USING COGNITIVE WORK ANALYSIS TECHNIQUES TO IDENTIFY HUMAN FACTOR HAZARDS

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Accidents in the process industries can be attributed, at least in part, to human causes. Hazard studies are commonly used in industry to identify and manage risks. This paper describes a methodology, called HumHID, which potentially improves hazard identification associated with human factors. The approach is based on cognitive work analysis (CWA) techniques, human factors/error taxonomies and the blended hazard methodology (BLHAZID). A desk-top case study is used to illustrate the application of the methodology. The results show that a combination of CWA, human factors/error taxonomies and BLHAZID techniques provides a structured means of identifying hazards associated with human activity as well as showing the causality behind the hazards which can be used to guide redesign work.

INTRODUCTION

The contributions that humans appear to make to industrial accidents are well documented. Between 50% and 90% of process accidents have been attributed to human causes (Baybutt, 2002). There is a large body of knowledge on how human factors contribute to industrial accidents. However, few companies use that knowledge because there is no simple, straightforward framework that identifies human-related risks in a way that helps companies alleviate them (Baybutt, 2003). This paper proposes a human factors hazard identification (HumHID) methodology that allows companies to efficiently and effectively identify human-related risks. It also provides an understanding of the causality behind these risks which can be used to guide redesign work.

Hazard identification

Hazard identification techniques are used in industry to check that all significant hazards have been identified so that they can be eliminated, mitigated, or managed. Common hazard identification methods include Hazard and Operability studies (HAZOP), and Failure Mode and Effects Analysis (FMEA). Conventionally, these techniques focus on assessing hazards associated with plant and equipment.

Hazard identification techniques have been developed and improved over time. One of the more recent advances is the blended hazard methodology (BLHAZID) (Seligmann et al., 2009; 2010). BLHAZID combines the strengths of the HAZOP and FMEA techniques to create a semi-automated methodology that produces cause, deviation, and implication relationships for process deviations and component failures. These relationships, represented as *cause-deviation-implication* triplets, can then be used to facilitate risk mitigation as well as real-time fault diagnosis. The BLHAZID methodology is based on the Functional Systems Framework (FSF) (Cameron et al., 2007; 2008) that advocates the importance of the interaction between plant, procedures and people in a system. The proposed HumHID methodology addresses the "people" part of the system with a framework that could be integrated with the BLHAZID methodology.

Analysing the "people" part of a system

Addressing the "people" part of the system with a hazard identification study requires us to identify work domain elements allowing human actions that could cause process accidents or that could hinder human correction of abnormal operations before they become accidents.

At present, most hazard identification techniques used to identify human factors that might cause accidents are based on brainstorming and/or human factors checklists (Baybutt, 2002). These techniques tend to be too simplistic or too cumbersome (Baybutt, 2003), or require specialist knowledge (Shorrock, 2002). Baybutt (2002) proposed a more rigorous method based on the layers of protection analysis (LOPA) framework. However, as Baybutt (2002) states, the success of LOPA-HF depends on a preceding hazard analysis that takes human factors into account.

Shorrock (2002) and Shorrock & Kirwan (2002) proposed another method, called TRACEr, which analysts could use to predict cognitive errors using hierarchical task analysis, human factor taxonomies and a structured approach. However, according to Stanton et al. (2005), the TRACEr method is too complicated, laborious, and resource intensive.

A further human hazard identification method proposed by Lawrence and Gill (2007) is based on the FMEA framework. Accordingly it is prone to FMEA weaknesses as outlined in White (1995). The method is also very dependent on "locating the relevant expert judgement and domain knowledge" (Lawrence & Gill, 2007, p. 781).

Other methods such as Systematic Human Error Reduction and Prediction Approach (SHERPA), Human Error Template, (HET), Task Analysis For Error Identification (TAFEI), Human Error HAZOP, Technique for Human Error Assessment (THEA), Human Error Assessment and Reduction Technique (HEART) and Cognitive Reliability Analysis Method (CREAM) rely on a well-conducted hierarchical task analysis which is time consuming and can suffer from low reliability (Stanton et al., 2005). Hierarchical task analysis methods also lack a framework that could easily be semi-automated.

