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Serious Injury and Fatality Prevention: Leading Indicators, Cumulative Risk and Safety Networks

nsc National Safety Council

Introduction

For nearly thirty years, workplace data has shown total recordable injury rates have more rapidly decreased than work-related fatalities (Bureau of Labor Statistics, 2021a, 2021b). This finding conflicts with the predictive assumption built into Heinrich's safety triangle and has led to the construction of a new approach to serious injury and fatality (SIF) prevention focused on the different precursors leading to SIF events (Martin and Black, 2015). This revised method defined a new direction for research on leading indicators for SIF prevention.

In the Campbell Institute white paper, "Serious Injury and Fatality Prevention: Perspectives and Practices," a set of definitions were established to help leaders understand and collaborate on SIF prevention. In "Designing Strategy for Serious Injury and Fatality Prevention," a blueprint was developed for SIF prevention programs. This white paper addresses leading indicators for SIF prevention by discussing programmatic elements organizations can use to design their program. Additionally, two frameworks will be introduced to support SIF prevention efforts – cumulative risk assessment and social network analysis.

Leading Indicators

The Campbell Institute organized a workgroup of environment, health and safety (EHS) professionals to define a set of key leading indicators relevant for SIF prevention. Leading indicators are proactive, preventive and predictive measures that monitor and provide current information about the effective performance, activities and processes of an EHS management system. Leading indicators drive the identification and elimination, or control, of risks in the workplace that can cause incidents and injuries.

Leading indicators most commonly have the following characteristics:

- Achievable
- Actionable
- Explainable
- Meaningful
- Timely
- Transparent
- Useful
- Valid

The characteristics of a predictive leading indicator are dependent on context, and the strength of a correlation may vary over time. This concept is especially true for new leading indicators as it takes time to implement an indicator, see quantitative results and gain credibility between the workforce and leadership. To help manage changes in correlation, an analytical framework to generate leading indicators for SIF prevention was developed.

Serious Injury: A permanent impairment or life-altering state, or an injury that if not immediately addressed will lead to death or permanent or long-term impairment.

SIF Potential: A near miss incident that could have resulted in a serious injury or fatality if not for certain barriers or countermeasures.

SIF Precursor: A high-risk situation in which control measures are absent, ineffective or not complied with, and would potentially result in a fatality or serious injury if allowed to continue.*

**DEKRA, 2019.*

Interviews were conducted with nine Campbell Institute member organizations where interviewees shared details about leading indicators and SIF prevention approaches. The interviews included questions about data collection efforts and analysis strategies, leading indicators related to SIF prevention, leadership and employee engagement around SIF prevention, and challenges organizations have faced. This process identified foundational elements for a leading indicator program, a list of leading indicators for SIF prevention and how safety networks are critical to an expanded approach to risk assessment.

Workgroup Participants

AECOM
Ameren
The AES Corporation
The Boeing Company
Cummins, Inc.
Dow
Exxon Mobil Corporation
Krause Bell Group
The Mosaic Company
Owens Corning
Parsons Corporation
United Rentals

A Systematic Approach to EHS

The best foundation for leading indicators is a rigorous EHS management system. Further, a systematic approach focused on risk often results in designing and implementing more effective controls. Without effectively identifying risk, an organization cannot take appropriate action to reduce injuries or prevent SIFs from occurring.

In addition to focusing on risk, a vital aspect is generating and effectively communicating appropriate cultural messages around safety. This requires quality education to ensure workers see the personal meaning behind safety efforts and controls. For example, requiring workers to wear a fall-protection harness might not be enough to address the root cause fully. Connecting the cultural meaning of a harness (e.g., a harness is a safety requirement) to its personal meaning (e.g., *this* harness might save *my* life) is essential for sustained behavior change.

Addressing the "whys" of safety in messages and training can create and diffuse new meaning into a safety culture. When a message resonates, workers can promote the message across the organization. Combining a risk-based system with effective communication will lay the groundwork for a successful SIF prevention program.

