THE INFLUENCE OF DRIVER'S PSYCHOLOGICAL STATES ON THE SAFETY PERCEPTION OF HYDROGEN ELECTRIC VEHICLES

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ABSTRACT
The environmental and sustainable problems caused by automotive exhaust emission have received more attention than ever. Innovative vehicle technologies, such as hydrogen fuel cell and electric vehicles (EVs), have been developed a long time ago to cope with the problem. Public acceptance of these EV technologies is critical to their successful replacement of the internal combustion (IC) engine vehicles and thus reduce the emissions. Previous researches had shown that the main barriers were the lack of support infrastructures, high vehicle purchase cost and vehicle reliability with respect to safety. However, studies into the public safety perception of hydrogen-fuelled vehicles have still been limited to date. In this article, a quantitative survey was developed to investigate the public safety concerns of three types of vehicle powertrain: the IC engine, the hybrid electric and the solely EV. The study indicates the root cause of the low safety perception at present. The survey results also indicate that driving freedom is nowadays not just a problem of infrastructure only but is gradually becoming a psychological issue in terms of increased driver's mental stress, and thus, the overall driving safety is affected. Furthermore, this article states the existence of an evaluation chain to determine the driver's safety perception. In the end, this article proposed a comprehensive framework of the negation of driver's safety concerns regarding the hydrogen-fuelled EV, based on the results from the survey and a review of psychological effects. This framework intends to explain the perceived safety perception from a wider angle with some depth.
Keywords: electric vehicle, hydrogen fuel, psychological factors, safety perception.

1 INTRODUCTION

In recent years, the issues of global climate change have received more and more attention, and the problem of automotive vehicle exhaust emissions is one of the reasons. At the same time, increased air quality pollution is the most direct effect that the public is currently suffering. A recent report [1] showed that conventional internal combustion (IC) engine vehicles increase the health cost, and each vehicle in inner London costs NHS nearly £8000 over its lifetime. Hence, 'zero CO_2 transportation'' is the future that the automotive industry is heading. Currently, electric vehicle (EV) technologies are well-developed and are applied to the most recent vehicle models. Restricted emission standards, such as Euro 1 to 6, and the zero-emission trend of the future society are the major driving forces for the development of these innovative and sustainable EVs. For this reason amongst others, vehicle technologies are moving progressively from the IC engine (30% efficiency with harmful exhaust gases) to electric powered vehicles (70% efficiency with no emission gases) that consist of either a battery package (e.g. Tesla) or hydrogen fuel cell package (e.g. Toyota Mirai) [2]. Furthermore, recent research highlights the importance of moving from green energy to green logistics in order to develop sustainable and green transportation [3]. In this case, hydrogen fuel cell vehicles (HFCVs) expand the advantage of battery electric vehicle (BEV) even further as there could potentially be no emissions at all during the entire well-to-wheel process. This is because renewable energy sources (e.g. solar/tidal power) can be used to produce electricity,

ISSN: 2058-8305 (paper format), ISSN: 2058-8313 (online), http://www.witpress.com/journals
DOI: 10.2495/TDI-V3-N3-207-221

and then the produced electricity will be sufficient to produce hydrogen which can then be fuelled into the EV, with water being the only waste generated. Public acceptance of these EV technologies, such as HFCVs, is critical to their successful replacement of the IC engine vehicles. Previous researches had shown that the main barriers were the lack of support infrastructures, high vehicle purchase cost and vehicle reliability with respect to the safety [4, 5].