Therefore, there is still a need for an effective, efficient and usable human factors hazard identification methodology that can be incorporated into, and used by participants of conventional hazard identification processes. Such a methodology needs to provide a lean, systematic and structured approach to identifying factors associated with plant, procedures and people that could facilitate human contributions to, or hinder their prevention of industrial accidents. This paper describes such a methodology and illustrates its application with an industrial case study.

ANALYTIC APPROACH

To ensure that the HumHID process is effective it has been based on proven techniques. These techniques come from the cognitive work analysis (CWA) and human factors taxonomy domains, which are described in this section. The section concludes with a description of the HumHID methodology.

Cognitive Work Analysis (CWA) techniques

CWA is particularly suited to hazard identification in complex socio-technical systems because it focuses on identifying the technological and organizational constraints and affordances within a system that shape activity instead of trying to describe all the activity that might occur within the system (Vicente, 1999). CWA analyses constraints and affordances in five phases, with each phase linked to a different aspect of a system (Vicente, 1999). The phases analyse the work domain, control tasks, strategies, social and organizational factors and work competencies (Vicente, 1999).

The control task analysis and strategies analysis phases of CWA are particularly relevant to an analysis of human activity, because control task analysis focuses on activities that need to be done in the work domain to achieve the system purposes. Strategies analysis focuses on different ways that the activities could be done (Vicente, 1999).

Techniques that facilitate effective and efficient control task analysis include contextual activity templates and decision ladder templates (Naikar et al., 2006). *Contextual activity templates* decompose activity within a system by separating it by (1) work situations, which are segmented according to time and/or space, and (2) work functions which are segmented according to particular functions that need to be performed or problems that need to be solved (Naikar et al, 2006). The *decision ladder template* is a diagrammatic representation of processes that underlie reasoned action in the world (Rasmussen, 1982; Naikar et al, 2006). It is particularly suited to human hazard analysis work because it is linked with Rasmussen's (1982) skills, rules and knowledge framework.

Techniques that facilitate effective and efficient strategies analysis include flow diagrams and decision ladder templates as demonstrated by Jenkins et al (2007). Flow diagrams provide a simple but effective means of illustrating some of the ways an activity can be accomplished, from simple execution to more complex executions that include significant mental processing as demonstrated by Jenkins et al (2007). The decision ladder templates used in strategies analysis are the same as those described above for control task activity analysis.

People Framework

The People Framework of the BLHAZID methodology is used to identify the potential hazards associated with human activity. The framework draws on recent human factors/error taxonomy work (Gordon et al., 2005; Kim & Jung, 2003; Paletz et al., 2009; Rantanen et al., 2006; Shorrock & Kirwan, 2002) and accident causes (Kletz, 2009) and is a collection of potential areas of concern. The People Framework has been kept at a general level of detail suitable for the BLHAZID process and participants. Once finalized with industrial testing, the framework should be suitable for use with most systems.

The People Framework covers the perceptual, cognitive, communication, social, procedural and physical aspects of human activity (Table 1 shows a small section). For each of these areas the framework lists characterising variables and guidewords. Different combinations of characterising variables – guideword pairs describe the possible deviations in human activity. The People Framework also lists the possible causes of activity deviations. Thus, potential hazards that facilitate human contributions to, or hinder humans' ability to prevent, industrial accidents are identified by extracting from the People Framework all the combinations of *characterising variable – guideword – cause* triplets relevant to the activity being assessed. The use of these triplets in the HumHID process is explained in the next section. Table 1 shows an extract of the People Framework, highlighting the perception and communication sections of the framework.

Characterising Variables	Guidewords	Causes
Perception - of signals, object, actions, events		
Sense	None	Insufficient resources allocated
(See, hear, smell, taste, &/or touch)	Incomplete	Failure to search for information
	Too early	Wrong item perceived as right one
	Too late	Inaccurate knowledge of requirements
	Incorrect	Concealed signal
		Confusing signal
		Slips/lapses of attention/concentration
		Forgotten meaning/importance
		Violation or noncompliance
		Mismatch of requirements & actors ability
Communication		
Request more info	None issued	Mismatch of requirements & actors ability
Communicate decision	Incomplete	Failure to recognize importance
Instruct others to action	Too little	Violation or noncompliance
	Too early	Forget to send
	Too late	Forgotten by receiver
	Not retained	Assume done by another
	Unclear	Assume not needed
	Incorrect	Obstructed between sender and receiver
		Distraction/interference

Table 1. Extract from People Framework.

