feedback to organizations.

The need to evaluate and control health risks or wellness in the workplace is typically triggered by the recognition of a hazard and its potential adverse health outcome, or by new information and understanding of the potential risks. This involves understanding possible health outcomes and the associated workplace operations, processes, and materials exposures and risks.

According to the organization Step Change in Safety (n.d.), for leading performance indicators to play an effective role in the improvement process, there must be an association between and among what the leading metrics are measuring and the related lagging health outcome. For example, reducing the population exposed to harmful noise (leading health metric) should correlate with a reduction in hearing loss within the workforce (lagging metric).

Problem Identification

The first step in the process of developing leading health metrics is to define or identify the problem (health outcome) and the associated exposures or risks to be influenced. OSHA (2019) suggests instituting a target only after deep thinking about what to measure, and why it matters. The health outcome is a lagging metric. Identification is a key part of knowing or anticipating what hazards will create harm (or in the case of TWH, which environments will enhance health and well-being).

The health effect metrics may be either quantitative or qualitative with respect to disease diagnosis, biological markers, or clinical findings. Typically, illness or disease will take many years to become apparent. Thus, developing prevention-based leading indicators can help identify preventive actions before Illness and disease—or alternatively, improved health—become apparent.

Selection and Development of Balanced Leading Metrics

Once the lagging health outcome and associated metrics are identified, leading health metrics are then selected or defined for the given problem, guided by the following types of questions:

- What information is available with respect to the risk, controls, and health outcome?
- Can the health outcome be influenced or predicted?
- How is the exposure or prevalence of illness and disease best influenced?
- What is the population exposed or overexposed?
- Are there unknowns that need to be further evaluated?
- What other informant data is needed?
- To what purposes will the measurement be put - or, to put it another way, to whom will the information be made transparent?
- What are the costs of acquiring the metrics?

Leading indicators can come from a variety of sources, either within the OEHS program or within the organization, and external benchmark data. The general cycle of identifying, evaluating, and controlling OEHS risks (presented in Figure 1) can provide one approach for exploring and identifying leading metrics that correlate to health outcomes (Plog & Quinlan, 2012). A few example metrics have been included in the figure to show that leading metrics can come from the evaluation and control phases of the OEHS program.

When selecting or developing leading metrics, involving multiple departments and functions—such as human resources, operations, facilities and maintenance, and legal, in addition to health and safety—will foster health and safety culture growth (NSC, 2019). Including workers in the process may also improve selection and development of leading health metrics (OSHA, 2019).

Evaluation Metrics

Another opportunity for selection of leading metrics is based on exposure or risk evaluation activities. Evaluation is defined as the decision-making process resulting in an opinion on the degree of health hazard that exists (Plog & Quinlan, 2012). Thus, the purpose of evaluation metrics is to quantify the extent of the exposures (hazards or risks) associated with the identified outcome.

Once a potential problem is identified, it is typically evaluated or characterized to determine the population exposed and if exposures are being controlled. Workplace surveys, risk assessment, and monitoring (exposure monitoring, inspections, observations, etc.) may be used. The evaluation of the potential exposure leads to measurements in the workplace environment or biological assays to determine exposure levels in exposed workers. Results are used to make day-to-day decisions on sources of exposure that require better control or decisions about workers who may require removal from exposures.

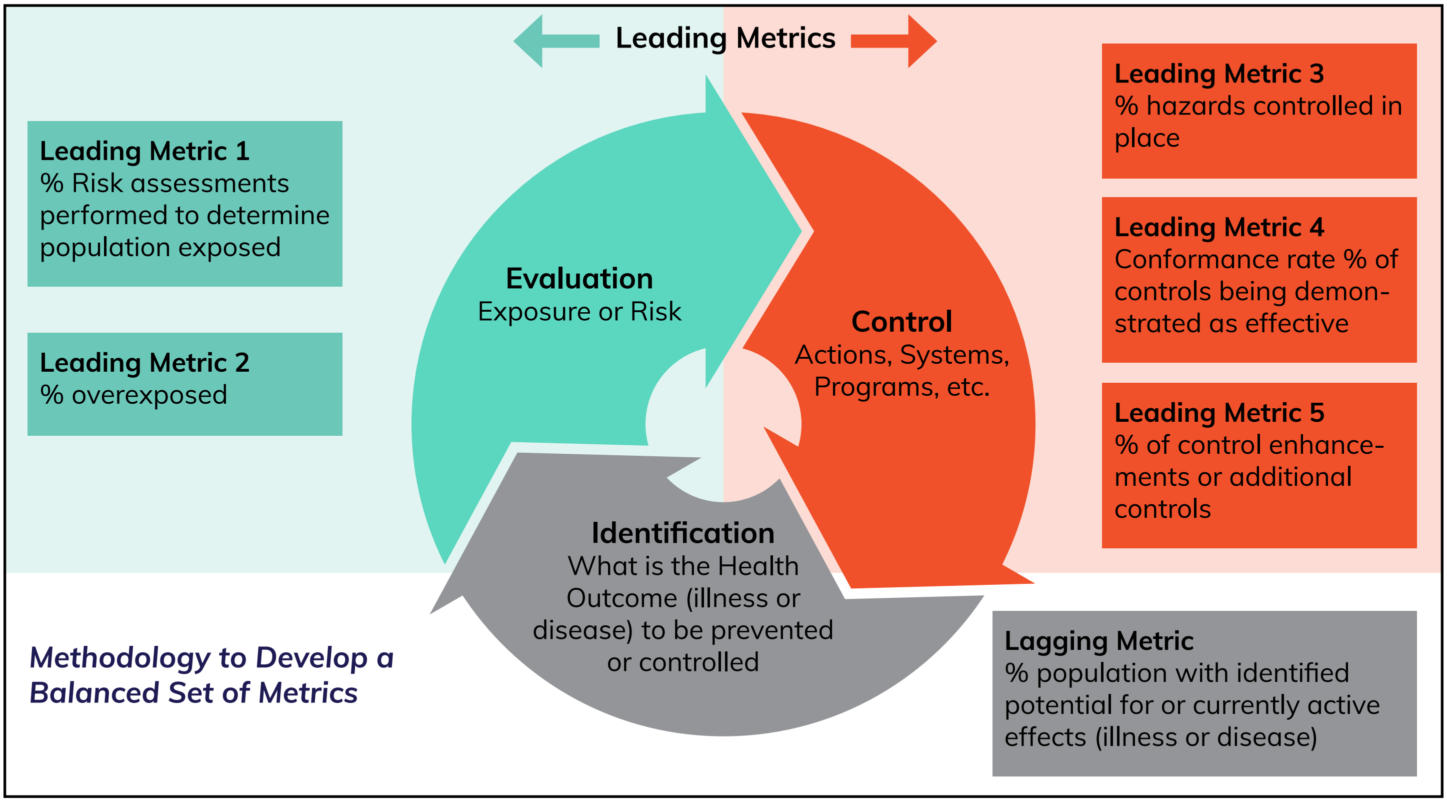

Figure 1 — Identifying, Evaluating and Controlling OEHS Risks: A Balance of Metrics

When exposure monitoring is the basis of the evaluation leading health metric, occupational exposure limits (OELs) are often used to determine if the population is overexposed. Overexposure is defined as monitoring results that do not support a conclusion that exposure levels have an acceptably low likelihood of exceeding the OEL.

These exposure levels can be aggregated and used to compute evaluation metrics. The evaluation leading metrics might be the percentage of work shifts exceeding the OEL, the population at risk, or the percentage of the at-risk population that is overexposed. The challenge for most organizations is this: in order to create these leading metrics, exposure monitoring results will need to exist or be created.

When monitoring every worker or work shift is not practicable, estimates from monitoring a few percent of workers or work shifts will have uncertainty that must be accounted for, most commonly by computing an upper confidence or tolerance limit on the estimate (see Appendix D). Accounting for uncertainty drives improvement in the quality of exposure-monitoring programs. Uncertainty is reduced with more frequent monitoring and reduced exposure.

Once determined, controls, including TWH approaches, can be implemented and measured, ideally to see a reduction in the number of workers with the health outcome. Exposure monitoring and exposure control are linked, because detection of a high result provides an opportunity to identify the cause and thus prevent it from recurring. This process can be carried out using a balanced set of metrics.

Preventing adverse health outcomes can include reducing both the population exposed and the population that has been overexposed. In some cases, it could be valuable to measure both metrics to better understand and evaluate the reliability of the exposure metric. Reduction in the evaluation metrics, by themselves, may influence the outcome of disease or illness. Particularly since health outcomes have such a significant lag time in being recognized, measuring the influence of exposure reductions is a necessary part of management of a risk. The two evaluation-related leading metrics shown in Figure 1, metrics 1 and 2, are just some of the evaluation metrics possible.

Control Metrics

Safe working conditions and behaviors are achieved through the management of controls: provision of safe facilities, utilizing equipment, materials, work practices, and work design. Control metrics measure the presence and effectiveness of controls as well as continual improvement using the hierarchy of controls (known as management of risk).

Control metrics are additional leading metrics developed from data created by the operation of programs, actions, events, systems, and so forth that both establish safe behaviors, working conditions, and work design and provide employers and workers with information and tools they need to minimize potential risks and exposures.

