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Utilizing the Human, Machine, and Environment Matrix in investigations

David Curry, John M. McKinney *

Packer Engineering, 1950 North Washington Street, Naperville, IL 60563, USA

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Abstract

"How did we get into this situation?" How many times has this question been asked at the outset of an investigation, or more importantly, at the completion of an investigation? If the answer is not readily and thoroughly apparent, the investigation is not complete. Subsequently, those who will have the responsibility for correction of the conditions leading to the incident will not have all the information necessary to properly complete their task.

For many years, in many writings, the Human/Machine interaction and its impact on process design has been discussed. The same impact should be examined when performing incident investigations. Consideration of the interaction of human and machine along with the environment in which they are used has long been recommended by the National Safety Council, in both design and investigation.

Keywords: Accident; Investigation; Incident; Human factors; Change; Management; Interviews; Litigation; Third party injuries; Data collection

1. Background

On February 3, 1959, the wreckage of a four passenger Beech-Bonanza airplane carrying Richard Valenzuela (Ritchie Valens), Charles Holley (Buddy Holly), Roger Peterson, and Jiles P. Richardson (J.P. "Big Bopper" Richardson) was found. Their airplane had gone down in the middle of the night enroute from Mason City Airport in Iowa to Fargo, North Dakota. All three passengers and the pilot died on impact.[1]

Incidents like these can be explained, but due to the subject and intensity of most situations a specialist is needed to perform an accurate analysis. In some incidents, these accidents result in litigation. In these cases, the companies call upon experts, engineers, and/or investigators to the investigation site to perform an analysis. The investigators collect data and evidence, document the scene, and interview all witnesses and persons involved.

Through the collection of this data a complete scientific analysis is done. The data, observations, and logic need to be organized to facilitate clearer thoughts and conclusions. The analysis is also done in accordance to a code of ethics for an engineer to ensure the work is done with all honesty, integrity, equity, and impartiality. Their work is dedicated to the protection, safety, and well being of all persons. Once an analysis is completed, the findings are presented to the companies, and then all necessary information is given to the proper parties involved with the investigation. The presentation of the concluding analysis should contain no bias and uphold their neutrality in the case and follow all professional standards. At the conclusion of the investigation, the findings can result in recommendations for updated standards, improved safety regulations, and improved practices for both the worker and the employer.

An example of such an event is the toughened tire testing for tires placed on sport-utility vehicles and lightweight trucks. After 700 people were injured and over 200 people died, an investigation was made of the Firestone tires and Ford Explorer combination. The tires on sport-utility vehicles and lightweight trucks will now have to pass the higher standards of tests for passenger-vehicle tires starting in 2007.[2,3] Another example is the development of the Second Generation air bags. The air bag was developed to improve the safety of the driver and passenger in head on collisions. Investigations resulted when people were being seriously injured or killed when the air bag deployed. From

* Corresponding author. Tel.: +1 630 577 1896; fax: +1 630 505 1986.
E-mail address: jmm@packereng.com (J.M. McKinney).

[1] On this day: 1959—Buddy Holly killed in air crash. BBC News, 6/17/04 (http://news.bbc.co.uk/onthisday/hi/dates/stories/february/3/newsid_2802000/2802541.stm).

[2] Federal Standards for Tires tightened. *The Detroit News Auto Insider*, 6/22/04 (http://www.detnews.com/2003/autoinsider/0306/24/c01-201315.html).

[3] Feds Issue New Tire Safety Standards. *Consumer Affairs.com*, 6/22/04 (http://www.consumeraffairs.com/news03/tire_safety.html).

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the conclusions of these investigations, air bags are now being made to inflate/deploy with 20–35% less energy.[4]

2. Introduction

An incident can be defined as an unplanned occurrence that result in injuries, fatalities, loss of production, or damage to property and assets. Without a firm understanding of the cause of an incident, prevention of future occurrences becomes extremely difficult. Preventing incidents is extremely difficult in the absence of an understanding of their causes. Over the past 80 years, a variety of incident causation theories have been proposed. Some of them include the following.

