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Mining safety rules for derailments in a steel plant using correspondence analysis

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ABSTRACT

In this study, we have analyzed a steel plant's derailment data using correspondence analysis. The primary purpose of this analysis is to find out associations of categories of factors contributing to the derailments which ultimately lead to the development of meaningful rules for preventing derailments. 348 derailment incidents collected over a period of 42 months were analyzed considering 4 factors namely, shift of working, location, cause of derailment and department responsible. Descriptive statistics show that by shift of working there is not much difference in the occurrence of derailments. But from location, cause of derailment and responsibility (departments) points of view, 'raw material line', 'manual operations' and 'production (raw material)' accounted for 50%, 60% and 48.28% of derailments, respectively. From correspondence analysis, it is found that 'level of movements', 'level of human involvement', 'management of wagons', and 'criticality of movements' are the hidden root causes of derailments in the plant studied. In order to improve the safety of in-plant rail transport of the plant studied, the plant management should (i) collect and analyze derailment data related to 'level of movements' and 'human involvement', (ii) adopt collaborative maintenance of wagons as external agencies are also involved in rail transport, and (iii) practice risk based maintenance of the in-plant rail transportation systems.

1. Introduction

Managing safety is a perennial problem to every organization. In Indian manufacturing sector the fatal accident rate is close to 100 fatalities per million employees against the range from 10 to 30 in advanced countries (DGFASLI, 2009). Large industrial plants in the chemical, automobile, and steel industry often occupy entire quarters of cities and as a result heavy freight are required to be transported between widely spread terminals. To maintain a timely around-the-clock production process, it is often indispensable to operate a private industrial railroad (Lübbecke and Zimmermann, 2003). The permanent nature of the tracks allows plants to build the production system around them. It provides a much more automated system of transport compared to roadways and allows for more reach, flexibility and transportation of heavier freights compared to conveyor belts and other forms of transportations (Agarwal, 2008). It also brings the problem of derailment of rolling stock with it. A derailment can include a minor lateral movement of a loco to major accidents, damaging the tracks and materials, halting the production line and sometimes even causing fatalities.

In-plant railway or locomotive routing and scheduling has been covered by researchers in detail (Vaidyanathan et al., 2008; Lübbecke and Zimmermann, 2003; Charnes and Miller, 1956). Additionally, derailments of trains carrying hazardous materials or passengers, and the subsequent effects have also been studied extensively (Glickman and Rosenfield, 1984; Bagheri et al., 2011; Evans, 2000). Christou (1999) investigated various possible reasons for collision of trains in marshalling yards and port areas, in which 617 accidents cases were reviewed where there were 2494 fatalities and 17,943 injuries and subsequently enumerated the causes of such accidents, e.g., explosions, fire, tank failure and operator's error. There are many studies dealing with component level failures of the rail transport system (Wanming et al., 2002; Ishida et al., 2006; Sato et al., 2008; Hung et al., 2010; Banerjee, 2013; Wu et al., 2013; Underwood and Waterson, 2013). Liu et al. (2010) describes a cost effective framework of preventive actions to minimize rail accidents caused by derailment.

Wallace and Vodanovich (2013) argued that the causes of derailments cannot be attributed to only an individual component failure or due to human error. Thus there is a need of more advanced and in depth studies on derailments and safety in a closed environment like a steel plant or other manufacturing plants. While the direct causes of an industrial accident are easily recognizable, indirect causes cannot always be easily recognized or

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attributed to the accident. Also all the indirect causes cannot be found as there are some damage categories that are very subjective and are not formulated or defined clearly (Lagerlöf, 1975). An industrial accident can be thought of as a function of the accident location, cause of the accident, certain departments involved, and time of the day when accidents take place. The cause of an accident could be any of these factors alone or a combination of them. While it is possible to subjectively allot every piece of data to a particular factor, we need mathematical analysis to filter through the data to find out a clear picture of such events.

Accident/incident data analysis can be done using either the traditional or non-traditional approach depending on the data structure under consideration. The data collected with respect to the derailment case are categorical in nature, as a result the traditional multivariate techniques like principal component analysis or factor analysis cannot be applied. Correspondence analysis or CA is a special form of multivariate analysis technique specially used for dealing with categorical or nominal data. This technique is particularly suited to discrete data represented in the form of numerical frequencies. Among various advantages of using CA few are worth mentioning, e.g., CA does not require any distributional assumption for analyzing the data under consideration. Being multivariate in nature CA unravels the inherent relationship among variables that otherwise remains undetected even after performing series of pairwise analysis (Hoffman and Franke, 1986) Along with this it also provides a visual representation of the relative association among variables in lower dimensions.