Data on controls may be created through management of hazardous material inventories; surveys of engineering controls performance (ventilation, sound barriers, etc.); compliance with administrative actions (such as limiting time around exposure); training completed; and use of personal protective equipment (PPE).

Controls also include medical placement evaluations, to assure employees are healthy enough to perform their job duties, and wellness programs to promote good health. Analysis of clinical findings from both initial and periodic medical evaluations can provide leading metrics on the frequency of findings that suggest positive or adverse trends in employee health.

Monitoring and measuring the implementation and effectiveness of controls requires management commitment, coordinated programs, training, and employee participation. Additionally, medical surveillance, inspections and observations (monitoring), and workers' compensation data may indicate whether controls are effective or if additional controls are necessary.

Metrics may also be designed to influence actions or behaviors. Unlike a lagging metric, which measured past results, a leading metric may drive action. For example, measuring the number of people required to wear hearing protection may provide an incentive to reduce noise through engineering controls so that hearing protection is not required. Another example is the measuring of participation in wellness activities, which may prompt organizations to motivate such participation.

Three control metrics shown in Figure 1—metrics 3, 4, and 5—are just some of the possible control-related leading metrics.

Developing a Correlated and Balanced "Set" of Metrics

Identifying leading indicators as a measure of health can range from simple to complex, depending on the number and range of risk factors and exposures associated with a particular health impact. There are almost always multiple factors that can change or influence the expected outcome. Only rarely is there a direct link between any one leading metric and a health outcome.

In particular for chronic health effects, there are many interrelated variables that can contribute to the risk of illness, disability, or disease over time. The lapse of time between exposure and the ultimate health impact (latency period) can be a significant barrier to isolating or even understanding a causal factor that then could be measured and tracked in real time.

Thus, the goal should be to create a balanced "set" of metrics that each relate to certain aspects of health and well-being—as well as to each other—and that together, can better assess and better monitor overall risks and potential risk management actions and influence the outcome. In a balanced set of metrics, each metric will be complementary or somewhat dependent on another. The Balanced Scorecard Institute (2020) lists this "connect the dots" as a key benefit of performance management and strategic planning.

One technique to increase the likelihood that the metrics are dependent and are directed toward the health outcome (i.e., the lagging metric) is to systematically and progressively use the numerator and denominators from one metric as numerators and denominators for the next. Often, this means that a numerator in the identification or evaluation metric may become the denominator for the next metric.

The case study below demonstrates the balanced set of metrics approach. The scenario is hearing loss due to noise exposure in the workplace; however, any risk or exposure (or health outcome) can be addressed by this approach. In this health-protection scenario, an undesirable health outcome—the number of confirmed audiogram threshold shifts (hearing loss)—is the lagging metric.

Likewise, the five leading metrics presented in the case study are not the entire universe of evaluation and control metrics. Rather, they are examples used to demonstrate the balanced set of metrics approach. Additional or different metrics could be selected or included. In particular, the control part of a balanced set of metrics can be quite extensive, depending on the breadth and scope of the OEHS program and control efforts.

In many cases, each of these leading metrics may be expanded. For example, the percentage of controls in place could be expanded to examine the distribution to the hierarchy of controls, that is, what percentage of controls are engineering controls versus personal protective equipment. Table 1, Examples of Leading Health Metrics and Concepts, presents other evaluation and control metrics for health protection and health promotion in the workplace.

Although some leading metrics need to exist prior to the next metric, they are all considered as a set of metrics. One would expect that, as the conformance rate of a control goes up (assuming the right control was selected), adverse health outcomes would be reduced. This is the ultimate desired outcome (or lagging metric) for any health problem. If the right controls, programs, or decisions are made, there should be good correlation within the entire set of metrics.

The benefit of the balanced set of metrics approach creates an opportunity throughout the process of implementing an OEHS program to check on its effectiveness, without simply waiting for the medical monitoring to confirm that something was amiss. Likewise, if not all of the overexposed workers are identified, all the controls in the world will not prevent health problems.

Case Study — Balanced Set of Metrics

Scenario: Noise Exposure in the Workplace

This scenario addresses noise exposure in the workplace by way of a workplace where there is loud equipment operating. The exposure is noise, defined as unhealthy levels of sound. The population at risk is the number of people who work in the noisy areas. In a typical environment, there may be multiple noise exposures, and people may move around and perform numerous activities throughout the day. Refer to Table 2 for the following discussion.

Lagging Metric: Identification

The lagging metric (health outcome) measures the number of hearing losses. There will be a lag time between exposure to noise and hearing loss. A balanced set of metrics will help predict or influence the reduction or elimination of hearing loss.

Leading Metrics: Evaluation and Controls

Hearing loss typically occurs based on an exposure or risk factor. In the United States, OSHA sets an occupational threshold action level of 85 dBA as the average level of noise that should not be exceeded in an 8-hour day. If exceeded, OSHA requires implementation of a hearing conservation program to prevent hearing loss. Note that an organization may follow other criteria to determine overexposure including, in this case, the audible sound TLVs of the (ACGIH or NIOSH recommendations).

A hearing conservation program or process has a number of evaluation and control activities that, if performed and managed well, will help prevent hearing loss. To be managed well, in part, these evaluation and control activities need to be measured so that the organization can be held accountable.

Evaluation Metrics

The purpose of evaluation metrics is to quantify the extent of the exposures (hazards or risks) associated with the identified outcome. In this case study, two evaluation metrics have been selected.

- ***Leading Metric 1 (% of assessments completed)*** is the percentage of assessments or monitoring to make sure all potential exposures have been assessed. Exposure monitoring is performed to determine what part of the population is "overexposed," meaning at the 85 dBA level or above for their 8-hour workday. This monitoring can be qualitative (a walk-through survey) or quantitative (actual sound level or noise dosimetry measurements). This metric requires values for (a) number of noise assessments performed, and (b) number of noise assessments required.

Note: A risk assessment will typically generate some of the values used in subsequent leading metrics. For example, in Table 2, number of population overexposed to noise is numerator c, number of noise hazards controlled becomes denominator d, and number of noise hazards becomes denominator f.

- ***Leading Metric 2 (% of population overexposed)*** comes from the assessment process. To calculate metric 2, the numerator c, number of the population overexposed to noise, comes from the assessment, and the denominator d, number of the total population exposed to noise, comes from company worker information.

Note: If the entire population has not been assessed, or the assessment is partially incomplete, a confidence limit of percentage overexposed may need to be included.(See Appendix D).

Control Metrics

Control metrics measure the presence and effectiveness of controls (known as management of risk). In this case study, there are three:

- ***Leading Metric 3 (% of noise hazards controlled)*** is calculated from e, number of noise hazards controlled (numerator), and f, number of noise hazards (denominator). The denominator comes from the assessments.

- ***Leading Metric 4 (Conformance rate, % of effective controls)*** goes a step further. Conformance rate and trend metrics becomes a measure of the effectiveness of the actions taken. It is calculated from g, the number of controls effectively instituted, and h, the number of noise hazards controlled.

Note: These data will come from inspection and observation programs. For example, if people are required to wear PPE or perform work rotation to a set schedule, the organization should not just assume full conformance without some sort of verification and counting.

- ***Leading Metric 5 (percentage of control enhancements)*** may truly drive the prevention of hearing loss. If all the previous metrics are not at 100%, additional controls will be needed. If controls are not effective, or the number of noise sources are not being reduced, the exposure may not change. This metric could be either percentage of control enhancements (new or eliminated) or percentage of fewer noise sources, depending on how the organization chooses to control the noise overexposures.

Note: In this scenario, the numerator is h, the number of new controls (or noise sources eliminated), and the denominator is i, the number of noise hazards that are not effective (the reverse of numerator g).

If the number of noise sources go down, there will be reduced hearing loss and a savings not only in workers' compensation but also in the number of people required to take audiograms and wear hearing protection.

Lagging health outcome: hearing loss	Evaluation metrics: noise exposure		Control metrics: noise control		
Metric					
% with identified potential for or currently active hearing loss	1) % of noise assessments performed	2) % of population overexposed to noise	3) % of noise hazards controlled	4) Conformance rate (% effective controls)	5) % of control enhancements OR % of fewer noise sources
Numerator					
j) Number of confirmed audiogram threshold shifts	a) Number of noise assessments performed	c) Number of population overexposed to noise	e) Number of noise hazards controlled	g) Number of effective noise controls	h) Number of new controls/ elimination of sources or number of noise sources eliminated
Denominator					
c) Number of the population overexposed to noise	b) Number of noise assessments required	d) Number of the total population exposed to noise	f) Number of noise hazards	e) Number of noise hazards controlled	i) Number of ineffective noise controls

Figure 2 — Creating a Set of Metrics: Using Numerators and Denominators

The health outcome — the lagging metric — is reviewed in light of the leading metric data (See Figure 2). The lagging metric's numerator assumes that all people overexposed had their hearing tested. Certainly, *Metric 2 (% of population overexposed)* should be 100% in order to rely on the lagging metric (% of workers overexposed to noise with hearing loss (effect). Since non-occupational hearing loss is common, audiograms are often offered to all employees for health promotion while also providing some defense in depth that overexposures are being recognized. Exposure groups can be split out for separate analysis. If only the lagging metric is measured, % population with health effects, and all overexposed personnel were not measured, it could lead to a false sense that all personnel are protected.

