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Comparative risk assessment of vehicle maintenance activities: Hybrid, battery electric, and hydrogen fuel cell cars

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ABSTRACT

In this research, vehicle maintenance activities and their safety risks were statistically analyzed. This study focused on three types of vehicle: hybrid, battery electric, and hydrogen fuel cell cars. The repair activities and the risks for each power train technology were identified by a panel of experts. Depending on its frequency and severity, risk values were calculated for each maintenance activity. The method chosen was the staticized group method, which involves collection opinions from a panel of experts. The ten experts finally chosen were asked to anonymously respond to a survey that had been especially designed to reduce bias and ensure the quality of the data. The most dangerous vehicle maintenance activities were the manipulation of asbestos, charging and discharging of high value capacitors, and welding.

Relevance to industry: The results of this research reflect the urgent need for workers in the automobile sector to be trained for emerging risks in new technologies.

1. Introduction

In 2011, there were more than one billion motor vehicles in use in the world (Sousanis, 2011). For this reason, vehicle maintenance is an extremely important sector of economic activity. Nevertheless, despite its prominence, surprisingly little attention has been paid to the occupational health and safety conditions of mechanics and other workers at vehicle maintenance worksites. In fact, according to the Bureau of Labour and Statistics (BLS, 2011), workers in this sector had higher rates of occupational injuries and illnesses in comparison to workers from other sectors. During 2011, the number of non-fatal injuries and illnesses per 100 full-time vehicle repair workers in the United States of America was 3.9, whereas in other sectors such as chemical manufacturing or mining support activities, the number was 2.4 and 2.3, respectively.

This high accident rate has a wide range of causes and stems from multiple variables. For example, there are various stressors at the vehicle maintenance worksite, which include the following: (i) a noisy environment (Bejan et al., 2011; Dembe et al., 2005; Sorock et al., 2004); (ii) asbestos (Dotson, 2006; Cohen and Van Orden, 2008; Blake et al., 2008); and (iii) ergonomic conditions (Fredriksson et al., 2001; Vandergrift et al., 2011).

Although vehicle mechanics are exposed to a wide range of occupational risks, previous research has only focused on one risk type, and has not provided a comprehensive overview of the issue. More concretely, majority of the previous studies have centered on conventional combustion. However the rapid development and expansion of emerging automobile technologies has produced new occupational health and safety risks, which must also be considered.

Mechanics and workers employed in garages and repair shops generally have an elementary school education or have never finished high school. Many of them began working as apprentices and were trained on the job by more experienced staff. As a result, most of their skills were acquired on the job in practical “hands-on” contexts without any theoretical training (Barber, 2004; Hager, 1998). The recent appearance of new car technologies signifies that there is currently a scarcity of experts familiar with the unique design and characteristics of these vehicles. This lack of skilled personnel is a problem for the manufacturing and maintenance of these vehicles, but it is also a problem from the perspective of occupational health and safety.

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This research study calculated the safety risk of various repair activities for these new types of vehicle. In this regard, the maintenance of hybrid, battery electric, and hydrogen fuel cell cars were analyzed with the binary method as well as the staticized group method.

2. Methodology

Within the framework of this research, a specific risk assessment method was selected, based on the results of previous studies. In the construction sector, there are currently several risk quantification methods of varying levels of complexity and application. For example, Everett (1999) studied ergonomic risks pertaining to 65 construction activities and rated each risk factor on a three-point scale (*insignificant*, *moderate*, and *high*). The objective of his study was to identify risks leading to injuries from overexertion.

