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Precursors of High-impact, Low-frequency Events, Including Fatalities

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Precursors of High-impact, Low-frequency Events, Including Fatalities

**Prepared by
Construction Industry Institute
Research Team 321, Precursors of High-impact,
Low-frequency Events, Including Fatalities**

**Research Summary 321-1
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Executive Summary

Annual total recordable injury rates have shown great improvement over the past few decades, yet the rate of fatalities appears to have plateaued. Studies of catastrophic incidents in other industries have revealed that high-impact, low-frequency (HILF) events are preceded by events or conditions that can be detected and, if acted upon, can prevent the HILF incident. Although the precursors are often unique to each industry, the methods implemented to identify and analyze precursors are consistent. Using existing precursor analysis programs as guidance, CII Research Team 321 (RT-321) defined HILF events as *high-energy events that result in or have the potential to result in a fatality or life-altering injury or illnesses* and precursors as *reasonably detectable events, conditions, or actions that serve as warning signs of an event*.

The ultimate goal of the research project was to conduct rigorous scientific research that yielded a precursor analysis protocol for construction that would enable practitioners to pursue the following series of steps:

1. Assess conditions in a leading fashion.
2. Identify the presence of precursors, and quantify their extent, in a structured and methodical fashion.
3. Predict and prevent the potential for a HILF event.

In pursuit of this goal, RT-321 addressed the following essential questions:

- Are there precursors to HILF construction events?
- If so, what are they, and how can they be identified, analyzed, and used in a predictive fashion to prevent HILF events?

Addressing these research questions will help to address the fact that fatality rates have recently plateaued or even increased.

By using a combination of literature review, input from industry experts, empirical data collection, a series of randomized and blinded experiments, and objective multivariate statistical analyses, RT-321 was able to achieve the aforementioned goal and exceed original expectations. This project yielded the construction industry's first valid and reliable method for identifying the leading conditions that predict HILF events.

The RT-321 research process delivered the following key findings:

1. The process for predicting a HILF event is far more difficult than conducting a retrospective root cause analysis.
2. Precursors are different from leading indicators, and precursor analysis is different from monitoring and evaluating leading indicators.
3. The quantity of energy that is present in a work operation or condition before an incident occurs is a direct predictor of the severity of an injury.
4. Professionals are able to use the precursor analysis protocol developed in this research and their intuition to correctly predict the occurrence of HILF events with significantly better than random frequency.
5. The errors made in prediction were most often conservative.
6. Mathematical models provide a valid, reliable, and objective method for predicting the occurrence of HILF events.
7. The precursors for fatalities and severe injuries are indistinguishable from those that were involved in high-energy near misses.

RT-321's detailed research findings are presented in Chapter 4. The user-friendly predictive scorecard that RT-321 developed from these findings is the focus of Implementation Resource 321-2, *Guide to Precursor Analysis for Construction Fatalities*.

Introduction

In 2015, the U.S. Bureau of Labor Statistics (BLS) released its 2013 census data for work-related fatalities, injuries, and illnesses (BLS 2015). Construction recorded the highest number of fatalities of any industry, with a total of 856. Tragically, this marks the highest number of fatalities in the construction industry since 2009 and, more importantly, highlights the growing concern that the once-declining fatality rate in construction has recently plateaued. As shown in Figure 1, CII data show similar trends.

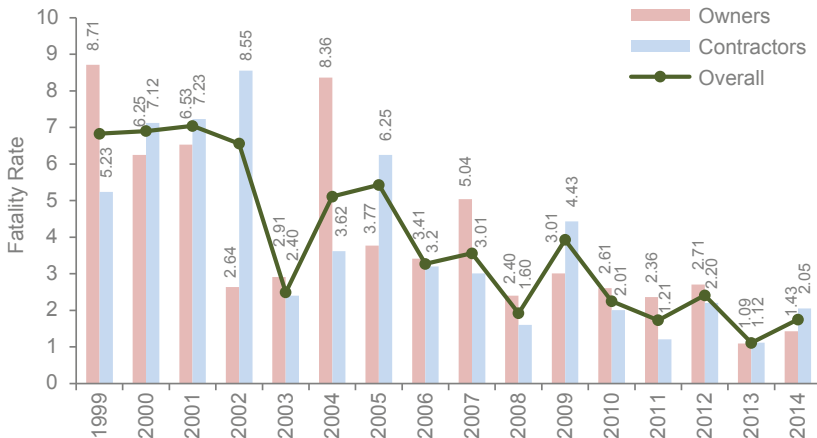


Figure 1. CII-reported Fatality Statistics

(Source: PAC2015-2, 2015 Safety Report)