As you can see here, new data is needed to verify the numerator j) the number of confirmed audiogram threshold shifts, while the existing c) number of the population overexposed to noise, comes from metric 2.

Thus, Figure 1 is depicted as a continuous circle. When designed correctly, leading and lagging metrics will be balanced (identification, evaluation and control) while completing a correlated and intertwined set, where numerators and denominators are often used multiple times within the set. All of which can, in some means, influence, predict or monitor each other.

As health metrics programs mature, revision to metrics or additional metrics may become part of the balanced set.

Tracking Leading Health Metrics and Change in Health Outcome

Use of leading health indicators should first be targeted to the critical problem areas, prioritizing the hazards with the greatest risk (the product of severity and likelihood). Where there are not critical concerns identified, many organizations find value in starting with "low-hanging fruit": those actions that can be quickly achieved with limited additional resources required. Addressing those actions can result in quick wins that can provide positive momentum to health-improvement programs. Leading indicators based on data already being collected will also be less expensive than developing metrics that require new data collection.

Once leading health metrics are adopted, they must be assigned, tracked, and analyzed according to a schedule determined by the organization when the metrics are implemented. Analysis should consider the following questions (Muller, 2018):

- Are the metrics correlated with health outcomes?
- How useful is the information?
- How useful are more metrics?
- What are the costs of collecting the data for the metrics?

Metrics should be evaluated and reassessed periodically to make sure they are accurate and relevant (OSHA, 2019). Metrics should measure success against some stated target or goal. The goal may be a continuous improvement target, such as percent improvement year over year, or it may be appropriate to have absolute goals, such as percentage of personnel impacted.

When developing and improving metrics, there should be allowance for change, flexibility, innovation, and failure. When selecting metrics, it is best to begin by using existing data collection and reporting systems where possible. However, this requires an understanding of data systems to properly interpret results.

For example, measuring absenteeism requires a consistent definition. In one case, an organization that tried to implement an absenteeism metric found that one operation historically defined and reported absenteeism as "not having a replacement available." The operation had dozens of reserve employees to fill in for employees who did not report to work on a given day. The organization did not count any absenteeism unless either the number of no-shows exceeded the replacements available or if there was no replacement for a specialized skill position. Using absenteeism as a metric required a major change to the plant's tracking system to make it comparable to other operations.

It may take time to develop data collection resources. If data is not readily available, plans and resources are determined to identify and collect relevant data.

It may also take time to see improvements. For many health outcomes, especially where there can be significant latency, it may take years to see measurable results. One advantage of leading metrics is that short-term goals can be created and tracked to identify those actions that can impact long-term results. For example, reduction of exposure levels or reduction of health-risk indicators such as smoking or cholesterol levels can have beneficial long-term consequences. Measuring the influencing factors may be as important as measuring the lagging effect.

Even the best measures are subject to confusion, misinterpretation, corruption, or goal diversion. All metrics must be properly interpreted and understood. Even the most common lagging indicator—OSHA recordables—requires understanding and interpretation. It is not uncommon for some operations to confuse OSHA recordability requirements with workers' compensation criteria. If such issues exist with well-established metrics, how much more potential for confusion and misinterpretation, let alone manipulation, exists for less common leading metrics?

Problems can be minimized by using existing data systems, but a good understanding of the data is still necessary. For example, many metrics use number of employees as a denominator. Often this is determined by number of hours worked/2000. However, the data for hours worked may come from a payroll system and may represent hours paid. This could include overtime hours that are paid at 150% or compensated nonwork hours such as vacation or jury duty. On the other hand, payroll hours may not include contract or temporary worker hours.

No matter what metric is chosen, it is important to understand the data that supports it.

Revision and Continual Improvement

It is important to recognize that a universally perfect leading indicator does not exist and that adjustments will need to be made over time. Leading indicators will evolve as an organization matures in its journey from recognizing compliance-based results or health outcome measurements of effects (illness, disease, or health enhancements) to predicting and influencing these outcomes. The set of metrics selected will ideally predict and influence the occurrence (ideally reduction or elimination) of the identified adverse health outcome in the worker population.

As organizations progress along a health program maturity curve, metrics will need to become more targeted and precise. Often, each subsequent program improvement is more challenging than the last; however, continual improvement requires attention and appropriate modification of the program, based on the feedback the metrics provide. As positive outcomes increase and concerns decrease, the value of these leading health metrics, and the health program in general, will become obvious to leaders and the organization as a whole.

For smaller organizations in particular, providing the organization with adequate time to familiarize itself and adapt to newly introduced metrics will ultimately lead to stronger support for leading indicators. There is utility in starting small and simply identifying top problem areas and prioritizing the hazards with the greatest risk (the product of severity and likelihood) (OSHA, 2019; International Standards Organization, 2018).

One approach to easing into the introduction of new metrics is to take advantage of data already available or easily collected, deciphering what data is in hand, what can be collected, and if it is useful (NSC, 2019). Also, it is imperative to respond to what is learned and to always transparently communicate progress to workers (OSHA, 2019).

Limitations of Metrics

The science of leading metrics has advanced swiftly in recent years, and many metrics have been proposed with the intention of shifting the conversation from lagging outcomes to predictive conditions. However, as William Bruce Cameron (1958) observed, "Not everything that can be counted counts," and there has been scant guidance to support the practitioner in ensuring a proper connection between the proposed leading metrics and the outcomes they claim to predict. Accordingly, the prudent health professional must remain both circumspect when developing leading metrics and wary that the selected metrics may not drive the desired change—or may measure the wrong thing entirely.

The point is that it is not enough to create a metric: it is necessary to monitor and manage the metric to make sure it is understood, interpreted consistently, and used to drive desired actions or behavior. Thus, the interrelationship between numerator and denominator becomes an important part of developing a set of metrics.

Measurement is not an alternative to judgment. Measurement demands judgment: judgment about whether to measure, what to measure, how to evaluate the significance of what has been measured, whether rewards and penalties will be attached to the results, and to whom the measurements should be available (Muller, 2018).

Conclusion

This document endeavors to advance the science of leading metrics by offering leading metrics specific to health outcomes—as opposed to metrics specific to safety or injury outcomes. It also proposes a metric development process that comprises multiple stages, including a validation stage. This allows the practitioner the confidence that he or she is not only measuring the right thing but also that the focus on such metrics is having the intended consequences.

How much of a result can be obtained depends on the magnitude of the actions and controls taken to deal with the exposure or risk. Each metric should have a target goal. In an effective application of leading health metrics, different parts of an organization will be accountable for different actions.

Metrics provide feedback to management that help evaluate the effectiveness of the selected actions. Metrics can also help identify needed course corrections and can suggest additional metrics that may help to more precisely identify needed actions. When these metrics are broadly used in an organization, there is a better chance of achieving the expected health outcome.

When the correct population is identified and the correct questions are asked, population-specific approaches can be identified that will reduce adverse impacts on health and increase actions that support greater health and well-being. In general, the portfolio of effective metrics for a given organization will be unique to that organization, but the individual metrics that comprise that portfolio follow some common approaches. Based on carefully reviewed references, this document provides examples of those individual metrics, which can be combined to develop a comprehensive metrics portfolio for most organizations.

In summary, developing and effectively using leading health metrics will reduce or eliminate adverse health outcomes as well as advance health and well-being. Better health and prevention of health problems (adverse effects) will benefit from identification of actions or solutions. Such results can then be predicted and expected if solutions are properly identified.

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Appendix A: Glossary of Terms

Audit. A systemic, independent, and documented process for obtaining information and evaluating it objectively against defined criteria.

Balanced set of metrics. A set of metrics that measures both a balanced and complementary set of leading and lagging metrics. The set of metrics provides a concise but comprehensive view of performance that is used to monitor, predict, influence, or manage workplace exposures, hazards, actions and conditions, while providing feedback to organizations.

Balanced scorecard. A set of measures that provides a concise but comprehensive view of performance, which is used to measure and provide feedback to organizations.

Conformance rate. Percentage of controls used properly, over the total number of controls present.

Control metrics. Control metrics measure the presence and effectiveness of controls implemented to manage risk, as well as continual improvement using the hierarchy of controls.

Evaluation metrics. Evaluation metrics measure the degree of health hazards and hazardous exposures.

Exposure. Occupational exposure that can be reasonably anticipated in the work environment from the equipment, tools, and materials associated with employees' job duties. Exposures from products and services subject to consumer or public safety and health protection programs are considered nonoccupational exposures.

Health. State of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity (WHO, 2020).

Health effect. Any health outcome (illness or disease) associated with exposures at the workplace. These may address negative outcomes, such as hearing loss or cancer, as well as positive outcomes, such as reduced obesity or increased satisfaction in the workforce. Health effects do not include injuries.

Health program. Programs define actions taken to influence health and/or health outcomes.

Health promotion. Actions taken by an organization to improve workers' health. This term generally implies a positive health effect, such as reduced weight.

Health protection. Actions taken by an organization to prevent negative health effects in the worker population.

