Patterns in Mining Haul Truck Accidents

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To help develop ergonomics audit programs for mining, one source of data on both work tasks and their failures is accident reports. These are available in most industries and are often used in human factors engineering, but typically to justify and evaluate interventions rather than to provide task details and failure mechanisms. Because fatal accidents in particular contain considerable detail resulting from thorough follow-up investigations, they are thus a useful starting point for analysis. A set of 40 detailed fatal accident reports for mining haul truck accidents were analyzed to develop repeating patterns of accidents. This paper examines the accident patterns found from the initial sample, the refined pattern analysis developed from a subsequent larger sample, and the task analyses used later to help develop valid audit programs.

INTRODUCTION

Mining accidents and injuries can be serious, even fatal, and occur frequently enough to be of constant concern to the industry, the workforce, and the regulatory authorities. In the U.S. alone, the average number of mining-related fatal accidents in 2009/2010/2011 was 47 per year, while in 2011 there were also 7,494 reported mining-related injuries (US Department of Labor, 2011). Santos et al. (2010) analyzed accident/injury reports for one type of mishap—haul truck use. Haul trucks are a heavy type of earth-moving equipment used in mining operations, and commonly carry 35-400 t of payload, with cabs 3-5 m above ground level. With such sizes of equipment, the marshaling of energy in use can be extreme, with consequent serious injury potential. As Santos et al. (2010) report, most of the injuries result from accident patterns commonly studied by the human factors/ergonomics (HFE) community: slips, falls, and struck against. The Santos et al. analysis of 1,382 injury records from five years of the Mine Safety and Health Administration (MSHA) database showed frequent HFE causal factors, including ingress/egress, maintenance, foot slippage, and equipment failure (see also Moore et al., 2009).

As part of a larger project to develop an HFE audit program (c.f., Drury and Dempsey, 2012) for use in surface mining, the research team involved in the current study needed to understand the tasks that operators perform and how these tasks can fail. This would provide the basis for asking pertinent questions in the audit (see Dempsey et al., 2012). One source of data on both work tasks and their failures is accident reports. These are available in most industries and are often used in HFE, but typically to justify and evaluate interventions rather than to provide task details and failure mechanisms. Fatal accidents contain considerable detail resulting from the thorough investigations required at this ultimate level of severity, and are thus a useful (if sobering) starting point for analysis. The detail contained in the MSHA "fatalgrams" and fatal accident reports (http://www.msha.gov/FATALS/FAB.HTM) provided a useful basis to start this work. MSHA fatalgrams include a description of the accident, details of the investigation, a discussion of causes, a root cause analysis, and enforcement actions. They are prepared by professional safety investigators. However, these reports do not attempt to classify the accident using the MSHA non-fatal accident classification systems. This last fact prevented the type of analysis performed by Santos et al. (2010), but also freed the investigators to develop "bottom-up" scenarios which reflected the overall pattern of each accident. Such a system has been used in the past by Drury and Brill (1983) for consumer products and by Wenner and Drury (2000) for aircraft ground damage accidents. Typically, strong repeating patterns of accidents emerge and remain stable as more accidents are analyzed.

FATAL ACCIDENT PATTERNS

A set of 40 detailed fatal accident reports for haul truck accidents were analyzed to develop repeating patterns of accidents (c.f. Wenner and Drury, 2000). These reports comprised 20 coal and 20 metal/non-metal haul truck fatalgrams, with the two different types of operations having potentially different underlying tasks and patterns and different regulatory requirements. These reports were read through and potentially revealing words, phrases, and sentences were marked for comparison. Several iterations