As these data suggest, there is a need for new injury-prevention methods that focus purely on the fatalities that continue to plague the industry. Enhancing traditional safety methods and using leading information to predict and prevent catastrophic fatalities are logical next steps for the industry. Research Team 321 (RT-321) addressed the observed problem by tackling the following research questions: *Are there precursors to HILF construction events? If so, what are they, and how can they be identified, analyzed, and used in a predictive fashion in order to prevent the occurrence of HILF events?*

In designing the research process, RT-321 relied heavily on other industries' successfully designed and implemented precursor analysis programs. In particular, NASA's Accident Precursor Analysis (APA) program, the aviation industry's Aviation Safety Action Program (ASAP), and the nuclear industry's Accident Sequence Precursor (ASP) program provided guidance.

Each industry has a unique set of precursors that relates to its distinct tasks, environments, and risks; however, despite the differences in precursors among industries, the underlying logic and structure of the precursor analysis processes are surprisingly similar. In fact, the protocols used to create the precursor analysis processes can all be segmented into three fundamental steps:

1. an in-depth deterministic analysis of past incidents to identify precursors
2. development of a system for incident investigation with specific information criteria to support data collection *in a leading fashion*
3. a probabilistic risk assessment based on continuously updated information regarding operations.

All industries place emphasis on the leading and predictive nature of their programs, and RT-321 followed this same general method.

Research Overview

The RT-321 research process was both complex and extensive. To enhance the readability of this report, the team organized the summary as a series of phases, with each involving a specific theme. These phases are illustrated in Figure 2, which can be used as the map for this research summary. Because this research process involved many interdependent phases, each section follows the same format: objectives and summary, methods, and results. Each phase also includes a figure that follows the format in Figure 3.

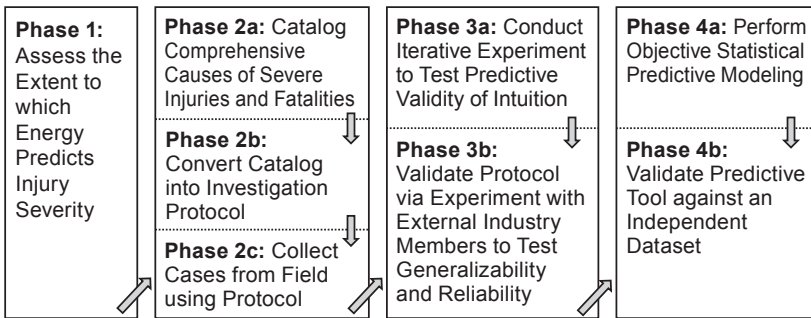


Figure 2. Overarching Research Process and Organization of this Summary

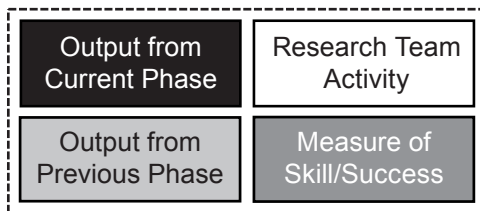


Figure 3. Figure Key Showing the Color Scheme Used in Each Figure

Phase 1: Assess the Extent to which Energy Magnitude Predicts Injury Severity

Objective 1: Define the “high-energy” threshold by testing the hypothesis that the quantity of energy in an environment is a direct predictor of the potential severity of an event.

Because precursor analysis is resource-intensive, it is not realistic to implement it before every work period. Thus, the research process began by addressing a core question: *When do conditions exist that have the potential to cause a HILF event?* Suppose a painter is working in isolation, in a well-ventilated space, with low volatile organic compound paint, on a level ground surface clear of debris, and away from all other activities and equipment. It is reasonable to assume, under these benign conditions, that a HILF event is very unlikely if not impossible, simply because there is not enough danger in the environment. Conversely, suppose a crew of workers is installing a large pipe spool 40 feet from other active crews. Obviously, this situation possesses the characteristics that could possibly lead to a HILF event. Based on these types of observations, RT-321 offered the following hypothesis: *The quantity of energy in an environment before an incident occurs directly predicts the severity of an injury.* If this hypothesis is correct, then the team could obtain empirical evidence for a specific energy threshold that defines the HILF boundary.