Identification. Any process or information used to anticipate or recognize potential health outcomes resulting from occupational exposures, risks, or hazards.

Injury. Physical harm or damage to a person resulting in personal discomfort, bodily harm or impairment, marring of appearance, or death.

Lagging metric. Performance measure of after-the-fact occurrences, such as injury and illness rates and prevalence or risk of illness or disease. Lagging indicators frequently focus on results at the end of a time period and characterize historical or retrospective performance.

Leading health metric. A measurable, meaningful, actionable, evidence-based indicator. It can be used to monitor, predict, influence, or manage exposures, hazards, actions and conditions of work that may impact worker health and well-being.

Leading metric. Performance measure that is predictive or capable of influencing results and is aimed at the prevention and control of future events.

Metric. A standard of measurement or a measured value, as compared to a target or goal.

Overexposure. Exposure to a work environment in which levels are not being controlled to acceptably low likelihood of exceeding occupational exposure limits (i.e., < 5%). Most commonly, organizations will establish the goal of achieving this level of performance without factoring in the assigned protection or reduction factors of personal protective equipment worn by employees.

Rate. A measure, quantity, or frequency measured against some other quantity or measure.

Risk. An estimate of the probability of a hazard-related incident or exposure occurring and the severity of harm or damage that could result (ANSI/ASSP, 2011).

Risk assessment. Overall process of risk identification, risk analysis, and risk evaluation.

Risk control. Process used to minimize loss from hazards by treating or mitigating their consequence or occurrence.

Total Worker Health. See Appendix B.

Well-being. NIOSH defines worker well-being as an integrative concept that characterizes quality of life with respect to an individual's health and work-related environmental, organizational, and psychosocial factors. Well-being is the experience of positive perceptions and the presence of constructive conditions at work and beyond, which enables workers to thrive and achieve their full potential.

Worker. A person performing work or work-related activities that are under the control of the organization. Workers may include temporary and subcontractor employees.

Work environment. Physical and psychosocial aspects of the workplace.

Workers' compensation. A form of insurance providing wage replacement and medical benefits to workers injured in the course of employment, in exchange for mandatory relinquishment of the workers' right to sue their employer for the tort of negligence.

Workplace. Locations under the control of the organization where a person needs to be or go for work purposes. The employer's premises and other locations where workers are engaged in work-related activities or are present as a condition of their employment. The employer's premises encompass the total establishment.

Appendix B: Total Worker Health and Leading Health Metrics

What is Total Worker Health®?

Total Worker Health® (TWH) is defined as policies, programs, and practices that integrate protection from work-related safety and health hazards with promotion of injury and illness prevention efforts to advance worker well-being.[1]

Approaches to TWH are integrated and comprehensive in that they focus on health protection and disease prevention for both work and nonwork issues. They prioritize changes to improve the organizational context for work, the physical environment, and psychosocial factors that impact workers. Worker-level behavior modifications are secondary in the TWH approach.

The emphasis of TWH approaches is captured in the TWH hierarchy of controls (Lee et al., 2016), which tracks the traditional industrial hygiene hierarchy of controls by first seeking to eliminate working conditions that threaten worker safety, health, and well-being.

Second, if elimination is not possible, the TWH-consistent approach is to substitute or replace unsafe, unhealthy working conditions with safer, health-enhancing policies, programs, and practices that improve the workplace safety and health culture. The removal of impediments to well-being through work environment redesign is similar to the application of engineering controls designed to isolate workers from hazards.

The least effective controls are those that depend on behavior modification, including worker education and encouragement of personal change.

Leading Health Metrics Consistent with TWH Approaches

Leading health metrics in occupational safety and health programs ideally should be consistent with TWH approaches, including the TWH hierarchy of controls. Although some nonintegrated, siloed occupational safety and health or wellness efforts have been marginally successful at addressing worker safety, health, and well-being, many studies have found that integrated approaches are more efficacious.[2]

Given the complexity of workplace and work issues impacting the workforce, multilayered and multidimensional approaches to leading health metrics will be more informative than single-topic measures. In fact, no one measure or outcome is currently recommended to assess TWH policies, programs, and practices.

Rather, measures may be categorized as structural, process, and outcome, with outcome measures further divided into organizational level and worker level.[3] Targeting organizational level measures is consistent with the TWH hierarchy of controls. Examples of leading organizational measures might include those that address leadership, policy, working conditions and environment, safety culture, and productivity.

Lower on the TWH hierarchy of controls would be measures that focus on worker-level outcomes. Examples would include safety practices, individual health conditions, job satisfaction, healthcare utilization, and personal health behaviors—all of which are more likely

1 Tamers, S.L., Chosewood, C.L., Childress, C., et al. (2019, January). Total worker health 2014-2018: The novel approach to worker safety, health, and well-being evolves. International Journal of Environmental Research and Public Health, 16(3), 321.

2 National Institute for Occupational Safety and Health (NIOSH). (2012). The NIOSH Total Worker Health program: Seminal research papers 2012 [Research compendium]. [DHHS-NIOSH Publication No. 2012-146]. U.S. Department of Health and Human Services. Centers for Disease Control and Prevention.

3 Tamers, S.L., Goetzel, R., Kelly, K., et al. (2018). Research methodologies for Total Worker Health: Proceedings from a workshop. Journal of Occupational and Environmental Medicine, 60(11), 968-978.

to be lagging indicators of health.

Furthermore, workplace policies that discriminate against or penalize workers for their individual health conditions or create disincentives for improving health are inconsistent with the TWH approach.

Another approach to assessing leading health metrics from a TWH perspective is to consider the defining elements of TWH.[4] Five elements form the foundation of TWH, and each of these can be used to create organization-specific measures of health. The defining elements of TWH are:

- Demonstrate leadership commitment to worker safety and health at all levels of the organization.
- Design work to eliminate or reduce safety and health hazards and promote worker well-being.
- Promote and support worker engagement throughout program design and implementation.
- Ensure confidentiality and privacy of workers.
- Integrate relevant systems to advance worker well-being.

Each of these defining elements can be used to design leading measures of health that tap into organizational readiness for change.

In summary, the breadth of TWH policies, programs, and practices requires different measures and outcomes based on the questions of interest and the interventions being evaluated. Tamers et al. (2018) offer specific examples of TWH measures and outcomes across a variety of categories and at multiple levels that are considered relevant to occupational safety and health.

The NIOSH fundamentals of TWH approaches (Lee et al. 2016) provide a framework for assessing the defining elements of TWH. These resources can be used to develop organization-specific, leading health metrics.

[4] Lee, M.P., Hudson, H., Richards, R., et al. (2016). Fundamentals of Total Worker Health approaches: Essential elements for advancing worker safety, health, and well-being [DHHS-NIOSH Publication No. 2017-112]. NIOSH Office for Total Worker Health, Centers for Disease Control and Prevention.

Appendix C: Selected Resources on Leading Health Metrics

Resource	Description of content
Allen, J.G., & Macomber, J.D. (2020). *Healthy Buildings.* Harvard University Press.	This book supports the premise that indoor environmental quality is a key factor driving human performance and productivity. The authors describe nine foundations of a healthy building and put forth a framework of both leading and lagging indicators for measuring the performance of buildings in providing healthful indoor environments. Indirect leading health performance indicators (HPIs) relate to the building and include its design, material selection, continuous commissioning, building certifications, integrated pest management, and enhanced ventilation and filtration. Indirect lagging HPIs include building system audits and observations, retro-commissioning, employee recruitment and retention rates, and perceptions of building performance. Cited direct HPIs, those that relate to employee health, are also categorized as lagging (e.g., illness trends and health symptoms among building occupants) and leading (e.g., employee experience—happiness, concerns, and positive sentiments). The "pulse" of buildings is taken by monitoring healthy building foundation aspects: water quality, dust/allergens, mold/moisture, IAQ/VOCs, lighting, ventilation/CO2, temperature/RH, noise/acoustics, and safety/security. 292 pp.
American College of Occupational and Environmental Medicine (ACOEM). (2020). *Guide to a Healthy and Safe Workplace.* https://acoem.org/acoem/media/PDF-Library/About_ACOEM/Guide-to-a-Healthy-Safe-Workplace-2020.pdf	Designed as a "roadmap to excellence," this guide includes three dimensions: economic, environmental, and social. Each dimension is further subdivided for a deeper dive into specific topical concerns. Each subdivision includes the relevant ACOEM standard for excellence and examples of leading and lagging metrics by level of program maturity, described as approach, deployment, results, and positive trends. 28 pp.
American Society of Safety Professionals & American National Standards Institute (ASSP/ANSI). (2020). Z16.1 *Safety and Health Metrics and Performance Measures, draft.*	The goal of standard Z16.1 is to define, help standardize, and validate various metrics as well as to describe an approach for developing a balanced scorecard. A balanced scorecard approach uses a mixture of leading, lagging, and value-based metrics. Multiple examples of each type of metric are provided and defined for application to various endpoints, including health, safety, fleet, productivity, cost, perception, risk management, training, and continuous improvement. Health metrics include sickness absence rate, presenteeism, disease prevalence, and health-risk factor prevalence.
Amick, B. (2014). *Ontario Leading Indicators Project (OLIP) Scorecard. Institute for Work & Health.* www.iwh.on.ca/sites/iwh/files/iwh/reports/iwh_project_olip_scorecard_2014.pdf	This scorecard can be used to assess how well your organization is performing on each leading indicator measure from the Ontario Leading Indicators Project questionnaire. An organization's individual results can be compared with absolute cutoffs. 2 pp.

