Abstract

Data-driven approaches coupled with technological interventions have noteworthy significance in managing and improving safety performance. This research aims at the development of a data analytics and virtual reality-based modeling approach for accident causation and safety training, which can help safety practitioners and other stakeholders to make better use of this effective accident prevention strategy. Electric overhead travelling (EOT) crane operations and related incidents are considered as a case study. The thesis addresses four important objectives as: (i) exploration of causal factors of EOT crane related incidents, (ii) development of virtual prototype-based simulator for EOT crane operations and visualization of accident scenarios, (iii) assessment of the effectiveness of developed simulator for EOT crane operators' safety training, and (iv) development of an integrated methodology to prescribe safety related interventions. The first objective is focused on exploring the associations amongst categorical causal factors using multiple correspondence analysis (MCA) augmented t-SNE algorithm and clustering techniques. Both categorical and numerical data are analyzed to explore meaningful safety rules and subsequent safety interventions. The second objective is focused on the necessity of development of an efficient dynamic accident causation modelling approach. In this process, VR based safety training simulator acts as an alternative to traditional safety management practices. The third objective is focused on the assessment of effectiveness of developed simulator for EOT crane operators' safety training in two aspect: (i) simulator effectiveness and (ii) safety training effectiveness. The fourth objective is focused on identifying the safety interventions with the help of a training simulator, and prioritizing and optimizing the interventions using safety function deployment (SFD), theory of inventive problem solving (TRIZ) and 0-1 multi-dimensional knapsack model.

In fulfilling the research objectives, the thesis has made contributions in two ways: theoretical developments and their practical implications. From theoretical developments point of view, this thesis proposed (i) a decision support system (DSS) for safety improvement using a multi-step knowledge discovery process involving multiple correspondence analysis (MCA), t-SNE algorithm and clustering techniques for categorical data and numerical data, (ii) data analytics (DA) and virtual reality (VR) based accident causation model (DA-VR-ACM) which works on the ideology of traditional ACMs along with a technological intervention such as DA and VR, (iii) safety training simulator, which works on the principle of DA-VR-ACM, for accident

modeling simulation, accident causation and safety training, (iv) a novel method for assessment of simulator effectiveness and safety training effectiveness, (v) a methodology for designing, prioritizing and optimizing the safety interventions. From the standpoint of practice, contributions can be summarized as (i) the developed methodologies are applied to a real case study in an integrated steel plant of India, (ii) in addition to primary causes of EOT crane accidents identified through descriptive analysis, application of multivariate statistical modeling approach resulted in extraction of 11 safety rules from mixed data analysis which subsequently helped accident path modeling, (iii) VR based safety training simulator is better than desktop based training and there is no significant difference between young and experienced operators in VR based safety training, and (iv) proposed methodology enables the safety practitioners to explore the hidden causal factors behind incidents and design actionable interventions.

For the plant studied, primary reasons behind construction related incidents are side fall of material and inappropriate man/machine interface, maintenance related incidents are hit by object and slip/trip/fall, and operation related incidents are unsafe loading & unloading of objects. Considering the risk factor involved with incidents, it is observed that loss time injury (LTI) incidents frequently have medium and low injury risk and low reputation risk and fall of objects and hit by objects have high risk of injury, and equipment and environment damage. From the training perspective, it is shown that the proposed VR based safety training method helped the trainees in identifying 12 hazardous elements (HEs) and 13 initiating mechanisms (IMs). Further, it is also noticed that there is significant increase in hazard identification index after VR based safety training. Task prioritization analysis after safety training implied task 2 (Picking the ladle containing molten metal from the loco) and task 5 (Pouring the molten slag by tilting the ladle) need better training procedures, which can be attained through VR. Using prescriptive approaches, 26 safety interventions are identified which are further classified into three categories i.e., protective devices and guards, personal protective equipment and operator support system, and TRIZ based safety solutions. 15 out of 26 safety interventions are found to be optimum after considering the capital budgeting method. Safety performance, which is the measure of the effectiveness of interventions is improved by 15% after VR based safety training. After VR based safety training, it is observed that technology based interventions (obstacle detecting sensor, laser scanner, smart helmet, RFID, immersive safety training, and signalling and communication device) measures are having more weightage that traditional preventive measures. Though the findings of the study are related to the studied steel plant, the

concepts and methodologies developed in this thesis are generic and can be applied to other industries with similar features and conditions.

Keywords: Safety analytics; Accident causation modeling; Near miss incidents; Categorical data analysis; Multiple correspondence analysis; Virtual reality; Safety training; Safety function deployment; TRIZ, 0-1 multi-dimensional knapsack model