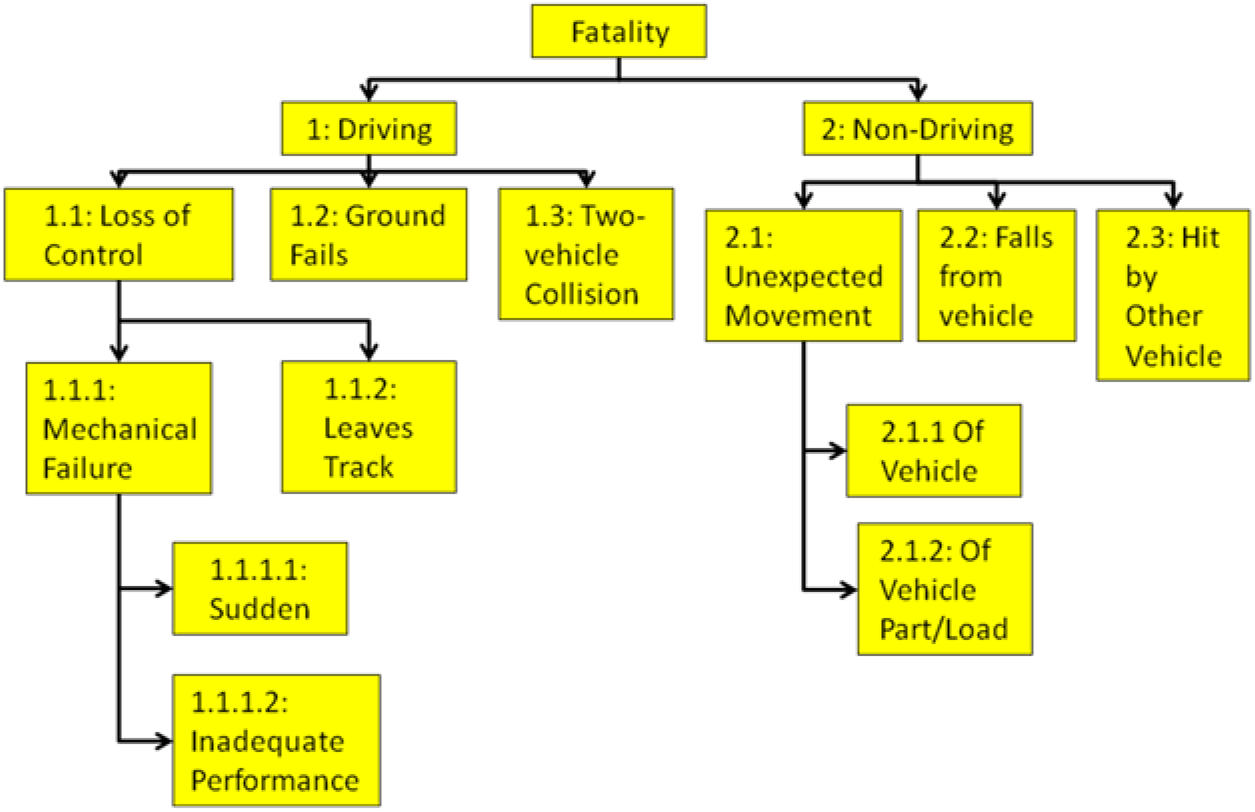

Figure 1: Initial Patterns for haul truck accidents.

of a coding scheme were used to produce a hierarchical scheme so that in the future the patterns could be collapsed upwards as needed—for example in formal tests of unequal distribution of causal factors across accident patterns (c.f. Wenner and Drury, 2000). Figure 1 shows this hierarchical set of accident patterns.

Note that for development of accident patterns, a relatively small sample is all that is required, because these are repeating patterns by definition. Note also that at this stage there is no attempt to count the relative frequencies, with the issue being one of finding repetitive patterns rather than guiding policies for safety improvement. Once adequate (see below) and stable (see above) patterns are determined, their definitions can be used for a more formal classification of larger databases, such as all fatalities over several years, or even non-fatal accidents. The adequacy of the derived patterns is measured by the number of accidents unable to be classified—the “Other” category. For this initial review of 40 reports, none were found to be unclassifiable.

In Figure 1 the accident patterns are described in a few words, but we can define them more completely as follows. For all of the accidents analyzed here, the outcome was a fatality, so that only the precipitating event is detailed in these descriptions, not the full accident event. A more refined set of the lowest level accident patterns will be presented in later figures.

1. Driving: The haul truck is being driven at the time of the accident.

1.1. Loss of Control: The driver experiences a loss of the ability to control the vehicle, either through a vehicle failure or error in following the intended course.

1.2. Ground Fails: The ground on the intended course gives way under the weight of the haul truck.

1.3. Two-vehicle Collision: Two vehicles collide, with either or both drivers contributing to the accident.

2. Non-Driving: The haul truck is not being driven at the time of the accident.

2.1. Unexpected Movement: While the operator is not expecting movement, the vehicle itself moves over the ground or part of the vehicle or its load moves relative to the vehicle.

2.2. Falls from Vehicle: The operator falls when moving on the vehicle, either during ingress/egress or vehicle maintenance.