Resource	Description of content
BHP. (2018). *Sustainability Report.* https://www.bhp.com/-/media/documents/investors/annual-reports/2018/bhpsustainabilityreport2018.pdf	This document identifies data for BHP stakeholders. For health and safety, BHP primarily tracks the following lagging indicators: workplace fatalities; total recordable injury frequency; hazards identified; high-potential injury events; occupational illness rates for both employees and contract workers; and the medical surveillance program. Leading indicators include field leadership; exposure reduction projects (diesel particulate matter, silica, and coal dust); peer-led Resilience Program participation; well-being as self-reported in the engagement and perception survey; and employee assistance program utilization. 74 pp.
Boyd, W, Brockhaus, A, Chini, M, et al. (2001). *Industrial Hygiene Performance Metrics. Falls Church: American Industrial Hygiene Association.*	This manual was the first performance metrics document strictly devoted to industrial hygiene metrics. This manual provides industrial hygienists with both a metric process and examples of metrics in 12 different IH areas. These areas are bloodborne pathogens, ergonomics, exposure assessment, health hazard abatement, hearing conservation, IAQ, IH surveillance, MSDS, occupational health, respiratory protection, SHE training programs, and ventilation systems. The manual also includes a set of universal IH management system-related metrics.
Budworth, N. (2013). *Performance Indicators - Made to Measure. Safety & Health Practitioner.* www.shponline.co.uk/culture-and-behaviours/performance-indicators-made-to-measure/	This article begins with a discussion of the characteristics of effective leading indicators. Indicators addressed in some detail include those based on safety auditing, behavioral and attitude assessment, safety inspections and safety sampling, and training delivery according to plan.
Bunn WB, Pikelny DB, Slavin TJ, and Paralkar S. (2001). *Health Safety and Productivity in a Manufacturing Environment. Journal of Occupational and Environmental Medicine, 43(1),* 47-55 https://journals.lww.com/joem/Abstract/2001/01000/Health,_Safety,_and_Productivity_in_a.10.aspx	This article describes the health and productivity management model at International Truck and Engine Corp. The program used an iterative approach to identify opportunities, develop interventions, and achieve targets through continuous measurement and management. The program includes safety, workers' compensation, short-term disability, long-term disability, healthcare, and absenteeism. 9 pp.
Center for Construction Research and Training (CPWR). (2018). *Safety Climate Assessment Tool (S-Cat).* https://www.cpwr.com/sites/default/files/research/Safety_Climate_Assessment_Tool-S-CAT_English.pdf	This tool assesses management commitment using perception surveys. Topics include aligning and integrating safety as a value, ensuring accountability at all levels, improving supervisory leadership, empowering and involving employees, improving communication, training at all levels, and encouraging owner/client involvement. 12 pp.

Resource	Description of Content
Center for Safety & Health Sustainability (CSHS). (2016). *CSHS Best Practice Guide for Occupational Health and Safety in Sustainability Reports.* www.centershs.org/assets/docs/CSHS_Best_Practice_Guide_Final.pdf	This guide describes essential elements for OEHS sustainability reporting and optional elements for such reporting. Essential elements include an overview of the organization's OEHS programs and key OEHS performance measures. Metrics include lagging safety-related indicators and general leading indicators. Optional elements for OHS sustainability reporting include metrics reflecting performance against continual improvement goals or targets; OEHS oversight of capital investments; OEHS training (e.g., OEHS training per 1000 hours worked); descriptions of the OEHS strategic risk-management process; and special programs (e.g., wellness and return-to-work programs). Additional suggested metrics include workers exposed above recommended exposure values but with safety equipment, safety culture indicators, and behavioral safety observations. 8 pp.
Centers for Disease Control and Prevention (CDC). (2018). *Introduction to the "New and Improved" CDC Worksite Health Scorecard.* www.cdc.gov/workplacehealthpromotion/initiatives/healthscorecard/pdf/CDC-Scorecard-Update-Webinar-Final-508.pdf	The scorecard is focused on health promotion and poses specific questions around broad categories including leadership commitment and support, measurement and evaluation, strategic communications, participation and management, programs, policies, and environmental supports. Specific health areas are tobacco use, high blood pressure, high cholesterol, physical activity, weight management, nutrition, heart attack and stroke, prediabetes/diabetes, depression, stress management, drugs and alcohol, sleep and fatigue, musculoskeletal disorders, OEHS, vaccine-preventable disease, maternal health and lactation support, and cancer. The document also discusses scoring. 32 pp.
Centers for Disease Control and Prevention (CDC). (2014). *The CDC Worksite Health ScoreCard.* https://www.cdc.gov/dhdsp/pubs/docs/HSC_Manual.pdf	This CDC document is a tool designed to help employers assess whether they have implemented evidence-based health-promotion interventions or strategies in their worksites to prevent heart disease, stroke, and related conditions such as hypertension, diabetes, and obesity. The 16 health topics covered include organizational supports for health promotion as well as OEHS. It describes steps for using completed scorecard results to improve a worksite's health-promotion programs. 75 pp.
Construction Owners Association of Alberta. (2011). *Workplace Health and Safety Performance Improvement Guide.* https://www.coaa.ab.ca/COAA-Library/SAF-PIM-CBP-01-2011-v1%20Workplace%20H&S%20Performance%20Improvement%20Guideline.pdf	This guide discusses numerous leading and lagging metrics. Examples of lagging metrics include fatalities, lost time, total recordable injuries, recordable occupational illnesses, and severity rate. Examples of leading metrics include manager active participation, supervisor active participation, worker active participation, contractor management, communications forums, compliance, hazard identification process, field-level hazard assessments, focus audits and inspections, tracking of outstanding action items, training conducted, proactive A&D testing, employee perception surveys, near-miss reporting, trend identification, and health programs. 7 pp.

Resource	Description of Content
Council of State and Territorial Epidemiologists (CSTE). (2018). *Occupational Health Indicators: A Guide for Tracking Occupational Health Conditions and Their Determinants.* https://www.cste.org/page/OHIndicators?&hhsearchterms=%22leading+and+performance%22	Written for an audience of government personnel (e.g., epidemiologists), this guide provides a detailed description of 24 occupational health indicators (OHI), some of which are considered to be leading indicators. Each section includes a brief definition of the specific measures of that OHI, the source(s) of the data used to calculate the indicator measures, a description of the public health significance of that indicator, and links to the data tables and figures. The tables and figures show OHI results by state and, when available, the United States, from 2000 to 2015. Technical notes are included to explain important data issues involved in generating the indicators. 24 pp.
Esposito, Paul. (2014). The Balanced Scorecard: A Powerful Tool for Risk Management. American Society of Safety Professionals. http://box5643.temp.domains/~starcoo0/wp-content/uploads/2020/07/RM-Insight-Vol-13-No-3-18-23.the-balanced-scorecard-a-powerful-tool-for-RIsk-Management.pdf	This article describes the balanced scorecard concept created in 1992 by Robert Kaplan and David Norton. This concept was initially employed to help public agencies better manage and measure performance. Its more current use is as a more integrated system of performance measures in four categories: financial performance, customer knowledge, internal business processes, and learning and growth, as applied to risk assessment and management as part of successful OEHS management. 6 pp.
Esposito, Paul. (2018). Safety Metrics: Corporate & Site-Level Scorecards. *Professional Safety Journal, 63(6)*, 30-33. https://www.assp.org/docs/default-source/psj-articles/bp_esposito_0618.pdf?sfvrsn=2	This article explores leading metrics to measure safety performance presented in a balanced scorecard format. It discusses which metrics may be most valuable to start with, and identifies risk-centric alternatives to incident rate metrics (lagging indicators).

Resource	Description of Content
Forskningscenter for Arbejdmiljo. (2007). *Questionnaire on Pyschosocial Factors at Work.* https://nfa.dk/-/media/NFA/Vaerktojer/Spoergeskemaer/COPSOQ/Copenhagen-Psychosocial-Questionnaire-COPSOQII/5_copsoq-ii-medium-size-questionnaire-english.ashx?la=da	This questionnaire focuses on psychosocial factors at work. It includes questions that assess psychosocial factors with respect to work environment and job satisfaction at the job level, the workplace as a whole, and work and private life. 11 pp.
Global Reporting Initiative (GRI). (2018). GRI 403: *Occupational Health and Safety.* www.globalreporting.org/standards/gri-standards-download-center/gri-403-occupational-health-and-safety-2018/	This standard is part of the GRI Sustainability Reporting standards designed for organizations to report on their economic, environmental, and social impacts. GRI 403 fits into the social impact-topic series of reporting standards. Organizations choosing to adhere to this standard are expected to disclose information in their sustainability reports about their OEHS-related activities. Disclosures include those related to a broad range of OEHS-related topics: OEHS management system implementation, health promotion, training, worker participation, health services, and standard lagging indicators (e.g., work-related injury and illness rates). 32 pp.
Global Reporting Initiative (GRI). (2019). *A Culture of Health for Business: Guiding Principles to Establish a Culture of Health for Business.* www.globalreporting.org/SiteCollectionDocuments/2019/GRI_RWJF_CultureofHealthforBusiness.pdf	This technical document puts forth four guiding principles intended to help establish a "culture of health for business." The principles support the premise that it is in the best interests of the private sector to assist with the maintenance and improvement of population health by adopting such a culture of health business practices. This document presents 16 such practices: health culture; responsible corporate political activity; responsible marketing; health promotion and wellness; paid family and medical leave; health insurance; equality, diversity, and impartiality; financial literacy; work time; job security; pay practices; occupational safety and health; physical environment; community environmental impacts; social capital and cohesion; community involvement. Examples are provided of metrics, both leading and lagging indicators, to measure the implementation of the practices. Most of the examples relate to health promotion with a few relating to health protection (OEHS). 147 pp.