CA has found application in various fields till date. Higgs (1991) showed the application of CA in brand mapping domain. Park et al. (2007) used the CA approach in studying population genetic data. Pusha et al. (2009) used polar classification approach, which being an amalgamation of CA and angle based classification, in fault isolation process. They argued that application of CA provides more resolution power between fault clusters and also subsequent dimensionality reduction. Aravindan and Maiti (2012) used CA for integrated analysis of defect data in a supply chain. In the area of accident analysis Lu et al. (2012) demonstrated the use of CA in exploring the association between fire causes and influence factors. Though it can be argued that alternative to CA methodology, log-linear model can also be used to (i) extract hidden dimension from data, (ii) reduce dimensions and (iii) visualize data on reduced dimension. But it should be kept in mind that log linear model does not provide the mechanism to visualize the data on the reduced dimensional co-ordinates. Thus, unlike log linear model by using the CA, apart from finding the association among the categories of the variables, we can also find the hidden variables responsible for the derailment incidents,

The motivation behind this research endeavor is three folds. Firstly, availability of scanty literature on the issue of derailment in steel industries urges us to address this area of research. Secondly, we require to find out the hidden causes responsible for the derailment incidents which are apparently non-intuitive and finally to develop a rule base structure, which in turn will provide a guideline framework management to take necessary interventions for reducing such derailment incidents.

Present study introduces an existing system where the case of an integrated steel plant is considered. Further, it presents a case study and interpretation of results, which is followed by some subjective observations and suggestions based on the aforementioned analysis. The rest of the paper is organized as follows. In Section 2, the methodology adopted is described that contains data structure and correspondence analysis of the data. A case study of a steel plant is presented in Section 3. Both preliminary analysis involving charts and advanced statistical modeling using CA are presented in this section. The findings of the analyses are discussed in Section 4 followed by conclusions in Section 5.

2. Methodology

2.1. Data structure

The derailment data across the company has to be structured for easy retrieval and analysis and therefore the data has been classified in dimensions understood by the stakeholders. The dimensions considered in the proposed methodology are:

2.1.1. Shift of derailment (S_i)

Steel-making is a continuous process which requires round the clock presence of workers. Each day is divided into three shifts of work. A shift is the mandatory 8 h period of work including the assigned breaks. Shift A (*morning* shift) starts at 6:00 AM and ends at 2:00 PM. Shift B (*day* shift) starts at 2:00 PM and ends at 10:00 PM. Similarly, Shift C (*night* shift) starts at 10:00 PM and ends at 6:00 AM next morning. To avoid fatigue and faltering biological clocks of workers, shifts are changed on a round-robin schedule for every worker on monthly basis. Besides these three, a general shift from 7:00 AM to 4:00 PM exists for non-production employees, e.g., for accounting and personnel, regular maintenance and clerical staff. Different shifts bring different attitude of workers, production goals and rush of transportation to the table. General shift can be disregarded in this context as employees in general shift are not involved in the actual transportation process.

2.1.2. Line (L_j)

Line indicates the type of tracks based on their primary usage by the departments. In this context it points to the general location of derailment in the plant (Positional Training Document, 1997). Following are the classifications of lines according to their primary usage:

- *Raw Materials Line:* Lines on which raw materials are brought in the plant and carried around.
- *Cooling Tank Line:* Lines in the storage (Cooling Tank) area of the plant.
- *Hot Metal Line:* Lines on which hot (molten) metal is carried around.
- *Finished Goods Line:* lines on which final products are carried around.
- *Maintenance Tracks:* Extra tracks that are used specifically for maintenance operations of rolling stock, cranes, etc.

2.1.3. Cause (C_k)

A derailment can be attributed to several broad classifications of causes. It may reveal the scheduling of maintenance, training and general work patterns of the workers. Following are the different classes of causes of derailment in the plant:

- *Manual:* Derailments that result from what is essentially a human error, e.g., application of sudden break, point crossing not set properly, etc.
- *Mechanical:* Derailments that result from failure of mechanical systems, e.g., tippler clamp failure, wrong winch operation, etc.
- *Jam:* Derailments that result from jam on rail tracks, e.g., coal jam, molten metal jam, etc.
- *Track Problem:* Derailments that result from faulty rail tracks, e.g., gauge slack, rail joint defect, etc.

2.1.4. Department responsible (D_l)

Though a large steel plant consists of more than two dozen departments, they can be grouped into different categories on the basis of similarity of function or location of operation.