2.3. Hit by Other Vehicle: The operator has left the vehicle and is hit unexpectedly by another vehicle.

The incidence of accidents in each of these accident patterns can be counted and tested to determine whether the pattern changes with external factors. As part of this study, a set of 133 fatality reports (107 haul truck operator and 26 non-haul truck operator) representing all haul truck-related fatal accidents for 1995 through 2010 were classified based on the related accident reports to determine the relevant pattern. The first outcome of this analysis was that there were no accidents among these 133 that could not be classified according to the patterns shown in Figure 1 at the highest aggregated level (i.e. Driving and Non-Driving). Further, the distribution of driving/non-driving accident frequencies changed significantly between haul truck operators and non-haul truck operators (chi-square (1) =

18.1, $p < 0.001$). Further breakdown by the separate accident sub-patterns (1.1, 1.2, etc.) was not analyzed because the chi-square test had three cells with expected values < 5. For operators, 75% of the accidents occurred during the driving pattern, while for non-operators, only 31% were while driving.

Refining the Classification

Subsequent to the above analysis, a research team member attempted to classify all fatal haul truck operator accidents from 1995 to 2010 (n=107). The main patterns were found to be adequate, but at the lowest level (1.1. Loss of Control and 2.1. Unexpected Movement) more detail could be used to classify the patterns more finely. These more detailed classifications are given in Figures 2, 3, and 4 to show how a bottom-up analysis can be refined with continued use and additional data.

At this more detailed level, causal factors begin to emerge, e.g., Speed (1.1.2.1.) or Alcohol/drugs (1.1.2.5) in Figure 3. In addition, the main systems whose failure precipitates the accident are more clearly delineated, e.g., 1.1.1.2 Steering Failure or 1.1.1.5.5 Service Brakes Fail in Figure 2. Failure of procedures can be seen in 2.1.3 Driver Leaves Cab Without Brakes, particularly the first two sub-classes (2.1.3.1 and 2.1.3.2) in Figure 4.

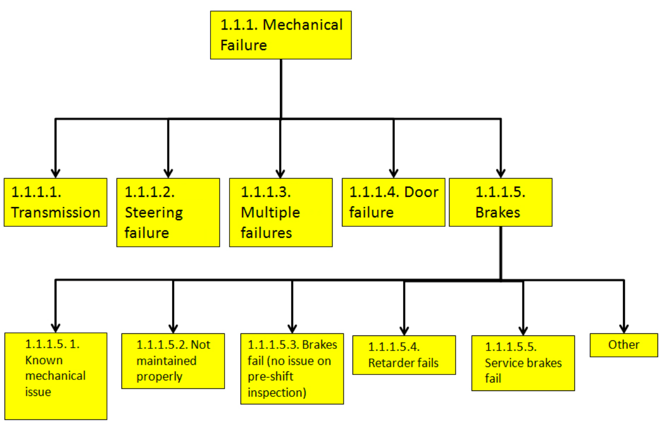

Figure 2: Further expansion of 1.1.1.

TASK DESCRIPTION DERIVATION

The above classification analysis leads to the determination of failures within the Task/Operator/Machine/Environment system, i.e. system failure modes. Implied in the analysis is also the set of tasks performed by the operators that have led to failures. Accident analysis is one traditional way of locating failure modes in human/machine systems. A complementary way is using task description and task analysis. While accident analysis finds existing failures (Reason, 1990), task analysis can find potential failures that do not necessarily appear in current accident records (Bisantz and Drury, 2005). Task analysis typically begins with a task description, using a scheme such as Hierarchical Task Analysis (HTA) (e.g., as presented by Stanton, 2006). This can involve either derivation of system tasks and structure from system descriptions and objectives, or observation of the current system if it exists (Drury, 2008). HTA gives hazard patterns and their logical precursors not yet seen, and is

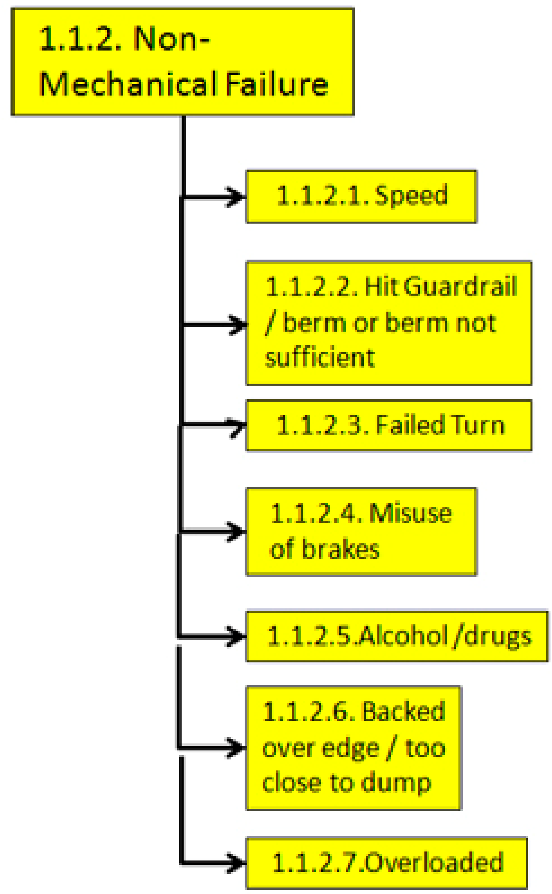

Figure 3. Further expansion of 1.1.2.