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A Clear Vision

After implementing a SIF prevention program, organizations can tie SIF-based leading indicators to safety goals. Dow, Parsons Corporation and United Rentals collect and track data measuring SIF prevention progress. Dow created a ten-year strategy that included goals to reduce injury rates, potential serious injuries and fatalities (pSIFs) and SIFs. Dow's annual reduction target for non-injury pSIFs is a common leading indicator for SIF prevention. Developing aspirational goals like the Dow example can play a role in building a cultural belief that all injuries, including SIFs, are preventable. However, some organizations choose not to create goals around SIF metrics because of the potential that these goals might create fear and discourage reporting. An organization's vision and approach to goal setting are heavily influenced by culture.

Leadership Communication

Campbell Institute members are committed to educating workers about the importance of SIF prevention. This includes proactive and consistent messaging campaigns and repeated training to increase non-technical communication skills. Organizations must start small and build a foundational understanding to help others learn. For example, Ameren tailors its messages for the broadest possible audience. This approach can help improve communication efforts, generate shared meaning across an organization, strengthen its safety culture and connect with employees personally.

United Rentals encourages leaders to humanize their safety and SIF prevention messages. For example, instead of citing "0.3 TRIR," they may reference, "two people were hurt." This approach aims to express the same message more inclusively while making it more relatable to everyone.

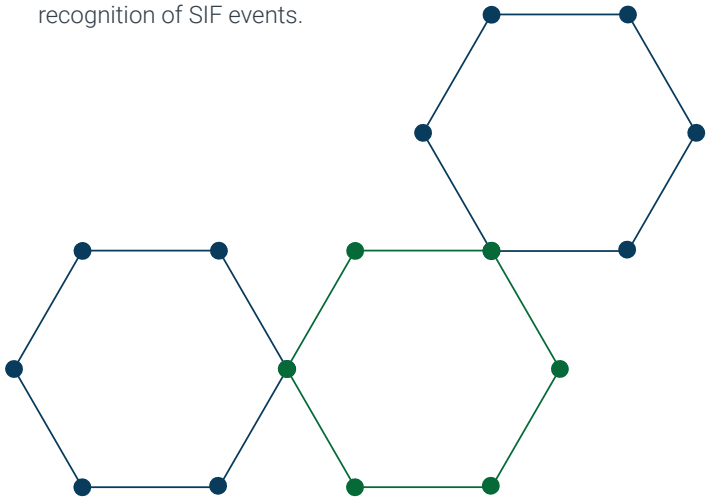
To counter the culture of fear surrounding pSIF and SIF reporting, leaders empower workers and help them feel safe through clear, consistent and supportive communication. It is vital for workers to know they will not be blamed for reporting a potential or actual event.

Continued communication can also help improve SIF fluency. Ameren expects all leaders to be educated on, and frequently discuss, pSIF and SIF prevention. Their leaders' fluency has impacted its safety culture by enabling the workforce to identify pSIF events correctly. Over time, with high-quality field observations, organizations can gain deeper insights and generate leading indicators and effective controls around SIF risk.

Data and Technology

An increase in incident reporting is common as organizations mature their approach to SIF prevention. The data from these reports can create what The Mosaic Company calls a "data lake." By creating, managing and exploring the "data lake," organizations can find connections and generate leading indicators that might effectively prevent SIF events. Further, encouraging workers to identify an event as a pSIF specifically can begin to identify the areas or activities containing the most SIF risk. Organizations found that including a check-box option to report a pSIF on an incident report has proven effective. AES uses handheld technology to gather pictures and information from the field. This increases the likelihood of reporting, and the amount of information gathered as workers can now enter real-time reports.

Organizations often use dashboards to visualize employee incentives and performance toward personal and organizational goals. Tracking incentives with quantitative data creates a clear and transparent way to monitor safety performance, build accountability and promote recognition of SIF events.