Proposed methodology

The major steps in HumHID are shown in Figure 1. At a high level, this workflow is analogous to the BLHAZID workflow illustrated in Seligman et al (2009; 2010).

1. Select system. The first step involves defining the system to be analysed by specifying the system purpose then identifying all the physical plant, procedures and control activities required to achieve that purpose. This ensures that all related plant, procedures and activities can be analysed together.

System selection and decomposition

1. Select the system to be analysed.
2. Define the work contexts and activity within the system using the contextual activity template and decision ladders.
3. Identify the human activity possessing significant risk using a high level risk assessment.
4. For activities with significant risk conduct a strategies analysis using flow diagrams to document the strategies.
5. Identify the strategy steps possessing significant risk using a high level risk assessment.
6. Construct decision ladders only for strategy steps possessing significant risk.

Hazard analysis

7. For each strategy step with significant risk
    a. Extract the data processing activities and states of knowledge used from the decision ladder.
    b. For each data processing activity and state of knowledge extract the relevant characterising variables using the People framework as a guide.
    c. For each characterising variable identify the relevant guidewords and causes using the People Framework as a guide.
    d. For each *characterising variable – guideword – cause* triplet, elicit its implications.
    e. From the implications set determine those regarded as consequences.

Figure 1. HumHID workflow.

2. Define work contexts and activity. The second step is to define and decompose the control activity needed to achieve system purpose into manageable segments, using contextual activity templates and decision ladders. Ideally, the decomposition should be done so that each segment is mutually exclusive to prevent unnecessary repetition in the analysis, and all segments together are collectively exhaustive so that all relevant work contexts are analysed. A decision ladder is then constructed to describe each work context.

3. Identify riskiest activities. The third step involves the execution of a high level risk assessment to identify activity segments with sufficient risk to undergo the full hazard identification process. Constraining the full analysis to significant risk activities improves the HumHID efficiency without compromising its effectiveness. The high level risk analysis involves assessing the likelihood and consequences of: 1) Not doing the activity; 2) Not completing the activity; 3) Doing the activity incorrectly; 4) Doing the activity out of order; 5) Doing the activity steps out of order. The result is a risk rating for each activity segment, which distinguishes segments with significant risk from those with no or low risk.

4. Strategies for significant risks. The fourth step involves conducting a strategies analysis on activities with significant risk. Flow diagrams illustrate the activity starting point, the different pathways or strategies that a person can use to execute the activity and the activity end point.

5. Identify strategy steps. The fifth step is to take the steps that make up the strategies and perform a high level risk assessment on them following the same process as used in step three. This risk assessment is done to constrain the hazard identification to strategy steps possessing significant risk.

6. Construct decision ladders. The sixth step is to make decision ladders for the strategy steps posing significant risk. This ensures that the hazard analysis is performed on information at the right depth, breadth and level of detail.

7. Hazard analysis. The final step of the HumHID process is to conduct the actual hazard identification. This involves extracting from the decision ladders the data processing activities and states of knowledge used to execute the strategy step, and then extracting from the People Framework the relevant *characterising variable – guideword – cause* triplets. This information creates a table that relates the activity defined by a decision ladder elements to *characterising variable – guideword – cause* triplets from the People Framework. Implications of each *characterising variable – guideword – cause* triplet are then identified and those classed as consequences are determined so that they can be addressed. The *cause* information can be used to address consequences by directing designers to the work domain elements that need to be eliminated, redesigned, or managed, in order to alleviate the potential impacts of hazards.

CASE STUDY

The following section illustrates the application of the HumHID technique to an industrial system in a desktop exercise. To test the feasibility of semi-automating the HumHID process, a pilot Excel workbook with appropriate macros was created and used for the case study.