therefore best suited to rare events and new or changed systems. In contrast, accident analysis gives rich detail of events that have already happened, making it well suited to long-running systems and deriving detailed precursors. However, accident analysis can only prevent the repeating of accidents that have already occurred, and relies on the quality of accident investigations and the resulting reports. Clearly, both HTA and accident analysis are needed to derive a comprehensive set of valid accident precursors for eventual inclusion into an audit system.

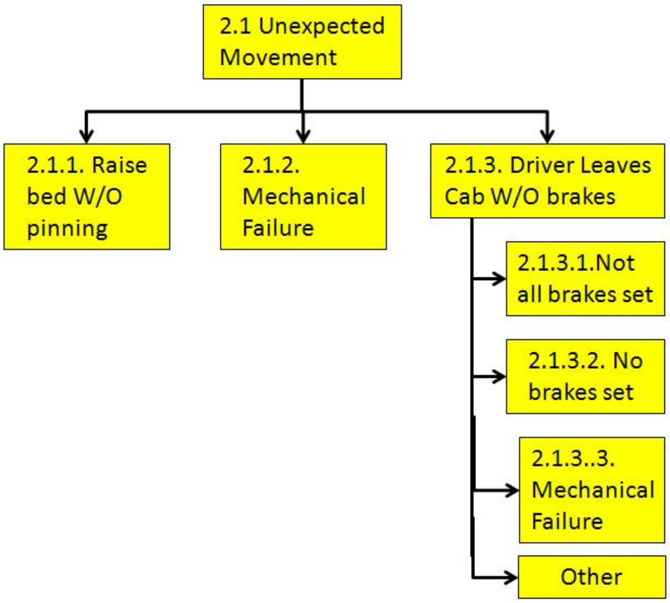

Figure 4: Further expansion of 2.1.

For this paper, the research team carried out observational studies of the work of driving haul trucks (see Dempsey et al., 2012), but guidance could be provided with an HTA developed from the activities recorded in the fatal accident reports already studied and classified. The highest level of the HTA really requires nothing beyond knowledge of the logic of the operation: Load, Drive, Unload, and Return Unloaded. From the injury analyses we can add one high-level task—Maintenance. The actual HTA derived from accident analyses included two levels of lower-level re-description. In fact, the HTA for Maintenance was imported directly from a generic maintenance task description developed earlier for aircraft maintenance activities (Drury, 2009), but was of sufficient generality to apply to any maintenance tasks.

Figure 5 shows the HTA of "Operate Haul Truck" derived from the task descriptions implicit in the accident reports. Its main use here was as guidance for more detailed task description activities based on direct observation of the tasks themselves (Drury and Dempsey, 2012). As a partial check on a task different from haul truck maintenance, the maintenance HTA ("5 Maintain Truck" in Figure 5) was matched with an existing HTA of a different mining task (changing a conveyor motor). These two HTAs were compared and many similarities were seen, suggesting that the generic task description can be used as an overall structure for HTAs of maintenance activities, whether of haul trucks or other equipment in mines.

Using accident reports as the basis of initial HTAs raises the question of what should be recorded in a task description. Accidents are by definition rare events and the sequence of tasks may not be representative of tasks typically performed by the operator, as these "normal"