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Maturing Risk Assessments

As previously identified, SIF prevention is dependent on effectively identifying and controlling risk. As organizations mature along their safety journeys, risk assessments must also take a more sophisticated form. Single hazard risk assessments are appropriate for some situations, but others may involve interactions between two or more hazards. The hazards should be assessed together to accurately measure the risk and determine if the situation may result in a SIF. It is challenging to evaluate the severity and probability of variable interactions and how they relate to SIF risk. However, organizations must emphasize understanding how hazards accumulate and affect risk in unexpected ways.

3 Certain	3	6	9
2 Possible	2	4	6
1 Unlikely	1	2	3
X	1 Minor Hurt	2 Recordable	3 Life Altering

** Example risk assessment from previous Campbell Institute SIF prevention research*

Cumulative Risk

Methodological limitations slowed progress on a formal conception of cumulative risk, but the need for an assessment capturing cumulative risk was apparent in the 1970s (U.S. Environmental Protection Agency, 2003). Not until 1997 did the Environmental Protection Agency release the first memo detailing a methodology to identify and measure various stressors (i.e., hazards) that accumulate and combine over time and increase risk (U.S. Environmental Protection Agency, 2003). Following its 1997 memo, EPA released a report, "Framework for Cumulative Risk Assessments," in 2003. The report defines cumulative risk as, "The combined risks from aggregate exposures to multiple agents or stressors" (U.S. Environmental Protection Agency, 2003).

Aggregate exposure includes exposure via "all routes and pathways from all sources of each given agent or stressor" (National Research Council, 2009). Agents or stressors are elements that increase risk depending on their *type* and *presence* or *absence*. Alternatively, a situation can become more vulnerable to risk if elements which improve risk are absent (U.S. Environmental Protection Agency, 2003).

Cumulative risk differs from other conceptions of risk because it accounts for multiple *agents* or *stressors* (e.g., hazards). It also considers the *source(s)* of these stressors – not just a stressor itself, but where or what that stressor came from (U.S. Environmental Protection Agency, 2003).

The following example shows how two variables, noise and toluene (a liquid typically used in a mixture with other solvents and chemicals), can combine to create a more significant event to stereocilia (inner ear hair cells):

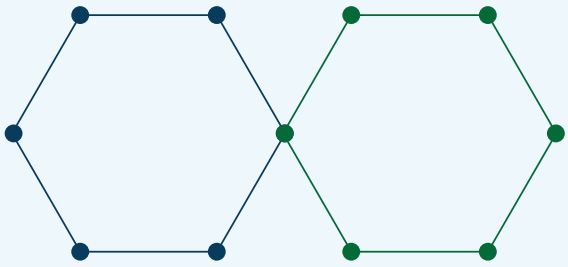
"… In rodent studies, exposure to noise alone has been found to injure the stereocilia, whereas exposure to toluene alone has been found to injure the outer hair cells. Even though the specific cells damaged by noise and toluene are different, the combined effect of these exposures has been found to cause a greater loss of hearing than would be expected from assuming response addition for each exposure." (Niemeier et al., 2020).

With SIF prevention, consider putting a boundary on a cumulative risk assessment to identify differential and similar effects based on hazard types. Physical hazards and personal factors can affect risk and accumulate differently across employees. For example, a fatigued employee working at heights may have an increased risk relative to a non-fatigued employee working at heights. Further, the risk from inclement weather will likely have a different impact for each individual when combined with working at heights, fatigue or both. Each organization must determine if the combined risks will cumulatively result in SIF potential.

Plan Do Check Act

EPA created a three-stage process (planning, analysis, risk characterization), establishing its methodological approach (U.S. Environmental Protection Agency, 2003). This is similar to a traditional risk assessment planning model. The fine-grained level of detail a cumulative risk assessment requires is time and resource-intensive. The following translation and adaptation of the EPA approach may help align efforts for an efficient implementation.