The team felt that it was critical to test this hypothesis, because it provides scientific justification for when to initiate a precursor analysis process. Unlike NASA launches, commercial flights, and nuclear power plant operation—where conditions are highly controlled, vary minimally, and continuously involve extreme amounts of energy—construction activities are diverse and range greatly in the amount of energy present at any given time. Thus, the industry needs some form of a gateway to initiate a precursor analysis process. The team postulated that the quantity of energy could serve as such a gateway. Although it was deeply rooted in logic and intuition, this theory had never been formally tested in the construction industry.

Phase 1 Methods

Testing the team’s hypothesis required an objective analysis to investigate the relationship between the severity of worker injury and the characteristics of a hazard energy that existed *before* the injury occurred. To achieve this, the team analyzed 505 injury cases using the process shown in Figure 4.

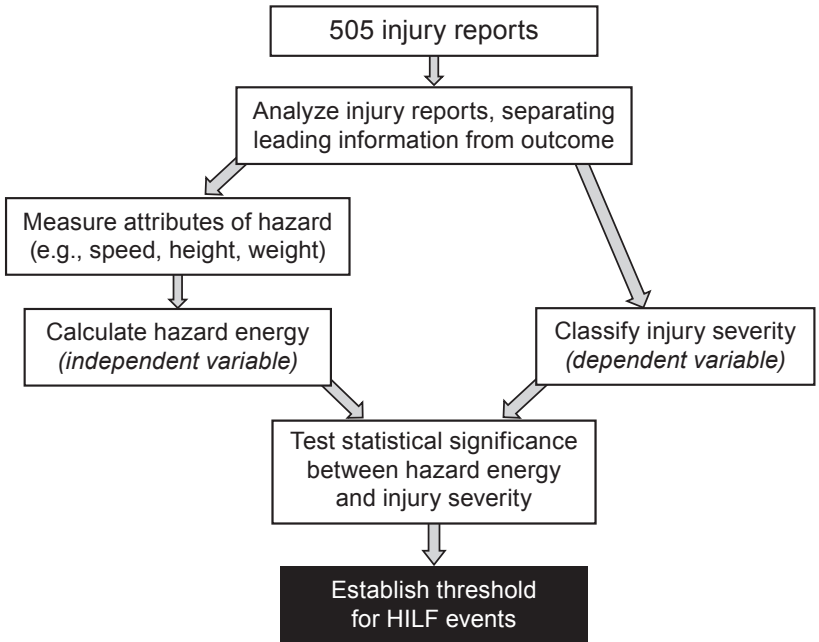


Figure 4. Research Process Implemented to Define the High-energy Threshold for HILF Events

Processing the injury report data first involved separating the independent predicting variable, *hazard energy magnitude*, from the dependent variable, *injury severity*. Using only descriptions of conditions contained within each written injury report, RT-321 researchers estimated the magnitude of energy preceding each injury by estimating height, weight, speed, and other physical characteristics of the equipment, tools, material, and workers. Once the team had obtained energy values for each report, these values were statistically compared to the actual severity of the injuries sustained. The sample included first aid (n=55), medical case (n=113), lost work time (n=280), and fatality (n=57) cases.

Phase 1 Results

The distribution of hazard energy magnitude within each severity classification was visualized with box plots showing the minimum, 25th percentile, 50th percentile, and 75th percentile, and maximum values. As Figure 5 shows, the distribution of energy magnitude is starkly different across severity levels. The red dashed line illustrates the selected high-energy threshold of 1,500 ft-lbs. Although very few fatal or near-fatal events occurred with energy levels lower than 1,500 ft-lbs, this value still involves a highly conservative choice. For reference, 1,500 ft-lbs is equivalent to an average-sized male worker at an elevation of eight feet.

Phase 2: Identify Potential Precursors, Build a Precursor Questionnaire, and Collect Cases

Objective 2a: *Create a comprehensive catalog of potential precursors to HILF events.*

Objective 2b: *Convert the comprehensive catalog of potential precursors into a questionnaire that can be used to determine the presence or absence of each precursor before a work operation begins.*

Objective 2c: *Deploy the questionnaire in the field to collect data for cases where high energy was successfully managed, there was a high-energy near miss, or a severe injury or fatality occurred.*

The team needed a starting point from which a precursor analysis process could be developed. The team decided that a list of potential precursors could be developed based on current literature and team experience, and then used as a means to craft a precursor analysis protocol. Additionally, the potential precursors were to come from actual construction work and incidents, in order to be representative of and generalizable to the construction industry. This list was intentionally comprehensive to begin with, and then refined to create an accurate process that could be realistically implemented.