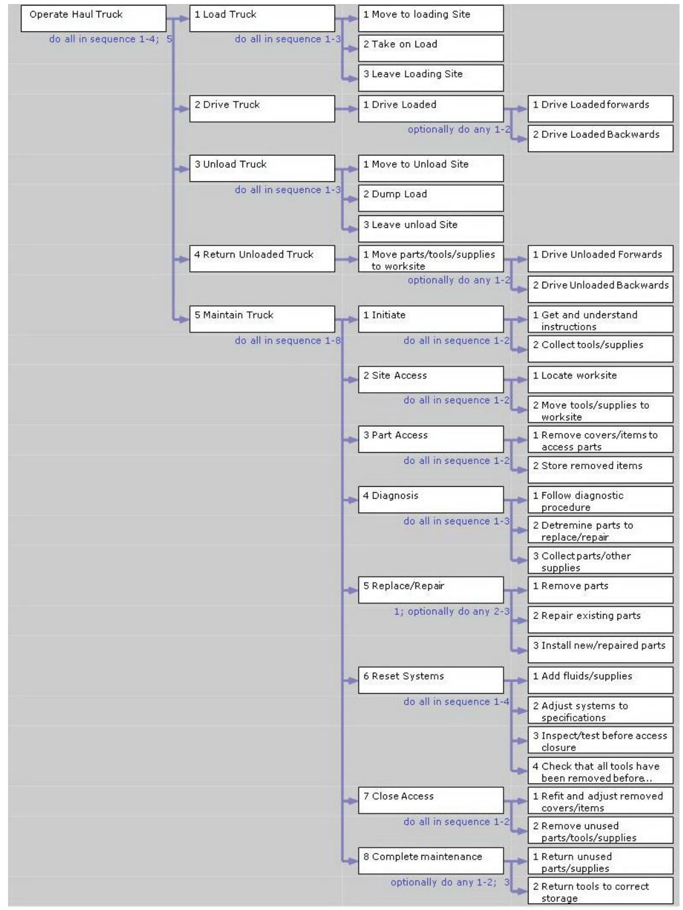

Figure 5: Initial HTA of "Operate Haul Truck"

tasks did not in fact lead to an accident. The issue of what to observe for a task analysis has been covered at length in prior works, see for example Drury (2008). The task analysis can describe what tasks people are required to perform in a system (e.g. as listed in technical or training manuals), or even be part of the systems design process for new systems. For existing systems, one can observe what tasks workers actually perform rather than what the system designers thought they would do. As Drury (2008) points out:

> "It would be a rather lazy HFE practitioner who merely observed the current system. There will always be a tension between using what should be done to guide the TA and using what is done, as they may differ appreciably."

Haul truck accident reports certainly detail what tasks were performed, at least as far as the investigators can determine in a fatal accident. However, it is of interest to ergonomists to determine *why* the performed tasks differed from what the designers intended should be done, as that can reveal for example socio-technical system pressures on the operator. An example would be the pressure for on-time completion of tasks. As with the rest of this project, such analyses can suggest appropriate questions for an ergonomics audit program.

IMPLICATIONS FOR ERGONOMICS AUDIT

Classifying accidents into repeating patterns helps to reduce the sheer volume of data to be considered in progressing towards a valid ergonomics audit program, as it reduces potentially hundreds of individual accident reports to a set of less than 20 patterns. Also, because these patterns are derived in a bottom-up manner from detailed reading of the rich descriptions in the original reports, there is no requirement to fit each aspect of each report into a category that may not apply. This differs from the more typically used ANSI Z16-based injury recording systems, such as the US Department of Labor's Occupational Injury and Illness Classification system (OIICS) (see U.S. Department of Labor Bureau of Labor Statistics, 2011). In that system, very generic classifications are used for the ergonomically interesting source of injury and event or exposure, whereas very specific classifications are used for the nature of injury and body part affected. Developing specific accident patterns for an occupation or task may not be as easy as using a standard classification scheme, but is potentially more revealing in terms of causal factors to be eliminated to improve safety.

While accident analyses provide causal factors of high face validity (e.g. "berm collapsed when haul truck drove up to it") that can be used directly in audits, they also provide more general factors derived from task analyses. Here we have only presented the task descriptions, but an HFE uses these descriptions with human performance data to determine potential mismatches between task demands and human capabilities (e.g. Stanton, 2006; Drury, 2008). As part of an overall project reported in Dempsey and Drury (2012), these task analyses are being derived from the initial task descriptions presented here. However, a greater depth of re-description is required to locate these mismatches and re-purpose them into audit items.

Finally, a use of these accident analyses that has only been hinted at in this paper is the counting of incidents/accidents/fatal accidents to make the case for eventual intervention aimed at reducing incident frequency or outcome severity. Once the HFE analysis has identified causal factors in actual accidents, the counting of these accidents becomes a powerful way to justify interventions. For example, the various mechanical failures of haul trucks (Figure 2) suggest that better design and/or maintenance of equipment would lead to a reduction of accidents due to these causes. Using the frequencies of the patterns derived here reveals how many accidents could be prevented by different degrees of effectiveness of design/maintenance. By starting from the most severe accidents, i.e. those causing fatalities, the case for intervention becomes very strong on both cost and social grounds.

DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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