Plan	Do	Check	Act
• Gather interested parties across the organization's network. o Toward the specified end of creating a relevant (to the organization) and effective (for the context) cumulative risk assessment framework. • Create risk profile after measuring essential elements (e.g. severity, likelihood, cumulative impact, etc.) • Develop a comprehensive plan for generating cohesion toward a safety network (if applicable) that can then effectively implement a cumulative risk assessment. • Develop and design appropriate cumulative risk assessment.	• Implement needed training that helps generate cohesion and safety networks (e.g. leadership engagement training, non-technical skill/ communication training). • Connect relevant workers across the safety network. • Conduct a network-led cumulative risk assessment.	• Analyze data in terms of appropriate interactions (e.g. not simply adding all variables together, but determining how they quantitatively interact). • Determine overall risk characterization. • Gather feedback from employees.	• Design and implement effective controls for the network of variables that combine to increase risk. • Track and reassess leading indicators generated from cumulative risk assessment. • Track and reassess control effectiveness.



Additive Risk Model

A hazard index model, or additive model, adds the cumulative risk of multiple hazards within a situation. The value of the hazards is calculated separately and summed to form a score that approximates total risk (Niemier et al., 2020). Analysts divide the exposure score by the threshold limit of the hazard, adding the dividends from all hazards. The additive score assumes the hazards are equally weighted.

Hazard Index

$$\text{SIF risk} = \frac{H1}{T1} + \frac{H2}{T2} + \frac{H3}{T3} \ldots \frac{Hn}{Tn}$$

Hn = Hazard Tn = Threshold

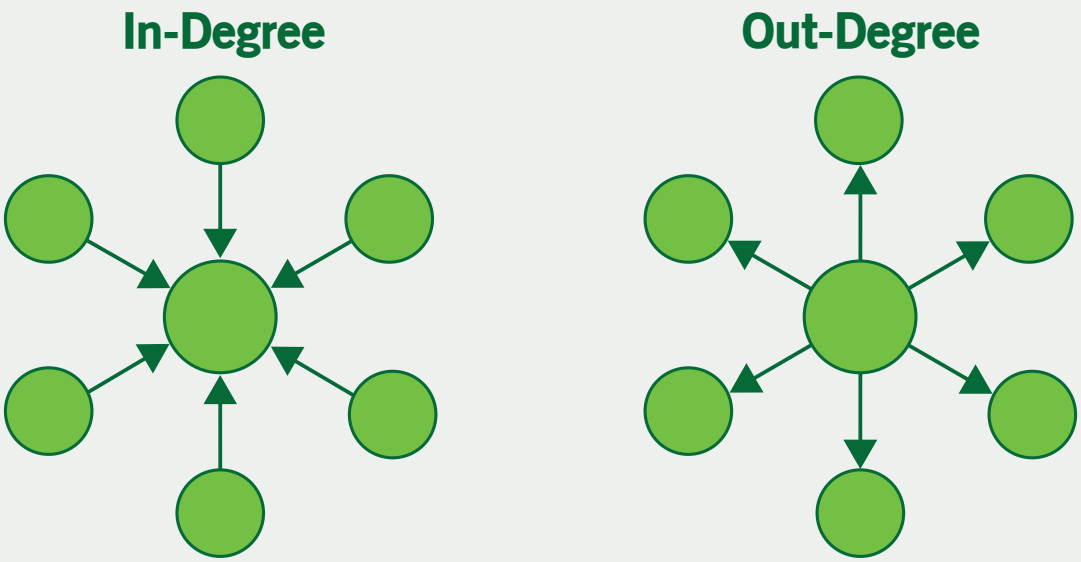
SIF risk may not always be wholly quantifiable, and it may be challenging to determine how and when particular variables should be added or if they interact at all. These complex decisions call for a cohesive network of individuals working together to determine relationships among variables and the associated level of risk. The level of knowledge, innovation and human interaction involved in a practical cumulative risk assessment can increase quickly, along with difficulty in integrating environmental, physical and psychosocial hazards into a risk assessment model. However, looking at hazards independently may limit an organization's ability to identify and prevent SIF events. Some of the practical limitations and complexity limiting the feasibility of cumulative risk assessments can be addressed using social network analysis.

The Role of Safety Networks

Social network analysis is a long-standing, empirically founded framework (for one of many overviews, see Li et al., 2021) that is referenced among EHS professionals but has not been formally identified. However, elements from social network analysis can be used to measure and analyze leading indicators for SIF prevention through the development of cumulative risk assessment modeling.

