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Applying systems thinking approach to accident analysis in China: Case study of "7.23" Yong-Tai-Wen High-Speed train accident

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ABSTRACT

Learning from accidents contributes to improvement of safety and prevention of unwanted events. How much we can learn depends on how deeply we analyze the accident phenomenon. Traditional causal analysis tools have limitations when analyzing the dynamic complexity of major incidents from a linear cause and effect perspective. By contrast, systems thinking is an approach of "seeing the forest for the trees" which emphasizes the circular nature of complex systems and can create a clearer picture of the dynamic systematic structures which have contributed to the occurrence of a major incident. The "7.23" Yong-Tai-Wen railway accident is considered to be the most serious railway accident in Chinese railway history and this research analyzed the accident using the systems thinking approach. From the national accident investigation report, the system elements were identified and the causal loop diagram was developed, based on the system archetype of "shifting the burden". For the problem symptoms in the accident report, the causal loop diagram not only illustrated their symptomatic solutions, but also identified their fundamental solutions. Disclosing how an underlying systemic structure finally resulted in a major accident assists the reader to prevent such accidents by starting from fundamentals.

1. Introduction

In the concepts of system safety and inherent safety in China, accident prevention has changed from passive controls after an accident to active ones (Luo, 2009). Although more attention has been focused on risk management based on hazard identification and risk control (Luo et al., 2003), learning from incidents is still a fundamental approach in accident prevention (Goh et al., 2010; Meng, 2011; Sklet, 2004). Accident prevention depends to a large degree on lessons learned from accident investigation. What we can learn in turn reflects the different perceptions of the accident phenomenon, which in the present day are called the accident models (Benner, 1978; Hollnagel, 2006). Providing conceptualization of characters of the accident, accident models typically show the relation between causes and effects (Qureshi, 2008). From an international viewpoint, accident models have started from relatively uncomplicated single-factor models of, e.g., accident proneness (Greenwood and Woods, 1919) and developed via simple and complex linear causation models to present-day systematic or functional models (Hollnagel, 2004, 2006).

One of earliest causation models is the Domino theory proposed by Heinrich in the 1940s (Heinrich et al., 1980). This model describes an accident as a chain of discrete events which occur in a particular temporal order. Causal factors in an accident which were not linked to technical components were classified as human error as a kind of catchall or "garbage can" (Hollnagel, 2001). Although the simple linear causation model was updated by Bird, Adams, and Weaver (Heinrich et al., 1980), it was later developed as the MES (Multi-linear Events Sequencing) (Benner, 1975) and STEP (Sequential Timed Events Plotting) (Hendrick and Benner, 1986) models, which provide a reconstruction of the process by plotting the sequence of events/actions that contribute to the accident. These models are limited in their capability to explain accident causation in the more complex systems that were developed in the last half of the 20th century (Qureshi, 2008).

In the 1980s, a new class of complex linear accident models endeavored to explain accident causation in complex systems. Reason's (1990, 1997) Swiss Cheese Model of defenses is a major contribution to this class of models, and has greatly influenced the understanding of accidents by highlighting the interrelations between real time "unsafe acts" by front-line operators and latent conditions caused by organizational factors (Hollnagel, 2006; Qureshi, 2008). Although causality is no longer a single linear propagation of effects, the complex linear accident models which were

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developed by Besnard and Baxter (2003) and Shappell and Wiegmann (2000) show that a static view of the organization is inadequate to capture the dynamics and nonlinear interactions between system components in complex sociotechnical systems. Therefore, new accident models based on systems theory, classified as systemic accident models, emerged.

Systemic safety models which describe an accident process as a complex and interconnected network of events have their roots in system theory and cybernetics. System theory includes the principles, models, and laws necessary to understand complex interrelationships and interdependences between components (technical, human, organizational and management) of a complex system. Two notable systemic modeling approaches, Rasmussen's (1997) hierarchical sociotechnical framework and Leveson's (2004) STAMP (System Theoretic Accident Modeling and Processes), endeavor to model the dynamics of complex sociotechnical systems.

With the increasing complexity of sociotechnical systems, modern technology has changed the nature of human work from mainly manual tasks to predominantly knowledge intensive activities and cognitive tasks. Cognitive system engineering (Hollnagel and Woods, 1983) has emerged as a framework to model the behavior of human–machine systems in the context of the environment in which work takes place. Based on its principles, two systemic accident models for safety and accident analysis have been developed: CREAM (Cognitive Reliability and Error Analysis Method) and FRAM (Functional Resonance Accident Model). CREAM is based on the modeling of cognitive aspects of human performance for an assessment of the consequences of human error on the safety of a system (Hollnagel, 1998), while FRAM is a qualitative accident model that describes how functions of system components may resonate and create hazards that can run out of control and lead to an accident (Hollnagel, 2004).