Single Event Theory is basically a “common sense” approach that regards an incident as being the result of a single, one-time easily identifiable, unusual, unexpected occurrence. All responsibility for the incident is placed on a single event or cause. This approach is simplistic in the extreme, and in general, an investigation that adopts such an approach does not produce a quality report or result in effective corrective or preventative actions.

The Domino Theory evaluates the incident as a series of related occurrences, which culminate in a final event that results in injury or illness. Like dominos, stacked in a row, the first domino falling sets off a chain reaction of related events. It is assumed that eliminating any one of these events would result in the chain being broken and the incident prevented. According to W.H. Heinrich (1939, 1931?), who developed the theory, 88% of all incidents are caused by unsafe acts of people, 10% by unsafe actions and 2% by “acts of God.” He proposed a “five-factor incident sequence” in which each factor would actuate the next step in the manner of toppling dominoes lined up in a row. The sequence of incident factors is as follows:

1. ancestry and social environment;
2. worker fault;
3. unsafe act together with mechanical and physical hazard;
4. accident;
5. damage or injury.

In the same way that the removal of a single domino in the row would interrupt the sequence of toppling, Heinrich suggested that removal of one of the factors would prevent the incident and resultant injury; with the key domino to be removed from the sequence being number 3.

Multiple causation theory is related to domino theory, but it recognizes that for a single incident there may be many contributory factors and that only a particular combination of these factors will lead to an incident. According to this theory, the contributory factors can be grouped into the following two categories: behavioral and environmental. The former category includes factors pertaining to the worker, such as improper attitude, lack of knowledge, lack of skills or inadequate physical, and mental condition. The latter category includes improper guarding of other hazardous work elements and degradation of equipment through use and unsafe procedures. The major contribution of this theory is the highlighting of the fact that rarely, if ever, is an incident the result of a single cause or act.

A variety of other incident causation models have been developed in recent years, but almost all share one common thread: the need to look at the incident from a wide perspective taking into account contributing factors from three primary sources—the human participant, the apparatus involved, and the environment in which the incident occurs. In a typical incident, all three sources interact and contribute to both the likelihood of an incident and its severity.

One of the critical elements in any incident investigation is compiling the necessary information in such a fashion that the causal chain can be determined. Often, data is available, but is haphazardly organized so that no recognizable patterns within it are apparent. This paper will discuss techniques for organizing incident-related information via a nine-element matrix, which addresses the Human, the Machine, and the Environment elements during three critical time phases—before, during and after the incident. Methods for defining and selecting criteria for each of the nine elements will be explored. Examples of type and depth of data and information for each of the nine elements (cells) will be presented, as well as answers to such questions as:

- How is the appropriate time frame for the “Before” incident period selected?
- Why do we look at the after incident time period?
- How do we collect and store data using these methods?
- How do we analyze data using these methods?
- How does this correlate with the scientific method?

3. History

The “Human–Machine–Environment Matrix” as described in this paper was developed by Alphonse Chapanis and Paul Fitts of the Army’s Aero Medical Laboratory during World War II. Both were tasked with investigating airplane accidents that had been determined to be the result of “pilot error.”[5] Due to the rapidly increasing complexity of aviation technology and the resulting human error, their investigations became progressively more challenging as time went on. Fitting the incident data into the “Human–Machine–Environment Matrix” allowed them to better organize their work product and data, as well as facilitating the development of clearer thought and conclusions.

The Federal Aviation Administration was one of the first governmental agencies to routinely use the “Human–Machine–Environment Matrix” in their investigations, with many civilian firms rapidly following suit. The organizational structure of the

[4] Air bags. *Ford Motor Company*, 6/17/04 (http://www.ford.com/en/innovation/safety/airbags.htm).

[5] New Book Release: *The Chapanis Chronicles: 50 years of Human Factor Research, Educations, and Design*. Human Factors and Ergonomics Society, 7/12/04 (http://cstg.hfes.org/bookchapanis.html).