The advantage of a network approach is that it considers how people interact with each other rather than only how they interact with the EHS management system. Safety networks are generated through cohesion between people and are measured in terms of their relationships (Kadushin, 2002). More relationships mean an increased ability to share knowledge, tools or metrics. These effects become more powerful when they expand beyond organizational walls and when combined with an individual feeling safe at work.

Quantitatively measuring relationships is commonly done in terms of the in- and out-degree. The in-degree is the number of people knowing a person, and the out-degree is the number of people a person knows. Organizations can map degrees and track relationships over time. This information becomes critical for understanding the flow of knowledge and the ability to use this to determine a hazard's actual or potential impact. Safety networks aid in accurately calculating cumulative risk and improving controls, thus creating a more effective SIF prevention program



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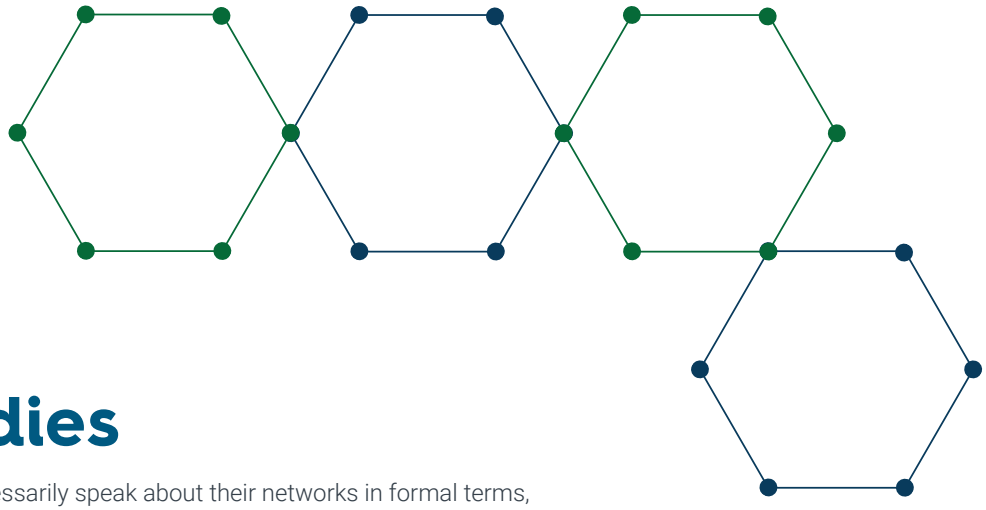

Case Studies

Though members did not necessarily speak about their networks in formal terms, their practices can be interpreted with a network lens. The following case studies show how members think about their safety efforts in terms of networks.

AES: Network Cohesion

AES observed frontline supervisors fixing issues on the spot but not formally reporting the issues or the corrections. This type of undocumented proactive behavior limits essential information in the network because the learnings from the data collection are not easily shared beyond those directly involved. Additionally, the corrective action may not have fully addressed the cause of the hazard, and risk may still be present. In a network comprised of information gaps, reactivity can unintentionally spread across the network, embedding this type of behavior into the culture.

The level of potential impact can be assessed by measuring the in and out-degree of the safety network. If a frontline supervisor has a low in- and out-degree interaction within the network, there might be minimal effect on the culture. However, if the supervisor has a higher degree of interaction, the effect may be significant. The accumulation of undocumented proactive actions will impact the flow of knowledge and the growth of cohesion in the organization.

When AES analyzed this issue, they identified that frontline supervisors found it difficult to remember and report the problem once back in their offices. AES implemented a digital report tool enabling frontline supervisors to report issues and corrective actions from the field and identify potential SIF incidents. On-the-spot reporting has restored the benefits of an active safety network. Technology, in general, can play a massive role in creating cohesion, improving relationships between employees or creating new connections by elevating all employees' in- and out-degrees.