BTX storage and transfer

Benzene-Toluene-Xylene (BTX) is a by-product of the BlueScope Steel Ltd. Gas Processing operations in Port Kembla, Australia. BTX is collected in storage tanks, and is periodically loaded into road tankers for transport to an offsite customer. The case study is based on the BTX loading system which consists of two bulk storage tanks (BTX-1 and BTX-2), piping, valves, pump, flow meter, dry break coupling and instrumentation, as shown in Figure 2 (Seligmann et al., 2010).

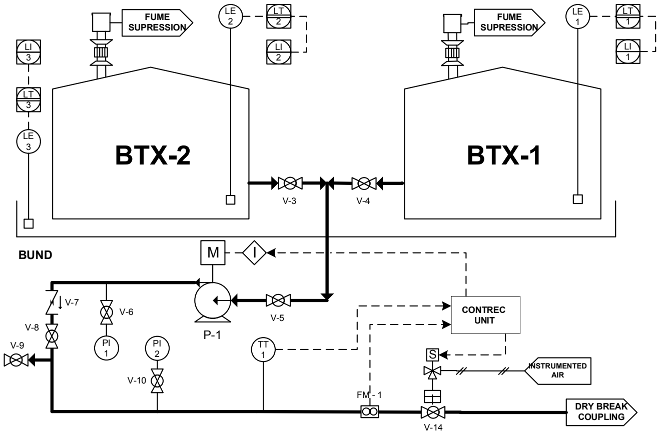

Figure 2. BTX storage and transfer system.

HumHID process

The case study proceeded as follows.

1. The scope of the case study was selected based on the system purpose - to safely and efficiently transfer BTX from

day tanks to a road tanker which is connected to the plant at the dry break coupling (shown in Figure 2). Information was collected for the case study from informal interviews with operators and observations of the loading bay physical layout and loading process, and from operating procedures, incident reports, the piping and instrumentation diagram, material safety data sheet and aerial photograph. This information was used to complete the rest of the HumHID process.

2. Contextual activity templates and decision ladders were used to define and decompose the activity required to achieve the system purpose. From the contextual activity templates it was identified that activity occurred across three different situations and four different functions and that there was seven unique activity segments. A decision ladder was then constructed for each of the seven activity segments by highlighting and annotating the elements of the decision ladder that were relevant to the activity being analysed. Possible shortcuts and shunts were then added and annotated.

3. Decision ladder information was then used as reference information for the activity segment high level risk assessment which was conducted as per the process described in the previous section. For BTX loading, three activity segments were given high risk ratings.

4. A strategies analysis was conducted on each of the high risk activities segments using the activity decision ladder to identify the different ways that the activity might be performed, ranging from skill-based behaviour to skill, rule and knowledge based behaviour, to achieve the required output. These strategies and the steps incorporated in them were portrayed with flowcharts.

5. The strategy steps were then subjected to another high level risk assessment.

6. Each strategy step with a high risk rating was then described using the decision ladder framework.

7. From the strategy step decision ladder, the highlighted data processing steps and states of knowledge plus any notations associated with them create the first two columns of the BLHAZID type table (Figure 3). The next three columns comprise relevant *characterising variable (C_Var) – guideword – cause* triplets selected from the People Framework. The last columns contain the implications identified for each triplet and the consequences which are unacceptable outcomes of the implications. Hence implications deemed to have unacceptable consequences can be addressed with the design insights highlighted by the causal information from the related triplet(s).

Figure 3 contains a strategy decision ladder from the case study and an extract of the BLHAZID type table created from the decision ladder and People Framework. The strategy step decision ladder shown in this figure uses the “Activation” and “Execution” data processing steps and “Alert” state of knowledge with a shortcut going from “Alert” to “Execution”. The arrows in the figure show how the “Activation” information is used in the first and second columns of the BLHAZID type table. Figure 3 also shows some of the *characterising variable – guideword – cause* triplets selected from the People Framework that are relevant to the activation data processing step as well as implications and, where appropriate consequences.

Results

The authors conducted reviews of the desk-top case study with The University of Queensland colleagues and BlueScope Steel personnel. The following comments were noted about the case study and HumHID process.