Resource	Description of Content
Government of Alberta. (2015). *Leading Indicators for Workplace Health and Safety: A User Guide.* https://open.alberta.ca/dataset/17acecf3-0922-41b3-97b8-8b43ac27c304/resource/00ea4194-eed2-4eb1-89d9-e7bc1c3f0e8a/download/2015-03-ohs-best-practices-bp019.pdf	This leading indicator development guide explains how to begin the development of leading indicators within your organization. There are questions in the guide to start one's thinking about how to develop leading indicators. The guide uses a framework of three OEHS performance categories: compliance, improvement (beyond compliance), and continuous learning. 35 pp.
Health & Safety Executive (HSE). (2001). *A Guide to Measuring Health & Safety Performance.* www.hse.gov.uk/opsunit/perfmeas.pdf	This guidance document discusses why to measure, what to measure, when to measure, who should measure, and how to measure health and safety performance. Discussions include potential issues with injury and ill-health measures and the importance of measuring performance for a health and safety system. 30 pp.
Hero Health In Collaboration with Mercer. (2016). *The Hero Health and Well-Being Best Practices Scorecard.* https://hero-health.org/wp-content/uploads/2017/01/US-Scorecard-V4-writable_1.2017.pdf	This scorecard is designed to help organizations learn about and determine health and well-being best practices. It is updated to keep pace with feedback from users and industry leaders. It specifically calls for strategic planning, and tends to be activity driven, with a focus on lifestyle management, communication, and worker offerings versus organizational change. The scorecard can be used as a health and well-being program inventory, as an indicator of program success, and as a program benchmarking tool. 56 pp.
Institute for Work & Health (IWH). (2015). *Institute for Work and Health Organizational Performance Metrics.* https://www.iwh.on.ca/tools-and-guides/iwh-organizational-performance-metric	The Institute for Work & Health Organizational Performance Metric (IWH-OPM) is an evidence-based, eight-item questionnaire used to help organizations assess and improve their health and safety performance. It was developed and validated by the institute in collaboration with health and safety professionals in Ontario. IWH-OPM scores indicate where improvements might be made to health and safety policies and practices in order to prevent injuries or illnesses.
International Petroleum Industry Environmental Conservation Association, International Association of Oil & Gas Producers (IPIECA/OGP). (2007). *Health Performance Indicators: A Guide for the Oil and Gas Industry.* https://www.iogp.org/bookstore/product/health-performance-indicators/	This guide includes leading health performance indicators (HPIs) geared toward the oil and gas industry. The HPIs are described as globally consistent standards of health management. Tier 1 HPIs are associated with the implementation of a health management system. Tier 2 HPIs are specific leading indicators intended to provide data from implementation of the Tier 1 HPI health management system programs: health-risk assessment and planning, IH and control of workplace exposures, medical emergency management, management of ill health in the workplace, fitness for task assessment and health surveillance, health-impact assessment, public health interface, and health promotion. 20 pp.

Resource	Description of Content
Johnson D., (2010). Industrial Safety & Hygiene News. (2010). *10 Essentials of McWane's Culture Change.* www.ishn.com/articles/89805-10-essentials-of-mcwanes-culture-change	Ten essential management system elements are identified in this magazine article. Accountability, one of the elements, is achieved using a combination of both lagging and leading performance indicators. Several leading health indicators are identified, including training hours per month, medical evaluations per month, respirator fit tests, hearing tests, IH samples collected, timely closure of inspection findings, and internal safety and health reviews.
Los Alamos National Laboratory. (2014). Energy Facilities Contractors Group ESH Working Group (EFCOG) *Industrial Hygiene Performance Indicator Guide.* https://efcog.org/safety/worker-safety-health-subgroup/?drawer=_Worker%20Safety%20and%20Health%20Subgroup*Industrial%20Hygiene%20and%20Safety%20Task%20Group	This document discusses IH leading and lagging metrics. It includes a general discussion with a few examples, and it describes types of performance indicators such as output, process, outcome, as well as the benefit of using multiple indicators to assess the effectiveness of IH programs. There is a table for reviewing performance indicators. 14 pp.
National Academies of Sciences, Engineering, and Medicine (NASEM). (2018). *A Smarter National Surveillance System for Occupational Safety and Health in 21st Century.* www.nap.edu/catalog/24835/a-smarter-national-surveillance-system-for-occupational-safety-and-health-in-the-21st-century	This document supports the improvement of existing OSH surveillance systems. It describes six objectives of an ideal OSH surveillance system that would shift surveillance efforts from simply documenting occupational disease (e.g., coal workers' pneumoconiosis). It advocates gathering occupational health hazard and exposure data that indicate the need for illness prevention measures—measures that can be used to anticipate and prevent work-related chronic disease and, to a lesser extent, acute disease and injuries. 319 pp.
National Safety Council (NSC). (2013). *Transforming EHS Performance Measurement Through Leading Indicators.* http://www.nsc.org/Portals/0/Documents/CambpellInstituteandAwardDocuments/WP-Transforming-EHS-through-Leading-Indicators.pdf	This document, first in a three-part series of white papers, defines leading indicators for environmental health and safety (EHS), gives an overview of them, explains their value, and discusses their primary characteristics. Research results include the finding that management commitment, engagement, understanding, and support are essential to effective EHS performance measurement. The paper also discusses a number of factors critical to enabling effective leading indicator implementation, including open communication, knowledge sharing, and high-quality technology and information systems for data management. The paper acknowledges that establishing a connection between leading indicators and actual EHS performance reflected by lagging indicators is an ongoing challenge. 26 pp.

Resource	Description of Content
National Safety Council (NSC). (2015a). Practical Guide to Leading Indicators. *https://www.thecampbellinstitute.org/wp-content/uploads/2017/05/Campbell-Institute-Practical-Guide-Leading-Indicators-WP.pdf*	This document, second in a three-part series of white papers, reflects the results of research to extend knowledge about leading indicators and their practical use. Results include the identification of more than 20 leading indicators and their classification into three broad indicator categories (systems-based, operations-based, and behavior-based). In addition, over 100 metrics were grouped under the 20+ leading indicators to form a matrix. Included in the paper are five case studies in which Campbell Institute participants share their experience using five different leading indicators. 20 pp.
National Safety Council (NSC). (2019a). Beyond Safety: Leading Indicators for Health & Wellbeing. https://www.thecampbellinstitute.org/wp-content/uploads/2019/08/Campbell-Institute-Beyond-Safety-Leading-Indicators-for-Health-and-Wellbeing.pdf	This document begins by introducing the concept of Total Worker Health, which integrates workplace health protection with health promotion. It makes a case for leading health indicators beyond those developed by Healthy People 2020, which primarily look at physical well-being. The document delineates five different categories for leading health and well-being metrics (education/awareness, reach, participation, satisfaction, and organizational health) and provides a list of 25 leading indicator metrics within those five broad categories. 11 pp.
National Safety Council (NSC). (2019b). An Implementation Guide for Leading Indicators. *www.thecampbellinstitute.org/wp-content/uploads/2019/08/Campbell-Institute-An-Implementation-Guide-to-Leading-Indicators.pdf*	This document, last in a three-part series of white papers, provides a closer look at the experience of eight Campbell Institute members/partners in developing leading indicators and implementing their use. The implementation experience is shared in the context of the plan-do-check-act management system-based model. Differing opinions regarding leading indicator adoption are shared along with brief case studies illustrating different leading indicator-related journeys. Key recommendations include the following: look at what is already being measured for potential leading indicators; avoid undue deliberative delay; make sure indicators are meaningful and actionable; obtain leadership support; and integrate leading indicators into the overall OEHS management system. 28 pp.
National Safety Council (NSC). (2019B). *An Implementation Guide for Leading Indicators.* www.thecampbellinstitute.org/wp-content/uploads/2019/08/Campbell-Institute-An-Implementation-Guide-to-Leading-Indicators.pdf	This document reviews the previous leading indicators-related work of the NSC's Campbell Institute. It then introduces of a model for benchmarking and ranking leading indicators based on four safety-culture maturity levels: reactive, dependent, independent, and interdependent. The document provides a comprehensive list of leading indicator metrics categorized as to organizational maturity level and complexity level (low, medium, or high). Guidance is provided on how to get started using leading indicators. 24 pp.
Occupational Safety and Health Administration (OSHA). (2019). *Using Leading Indicators to Improve Safety and Health Outcomes.* US Department of Labor. www.osha.gov/leadingindicators/docs/OSHA_Leading_Indicators.pdf	OSHA published this document to encourage employers to learn how they can use leading indicators to improve safety and health outcomes in the workplace. It defines leading indicators, describes their benefits, and explains the characteristics of effective indicators. Examples are provided of leading indicators used to improve different safety and health program elements. 18 pp.