While the approach to achieving safety is moving from accident analysis to resilience engineering (Hollnagel, 2008) internationally, in China however, few of these modern accident models have been applied in accident investigation. China has developed and run its own "mechanism" of accident investigation in which technical failure is still the key and only the traditional simple linear causation models have been adopted to find the causal factors of human error. With the rapid development of the economy, work safety is now being paid much more attention in China, but accident investigation methods have not been improved as expected.

The key benefit from accident analysis is to understand why accidents occur and how to prevent future ones. The traditional theories and methods applied in accident investigation in China still possess the following limitations (Fan and Luo, 2009; Tang et al., 2006; Zeng and Chen, 2011; Zhang and Chen, 2009):

(1) Most causal analysis tools view cause and effect linearly, and so do not consider the accident system holistically.
(2) Most causal analysis tools are not designed to model changes in the system across time and cannot reflect the dynamic properties of an accident.

A new perspective on Chinese accident investigation mechanisms is strongly indicated, so as to examine the nature of the problems from a broader view.

The approach of Systems Thinking is fundamentally different from that of traditional forms of analysis. Instead of focusing on separating the individual pieces of what is being studied, Systems Thinking focuses on how each component interacts with the other components of the system. It works by expanding its view to take into account larger and larger numbers of interactions as an issue being studied (Aronson, 1996) and has developed archetypes to map the nature of the system dynamically over time (Sherwood, 2008). Based on systems theory, Leveson applied the STAMP model to discover the reasons why major accidents which seem preventable and have similar systemic causes keep occurring (Leveson, 2011). Goh applied the Systems Thinking concept to analyze the Bellevue hazardous waste fire accident in Western Australia (Goh et al., 2010). This research showed that the tool of systems thinking employed in analysis of major incidents makes the systemic structure which contributed to the incident more readily understood (Goh et al., 2010).

Turning now specifically to the subject of this paper, on July 23rd, 2011, at 20:30:05, a train crash accident occurred on the Yong-Tai-Wen High-Speed coastal railway line, Zhejiang province, Southeast China. Six cars were derailed and two of them plunged from a bridge 15 m (50 feet) above the ground. The accident killed 40 persons and injured another 172, resulted in downtime of 32 h 35 min and direct financial losses exceeding 193.7 million RMB (about USD 31 million) according to the State Administration of Workplace Safety (SAWS, 2011). The accident raised many issues in the development of the railway sector in China. National organizations, media and the public all focused on the situation in this sector. The accident is considered to be the most serious railway accident in the development of the Chinese railway system (Suo, 2012). At the end of December, 2011, the State Administration of Workplace Safety (SAWS) issued the final investigation report which is regarded as the most detailed accident report in China until now. The open report disclosed the linear causes and effects of the accident. Learning from incidents, accidents and disasters contributes to improvement of safety and the prevention of unwanted events (Drupsteen and Guldenmund, 2014). How much we can learn depends on how deeply we analyze the accident phenomenon. In order to explore and readily understand this accident in depth, the aim of this research was to apply the Systems Thinking tool to build the causal loop diagram for the accident using "sharp end" information from the published national accident investigation report. The second aim was to adopt a proper archetype from the field of Systems Thinking and analyze the accident using an integrated and non-linear approach, trying to find the hidden causative and contributory factors at the "blunt end" which were not discovered in the original accident investigation report.

2. Systems thinking, causal loop diagrams and system archetype

Systems may consist of nonlinear, counterintuitive and dynamic feedback loops, and Systems Thinking is a discipline for seeing wholes. Traditional thinking used to break the whole into parts which usually causes the connections to disappear, but Systems Thinking is a framework for seeing interrelationships rather than individual pieces, for seeing patterns of change rather than static "snapshots". It is a "seeing the forest for the trees" approach (Cabrera et al., 2008; Goh et al., 2012; Jackson, 2005; Senge, 2006; Sherwood, 2008).

Real systems are comprised of a large number of interconnected elements/components/entities and exhibit very complex behavior as they evolve over time. Diagrammatically, if two elements have a cause-and-effect relationship, they are linked by a curly arrow. If an increase in the "cause" drives an increase in the "effect", then the link is indicated by " + " at the head of arrow; if an increase in the "cause" drives a decrease in the "effect", then the link is indicated by "−". If an action could not give rise to its result instantaneously, the cause-and-effect relationship is associated with a time delay, and the link is indicated by adding a new symbol "‖". Fig. 1 shows the links of different types.

The sequence and mutual interactions of the numerous individual cause-and-effect relationships make up "chains of causality" of