The case study indicated that the application of CWA techniques would provide a structured way of documenting BTX loading system activity. High level risk assessments would be a simple method of focusing the HumHID process on activities possessing significant risk, so ensuring the efficiency of the overall process. The decision ladders were easy to understand and it appeared they would support the systematic and comprehensive identification and documentation of human activity. The prototype Excel workbook would probably aid the efficiency and comprehensiveness of the HumHID by automating tedious tasks, guiding the user through the process and forcing them to consider all aspects of work from skills, rules and knowledge requirements to the perceptual, cognitive, communication, social, procedural and physical aspects of the activity.

The case study highlighted several opportunities. First, further streamlining of the process might be possible as there was significant duplication in the triplet information extracted for a data processing step and for the resultant state of knowledge. That is, there was significant duplication in the triplets chosen for activation and for alert. Second, the Excel workbook could be developed further to improve the efficiency and effectiveness of HumHID. Last, the results produced from the HumHID are similar in structure to the BLHAZID results shown in Seligmann et al. (2010). This suggests that there is an opportunity to develop an integrated people and plant hazard identification process.

The case study also had a number of limitations. First the HumHID case study analysed human activity required to operate the system in anticipated situations. Hazards from human activity can also arise from maintenance activities (Lawrence & Gill, 2007) and from unfamiliar and unanticipated situations (Jamieson, 2007), so the HumHID needs to be extended to cover these circumstances. Second the case study was conducted as a desktop exercise to prove the concept. Field testing is required to fully test the usability and benefits of HumHID over other human factor hazard identification techniques used by typical hazard analysis participants. Further field testing is also required to determine if incorporating HumHID into the BLHAZID delivers advantages over traditional hazard identification techniques.

CONCLUSION

A human factor hazard identification process, called HumHID, has been presented. The process incorporates proven techniques into a simple, straightforward framework that identifies human related risks and that can show companies the causes of these risks so designers can rectify them. The HumHID methodology was demonstrated with a desktop exercise of an industrial case study. Further work needs to be done to ensure the process is as streamlined and automated as possible. It should not compromise the analytical power in identifying hazards associated with plant, procedures and people that could facilitate human contributions to, or hinder their prevention of industrial accidents. Also it is vital to test the usability and benefits of the methodology against currently used techniques with typical hazard identification participants.

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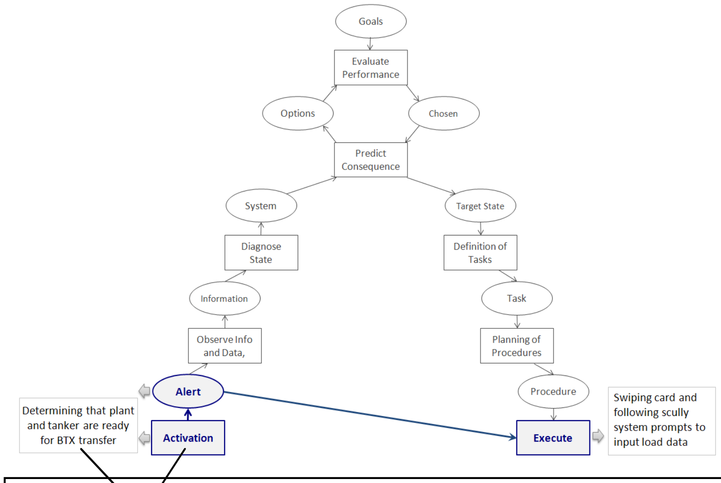

Decision Ladder Element	Description	C_Var	Guideword	Cause	Implication	Consequences
Activation	Determining that plant and tanker are ready for BTX transfer	Sense	None	No resource allocated	Loading delayed or not started	
				Failure to search for information		
				Inaccurate/incomplete knowledge of requirements		
				Slips/lapses of attention/concentration		
				Forgotten meaning/ importance		
				Violation or noncompliance		
			Inaccurate	Wrong item percieved as right one	Loading started before plant ready (valves in wrong position, safety systems not working)	BTX leak, explosion.
				Concealed signal		
				Confusing signal	Loading started before tanker ready (valves in wrong position, tanker not immobilised)	Tanker uncontrolled movement
				Mismatch between actor's ability and requirements		

Figure 3. Decision ladder and HFHAZID table extract from case study.

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