The concept of *safety risk* is defined as the product of the frequency and severity by various authors (Sun et al., 2008; Baradan and Usmen, 2006). Hallowell et al. (2011) and Jannadi and Almishari (2003) used a similar quantification method though enhanced with the component of exposure. The research study described in this paper used the binary method (British Standard Institution, 1996), in which unit risk is also the product of frequency and severity. *Frequency* is expressed in terms of worker hours per incident, whereas severity is defined in terms of impact to the worker per incident.

$$\text{UNIT RISK}\left(\frac{\text{severity}}{\text{work-hour}}\right) = \text{Frequency}\left(\frac{\text{incident}}{\text{work-hour}}\right) \times \text{Severity}\left(\frac{\text{severity}}{\text{incident}}\right) \quad (1)$$

After specifying the method of risk quantification, the next step was the selection of a suitable strategy to accomplish our research objectives. The two considered were the staticized groups research method and the Delphi method. The staticized group technique is similar to the Delphi method but differs from it in that it does not include feedback or iterations. When comparing the accuracy of both methods, various studies have reported that the staticized group method is more accurate than the Delphi method (Best, 1974; Rowe and Wright, 1996), whereas other research found no substantial difference in the accuracy of the two methods (Fischer, 1981; Sniezek, 1990). According to other studies, however, the Delphi method was found to be less accurate when there were many iterations (Gustafson et al., 1973; Boje and Murnighan, 1982).

According to Erffmeyer and Lane (1984), the staticized group approach is preferable because panel members are less likely to arrive at a consensus on an incorrect value. Based on Erffmeyer and Lane (1984) as well as the previous research cited, the staticized group was thus considered to be the most suitable method for our study.

2.1. Panel members

In staticized groups, a key factor in the quality of the study is the selection of the experts. According to Hallowell and Gambatese (2010), the level of expertise is the most important facet of a panel member. They thus provide a set of guidelines that include a flexible point system for the selection of expert panel members. This point system was taken and adapted to the purposes of our study. Table 1 shows the modified version of the point system, which was used to choose our panel of experts.

Table 1
Flexible point system for the selection of panel members.

Education and experience	Points
Bachelor in Engineering	4
Master in Engineering	6
Mechanical or electric background	3
PhD in Engineering	4
Master in Occupational Risk Prevention	4
Professional registration	3
Years of professional experience	1
Papers published in ISI journals	2
Author of a book in the field	4
Faculty member of an accredited university	3

The authors contacted 30 international experts in occupational safety risk with experience in the automobile sector. After a review of the background and availability of these candidates, fourteen of them were pre-selected. These candidates came from eight high-profile companies in the automobile sector and four university engineering schools. In addition to the flexible point system requirements, only one expert per company or per university was selected in order to ensure diversity.

All panel members met the requirements in the guidelines proposed by Hallowell and Gambatese (2010), which meant that they scored a total of at least eleven points in four or more education or experience categories. Nevertheless, of the fourteen pre-selected candidates, there were ten that were finally chosen as the most suitable. The other four professionals were thus excluded from the panel.

The qualifications of the panel members were the following:

- **Master's Degree in Occupational Risk Prevention**. All panel members had this degree, which guaranteed their expertise in safety at work and occupational risk. This was found to be the most valuable qualification because it meant that the panel member had high-level training in occupational health and safety and thus possessed the necessary level of expertise to evaluate risks in vehicle maintenance.
- **Bachelor's/Master's Degree in Engineering**. This degree assured that the members had the necessary background in engineering. This was clearly relevant because automobile repair activities for new types of vehicle involve cutting-edge technology, and only by being familiar with technical issues could panel members make accurately evaluate the risks involved.
- **Extensive professional experience**. Between them, the panelists had a total of 96 years of experience in the automobile sector. These years of experience allowed panel members to assess risks on the basis of what they had actually seen at the workplace.

2.2. Research design

In order to obtain information regarding risk levels, a web-survey was designed and made available to the experts. The survey was limited to panel members, who were given a password to access the site. The web-survey expired after all the data were collected in the stipulated time period.

The following strategies were used to optimize experimental design and eliminate bias:

- The order of the questions and the potential safety risks in the survey were randomized for each panel member. This reduced the contrast effect as well as the primacy effect.
- Independent frequency and severity rates were implemented.
- The anonymity of each expert was ensured.