Ameren: Quality Communication

As an energy provider, Ameren recognizes how crucial communication is to SIF prevention. Apprentices at Ameren have experienced difficulties sharing concerns with seasoned journeymen. Their different levels of experience can create a power imbalance that is challenging to navigate without proper training. To help workers address these issues, Ameren implemented a "safety recharge" training. Team members facilitated small group meetings where workers learned about accountability, quality conversation, and how to challenge and provide feedback to others.

The training quickly became the foundation for educating workers on the value of communication in safety. Ameren reinforced positive actions by practicing conversations and collaborating to create solutions for at-risk areas. Ameren also enlisted "coaches" to observe how workers interacted in the field and provided feedback when appropriate. As the program matured, Ameren implemented mobile applications and automated statistics showing participation rates. The data was shared with safety committees and enabled them to create strategies based on localized needs.

Upon full implementation of this training, an analysis showed that groups with high levels of interaction between coworkers had lower injury rates. Non-technical communication skills are crucial to developing and maintaining a cohesive safety network – one that enhances the engagement of all workers despite differences in experience or otherwise. This case study suggests that increased coworker participation in communication-based training enables workers to identify and share risk, which may be an effective leading indicator for SIF prevention.

Leading Indicators, Cumulative Risk and Safety Networks: Bringing It Together

Many organizations have found success in preventing injuries through the use of leading indicators. However, the effectiveness of any indicator is highly dependent on the quality of the data and the extent of its collection. Organizations can utilize the benefits of a cumulative risk assessment by implementing and tracking safety networks. This more sophisticated method of assessing risk can aid in SIF prevention by improving the identification of leading indicators and the data used to eliminate risk.

Safety networks, or social network analysis, help address the practical limitations of cumulative risk assessment implementation, but this concept spans far beyond the scope identified in this white paper. Future Campbell Institute research will explore broader applications for EHS and discover how social networks could change how organizations approach EHS management.

Using network analysis and a cumulative risk assessment strategy does not necessarily solve issues related to SIF prevention. Strategic thinking and organizational culture might be the most important indicators of successful SIF prevention. However, these concepts build a foundation of expanded understanding and encourage organizations to think beyond current solutions for evolving issues.

Appendix

List of Leading Indicators for SIF Prevention from Campbell Institute Member Organizations

Leading Indicator	Examples of Measures
Potential SIF rate/non-injury potential SIF rate	_____
# of corrective actions taken in SIF categories	The number of corrective actions taken in SIF risk categories
% of work done in specific risk categories	The percent of work being done in relevant risk based categories (e.g. working at heights)
# of equipment down	The percentage/rate/number of equipment not working or being turned over
Overtime rate	E.G. 10% overtime limit as a control for fatigue
# of loads per day/per person	_____
# of safety reports per site in terms of employee count	E.G. setting a specific safety report count goal
# of corrective actions in top three of hierarchy	Elimination, substitution and engineering controls
# of safety/SIF risk field observations	_____
Routing and tracking of transports	E.G. Apps, maps, weather conditions
# of safety walks to determine pSIF hazards	_____
Contractor hiring requirements	_____
Quality leadership engagement	_____
Safety representative time on site	_____

The following indicators might be related to SIF prevention. These types of indicators can add up or interact in a way that may lead to a SIF if left unattended.

Rate of employees taking safety surveys
% intent to stay in an organization
Employee wellbeing measures

General Leading Indicators for SIF Prevention from Campbell Institute Member Organizations

Training relevance
Training quality measures
Information retention measures
Communication quality measures

Safety Network Measures Toward Cumulative Risk Assessment and Safety Network Generation

In-Degree	Determines the number of incoming connections. For example, could be a measure of the number of times an individual is named as being known by other people in an organization. The number of incoming partnerships for an organization.
Out-Degree	Determines the number of outgoing connections. For example, could be a measure of the number of people an individual knows in an organization.
Total-Degree	The sum of in and out-degree. Can be used to determine people densely connected (e.g. popular, well known) within a network and identify strategies to best use their position in the network structure (e.g. safety champions).

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