Resource	Description of Content
Step Change in Safety. (n.d.). *Leading Performance Indicators: Guidance for Effective Use.* http://www.lustedconsulting.ltd.uk/step%20change%20-%20leading%20performance%20indicators.pdf	This document provides definitions on what leading health indicators are and how they can be used. It discusses the process for effective selection and use of leading performance indicators and describes the characteristics of good indicators. Part 1 provides guidance for effective use of leading performance indicators. Part 2 of this document focuses on leading performance indicators for safety. Part 3 discusses the leading performance indicators for occupational health. It includes characteristics of good indicators and how to select indicators based on program desired outcomes. In all of the above three parts, the document proposes that leading performance indicators be used in the context of three levels of safety culture maturity: compliance, improvement, and learning. 23 pp.
Stowell R. (2013). *Measuring Health and Safety Performance.* Safety & Health Practitioner. https://www.shponline.co.uk/safety-management/all-eyes-on-the-horizon/	This article highlights the myriad of indicators and the challenge for safety practitioners to have a "balanced suite." It examines advantages and disadvantages of commonly used OEHS leading and lagging indicators. The author asserts that an often-overlooked leading indicator, capable of providing an accurate, real-time picture of OEHS performance, is organizational competence. The article then explores how to match risk categories for operations with competence categories of workers—with the resulting matrix indicating the level of supervision required (e.g., person-task supervision requirement, including self-supervision).
Toellner J. (2001). Improving Safety & Health Performance: Identifying & Measuring Leading Indicators. *Professional Safety, 46(9)*, 42-47.	This article focuses on safety with a discussion of how trailing or lagging indicators likely are not good indicators of safety performance. Leading indicators represent an opportunity to improve safety performance, such as preventing accidents and incidents rather than managing them. 6 pp.
U.S. Department of Energy (DOE). (1996). *Guidelines for Performance Measurement.* https://www.directives.doe.gov/directives-documents/100-series/0120.1-EGuide-5/@@images/file	This document has a general discussion on the benefits of performance metrics and how to use them. 32 pp.
US Navy. (2018). *DOEHRS-IH Navy Metrics, Tools, and Informational Queries/Reports.* https://www.med.navy.mil/sites/nmcphc/Documents/industrial-hygiene/DOEHRS-IH_BUMED_IPR_IH_Metrics_Tools_Info_Queries-Reports_Explanation.pdf	This document lists numerous metrics (e.g., workplace hazard characterization, similar exposure groups defined or assessed) and provides explanation of metrics as well as numerators and denominators. 30 pp.

Appendix D: Estimating Exposure Performance Metrics

Introduction.

Exposure control focuses on maintaining compliance with OELs each work shift, since this limits adverse effects, whether due to cumulative dose or high dose rates. Treating any exceedance as an adverse event triggers early intervention through investigation of likely causes, so that it can be prevented from happening again.

A problem with computing metrics from exposure monitoring results is that most often it is practicable to monitor only a small percentage of work shifts. In statistical process control, the problem of deciding how many components to inspect before accepting the whole batch is answered with upper tolerance limits.

The same concept can be applied to exposure monitoring results to decide whether enough exposure periods have been monitored to conclude that sources of exposure are being adequately controlled. Monitoring that demonstrates that fewer than 5% of exposure periods exceed OELs is considered "statistically significant" evidence that no uncontrolled sources of exposure are present. The 95% upper tolerance limit of the 95th percentile (95-95 UTL) is a metric used to support this conclusion.[1] The 95-95 UTL serves as leading performance indicator by driving improvements in exposure-monitoring programs to reduce uncertainty.

Distribution Assumptions.

Most commonly, exposure-monitoring results are grouped by job title and location. This is the first approximation of a similarly exposed group (SEG), for whom a measurement of one member is representative of the exposures of other members of the group.

By job/by location						
Groups	306		289			
	Between		Within		Total	Total
	$\hat{R}_{95}$	Sigma	$\hat{R}_{95}$	Sigma	Sigma	GSD
5th %ile	1	0	3.7	0.33	0.33	1.40
25th %ile	2.5	0.23	9	0.56	0.61	1.84
50th %ile	4.8	0.40	26.2	0.83	0.92	2.52
75th %ile	10.3	0.59	65	1.06	1.22	3.39
95th %ile	44.7	0.97	445.6	1.56	1.83	6.25

Table 1 — $\hat{R}_{95}$ is the estimated ratio of the 97.5/2.5 percentiles of the exposure distribution. Sigma is the standard deviation of the log transformed data. Geometric Standard Deviation (GSD) is the antilog of sigma.

The distributions of occupational exposure monitoring results from a stable ongoing operation are expected to follow the lognormal distribution. Results are skewed, with most results above zero but at levels well below OELs and only a few exceedances.

A meta-analysis of variance by Symanski et al.[2] summarized 60 published reports that included 49,807 monitoring results for 571 job groups. Table 1 shows analyses of variance for exposure groups made up of workers with the same job title in the same location. Day-to-day variation in an individual's exposure (within worker) is large compared to variation between workers.

In most circumstances, only a small percentage of work shifts will be monitored with only a few sam-

1 Mulhausen, J., & Miltz, S. (2015). Descriptive statistics, inferential statistics, and goodness of fit. In J.S. Ignacio, W.H. Bullock, & S.D. Jahn (Eds.), A strategy for assessing and managing occupational exposures (4th ed.). American Industrial Hygiene Association.

2 Symanski, E., Maberti, S., & Chan, W. (2006). A meta-analytic approach for characterizing the within-worker and between-worker sources of variation in occupational exposure. Annals of Occupational Hygiene, 50(4), 343-57.

ples for any one SEG. The largest result of a set is most commonly estimated to be located at the n/(n+1) percentile. If the number of results is fewer than 19, the 95th percentile will be larger than the largest result (i.e., 19/20 = 0.95). Parametric statistical methods can be used to provide estimates of the 95-95 UTL in these circumstances.

The distributions of exposure-monitoring results are not expected to follow the lognormal distribution for construction and other projects where work and exposure determinants are continually evolving. Similarly, rolling up an organization's exposure monitoring results across jobs, locations, and agents will not be expected to be lognormal. In this situation, nonparametric methods can be used to estimate the 95-95 UTL.

In workplaces where exposures are well controlled, it is common for exposure monitoring results to be below a laboratory reporting limit. In statistical terminology this is called a censored data set, as opposed to a complete data set in which a value is provided for each result. Censored data methods for continuous variable data provide estimates if at least 25% of the results are detected and there are at least three detected results. If censoring is more severe than this, metrics can be estimated using binomial (yes/no) methods.

Computing Metrics for Lognormal Data from SEGs.

1. The **Minimum Variance Unbiased Estimator (MVUE)** is the best method for complete data sets with between 6 and 15 results and provides estimates that are similar to least squares regression for large data sets. However, this method does not accommodate nondetect results. It has been executed in a Microsoft (MS) Excel spreadsheet that is available at no cost from AIHA at https://www.aiha.org/get-involved/volunteer-groups/exposure-assessment-strategies-committee.
2. **Maximum likelihood estimation (MLE)** is considered the best method for large sample size (n > 15) data sets in which at least 25% of the data are detected. It maximizes the fit of a line to a data set through repetitive calculations, to arrive at a location and slope parameters that minimizes the difference (residuals) between actual and predicted results. This method dominates modern statistical computing and is supported by statistical software but is not well supported by MS Excel.
3. **Bayesian inference** has come into increasing use for small sample size (n < 15) complete or censored data sets. The data set must have at least three detected results. The method derives a posterior likelihood by weighting results from a prior distribution specified by the analyst and MLE calculated from results. With 15 or more detected results, the prior distribution has little influence on posterior estimates. This method is not supported by MS Excel. Free open-source software that supports this method is available at http://www.expostats.ca/site/en/tools.html.
4. **Least squares regression (LSR)** also called linear or log-probit regression, is a method of fitting a line to data that is supported by MS Excel. It provides the first approximation of the best line fit location and slope. Estimates will be slightly more conservative (safe) than MLE. Like the MLE, it is a large sample method that accommodates censored results if least 25% of results are detected.

Methods for Computing Metrics for Data Sets that are not Lognormal

1. **Kaplan-Meier Product Limit Estimator (PLE)** is the best method for estimating 95-95 UTL for complete or censored continuous data when n > 59 with at least 25% detected results. PLE is used in survival analysis for both clinical trials and materials testing. It is supported by statistical software but difficult to compute in MS Excel. PLE is best suited to rolling up an organization's data from across jobs, locations, and agents.

2. **Order Statistics and the Binomial Distribution** provide methods for estimating a 95-95 UTL when n > 59, even if there are no detected results. The 95% UCL of the rank of the largest result = 0.05(1/n), where n is the number of results. Thus, one is 95% confident that the largest of 59 results is less than the 95th percentile, the largest of 29 is less than the 90th percentile, etc. In distributions with some exceedances, a confidence interval for the rank of the OEL and percent exceeding can be estimated with the MS Excel function binom.inv and by binomial functions in statistical software.

3. **Quasi-Nonparametric Upper Tolerance Limits (QNP-UTL)** provide methods for estimating confidence intervals for data sets with less than 59 results that are all or nearly all censored. The basis for the method is theoretical and empirical evidence that the standard deviation in log-transformed occupational exposure monitoring results (sigma) will not exceed 2 (GSD < 7.4).[3] The 95-95 UTL is estimated by multiplying the largest result by a ratio computed using MS Excel formula =EXP((NORMS. INV(0.95)-NORMS. INV(0.05^(1/n)))*2), where n is the number of results. For example, for n=8, the ratio is 10.1, and the 95-95 UTL would be 10.1 times the reporting limit or the largest result if one or more results are detected. With 16 results the ratio is 4, with 30 it is 2, and with 59 it is 1.

4. **Ad Hoc Rules of Thumb** are used to guide engineering judgment in interpreting a single-exposure monitoring result. The technical basis for the OSHA regulatory action level of one-half the permissible exposure limit (PEL) was provided by a NIOSH analysis of variance published in 1977.[4] The analysis shows that if a single preliminary sample is larger than half the PEL, it is highly likely that more than 5% of unmeasured work shifts exceed the PEL even if day-to-day variation is minimal (GSD =1.22). For more typical distributions (GSD > 2), a single result greater than one-tenth the PEL indicates it is more likely than not that more than 5% of unmeasured work shifts exceed the PEL. This is the basis for the widespread practice of interpreting any single result of more than half the OEL as evidence of an uncontrolled source of exposure requiring corrective action, and a single result of more than one-tenth the OEL as evidence of uncertain control requiring further investigation.

The ACGIH concept of "peak exposures" provides similar rules of thumb for interpreting a single task monitoring result occurring for a short period of time within a work shift. For tasks requiring more than 15 minutes, a level greater than 3 times the OEL is evidence that it is more likely than not that 8-hour time-weighted average (TWA) OEL is being exceeded. For tasks requiring less than 15 minutes to complete, levels more than 5 times the 8-Hour TWA OEL provides similar evidence that it is being exceeded.[5]

[3] Davis C.B., & Wambach P.F. (2015). "Quasi nonparametric" upper tolerance limits for occupational exposure evaluations. Journal of Occupational and Environmental Hygiene, 12(5), 342-349.

[4] Leidel, N.A., Busch, K.A., & Lynch, J.R. (1977). Occupational exposure sampling strategy manual (NIOSH Publication No. 77-173). Centers for Disease Control and Prevention, National Institute of Occupational Safety and Health.

[5] ACGIH 2019 TLVs® and BEIs® Cincinnati, OH: ACGIH, 2019.

Worked Example

Table 2 shows exposure-monitoring results for respirable silica from a crew of millwrights and laborers installing process equipment. The project included various concrete fabrication tasks such as pouring machine pads and drilling holes for anchoring brackets. Results are from personal monitoring representative of typical work. Results were grouped by tools used, which were judged to be important determinants of exposure.

The goal of the monitoring campaign was answering the question of whether job hazard analysis steps included in work planning recommended effective controls.

Table 2 — 8-Hour TWA Personal Exposure Monitoring Results µg/m³ Respirable Silica

Rank	Bush hammer	Chipping hammer	Core drill	Drill	Mixing concrete	Rotary hammer
1	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
2	2.5	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
3	2.9	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
4	2.9	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
5	5.2	4.4	< 2.0	< 2.0	2.3	2
6	6.2	4.6	2.2	2.5	3.4	3.6
7	6.3	5.8	2.1	2.7	4.5	4.1
8	7.5	5.8	2.7	3.9	6.7	4.6
9	8.4		4.1	5		5
10				6.1		5.6
11				11.3		6.5
12						9
13						13
14						14
15						15.3

A preliminary inspection of individual results compared to the OEL of 25 µg/m3 indicate most results more than 10% of the OEL, justifying the establishment of an exposure-monitoring and control program. Each group contains a relatively small sample size of 8 to 15 results, with at least some results below laboratory reporting limits. The mix of tasks performed changed as the project progressed and were not assigned to any particular member of the crew.

In addition to analyzing each task, it was judged to be reasonable to combine the results to provide an overall performance indicator (see Figure 1).

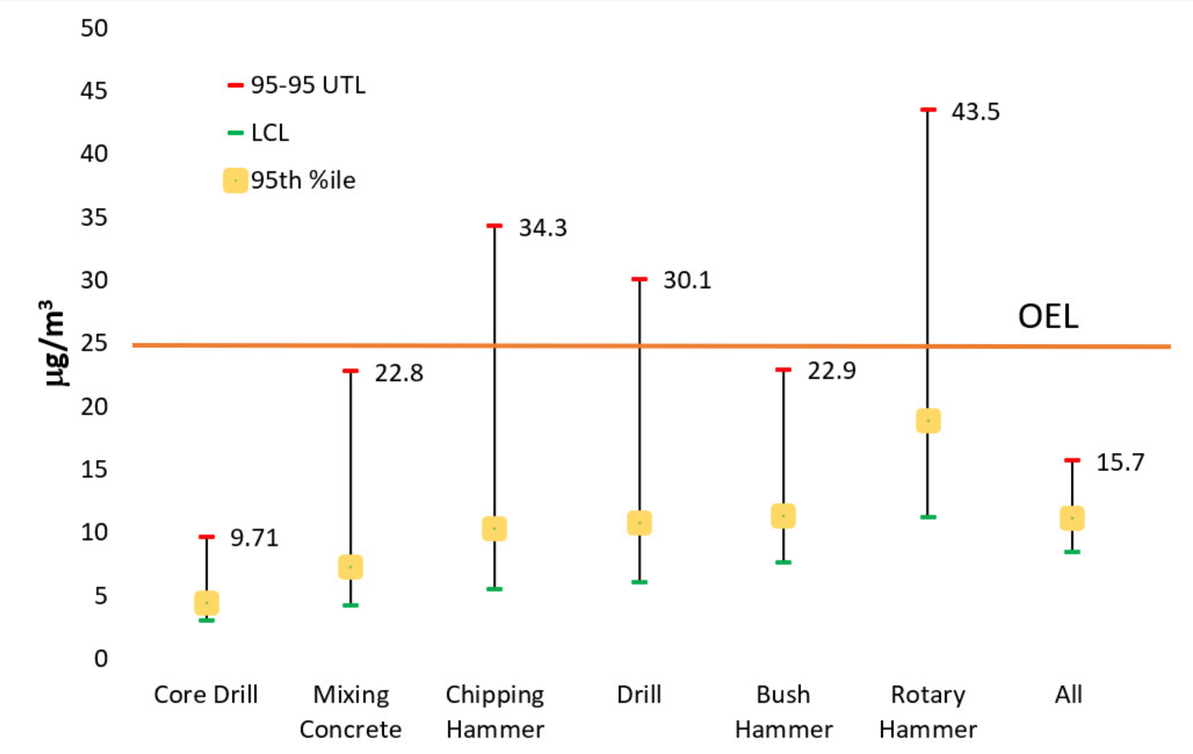

Figure 1 — Bayesian Estimates of the 95-95 UTI and the 95th Percentile and its 95 Lower Confidence Limit for Individual Tasks and All Tasks Combined

With small sample size and nondetect results, confidence intervals are large. With 60 results, the all-combined provides much tighter confidence intervals using either parametric or nonparametric methods. The uncertainty associated with a small sample number drives more frequent monitoring. In the aggregate, working conditions have achieved the desired level of exposure control. Better control of exposures associated with use of rotary hammers is an opportunity for improvement.

Discussion. Exposure risk, whether due to dose rate or total cumulative dose, is primarily determined by the frequency of excursions above OELs. The 95-95 UTL is a leading performance metric that measures the degree to which an organizations exposure monitoring program is monitoring frequently enough to assure excursions are rare events. When comparing relative risks of exposures to different agents, it can be made into a dimensionless ratio by dividing it by the OEL.

These indicators require either large sample size (~ 60) or large distance between results and OELs (> 10x) to have confidence exposures are being controlled. In this case we collapse exposure determinants such as materials, tools, and tasks into an all-combined performance indicator of the health protection program's success. With 60 results, several measurements are near the 95th percentile, and all estimates of the 95-95 UTL converge on the same result. They range from the PLE estimate of 13.8 to the MLE estimate of 15.9. Exposure-monitoring strategies should include the ability to aggregate data from across an organization's exposure control program so that large sample size is practicable if needed.

The skill set of data analysts, who can produce performance indicators needed to support an organization with an advanced safety culture, includes knowledge of how work is managed, the health risks associated with the work, and statistical methods and software. Improvement requires metrics to set goals and monitor progress and investigation of exceedances to identify corrective actions that will prevent recurrence. This combination of skills will often require a team.