At the early market entry level, the lack of support infrastructures limited the recharge or refuelling availability, and hence, the travel routes need to be planned carefully in advance. These planned routes are often away from the driver's familiar routes. The charging time required for BEVs is between 1 and 2.5 h and reach up to 42 h depending on the charging facilities, and thus this feature will affect the effective usage time of the vehicles as well [6] urban air pollution and foreign oil dependence caused by motor vehicles. This paper evaluates the primary transportation alternatives and determines which hold the greatest potential for averting societal threats. We developed a dynamic computer simulation model that compares the societal benefits of replacing conventional gasoline cars with vehicles that are partially electrified, including hybrid electric vehicles, plug-in hybrids fueled by gasoline, cellulosic ethanol and hydrogen, and all-electric vehicles powered exclusively by batteries or by hydrogen and fuel cells. These simulations compare the year-by-year societal benefits over a 100-year time horizon of each vehicle/fuel combination compared to conventional cars. We conclude that all-electric vehicles will be required in combination with hybrids, plug-in hybrids and biofuels to achieve an 80% reduction in greenhouse gas emissions below 1990 levels, while simultaneously cutting dependence on imported oil and eliminating nearly all controllable urban air pollution from the light duty vehicle fleet. Hybrids and plug-ins that continue to use an internal combustion engine will not be adequate by themselves to achieve our societal objectives, even if they are powered with biofuels. There are two primary options for all-electric vehicles: batteries or fuel cells. We show that for any vehicle range greater than 160 km (100 miles. However, since 2014, the uptake of HFCVs has begun to attract people's attention. Toyota launched a signature model of the passenger HFCV, known as Mirai. It has a maximum power output of 60 kWh with a peak output of 9 kW. It has a maximum power output of 60 kWh with a peak output of 9 kW, which allows the vehicle to be used as an emergency power source to power the house as well as onboard charging to other personal electrics, such as a laptop. Also, recent research indicates that transportation electrification is an unavoidable trend while the EV becomes more popular, which will increase the workload to the current grid system [7]. Hence, the use of this hydrogen vehicle feature enhances the vehicle to grid (V2G) concept and eventually improves the smart grid performance. It also has two 60L hydrogen tanks at 700 bar, which enables a range of 300+ miles and 5 min refuelling time. A previous study indicated that more than 80% of drivers (n=182) are praising this quick refuelling time, and willing to spend an extra 5-10 minutes travel time to go to a refuelling station [8]. The increase in the current number of hydrogen stations also helps to solve the infrastructure shortage at a slow rate. In fact, the infrastructure is currently facing the 'Chicken-Egg' scenario between the supply and demand of hydrogen stations. This situation would not be solved easily without government actions, and the solution is likely to involve installing and upgrading existing fuel stations rather than building new purpose-designed hydrogen stations solely.

As of 2018, other automotive companies also developed various models of HFCV, and it was not surprising that these vehicles still have a higher price due to limited manufacturing capacity. Overall, the use of fuel cell technology is accelerating in the automotive sector; the current technical specifications of the HFCVs have now satisfied our commuting requirements, and the price of vehicles will inevitably be reduced due to mass production in the near future. Recently, Hardman et al. [9] stated that there is a rise in the awareness of HFCV safety concerns based on the interview study of current early adopters of EV. Although various studies have indicated that the barriers of hydrogen EVs can be solved technically, the studies of public acceptance of such new technological solutions have been limited to date. Also, the previous acceptance studies were based on 'early adopter' types, and these participants typically have certain technical professions background and are living in rural or suburban multiperson households [10]. Therefore, they often had some EV experiences and some of them even had previous hydrogen-related vehicle experience before the surveys were conducted.

In reality, the safe retrofitting of fuel cells into areas with little prior experience of hydrogen, especially domestic environments, will raise a multitude of new issues. Regarding the transportation applications of the hydrogen fuel cell, people automatically think of issues such as the Hindenburg Airship when considering hydrogen as a fuel source. However, the Hindenburg airship was on fire without explosion, and the flaming ship was riding to earth as the clear hydrogen flame swirled harmlessly above passengers, and thus, there were 62 survivors out of 97 on-board passengers [11]. Therefore, the knowledge gap is one of the critical factors that creates psychological barriers. In 2018, Fry et al. [12] developed a framework to demonstrate the influence of the knowledge factor on the adopter aspect using Roger's diffusion of innovations theory. In addition, Li et al. [13] stated that the concern of EV driving freedom is no longer a solely technical issue but also gradually becomes a psychological issue as well. This is because the insufficient knowledge level leads to a lack of confidence for them, and hence, the level of anxiety and worry is increased as a result. Previous driver behaviour studies also indicated that the driving performance is directly related to the driver's mental workload [14, 15] and inadequate mental workload is one of the most important causation factors of traffic accidents [16].

The aim of this article is to understand the influences of various safety perception factors from the driver's point of view and then to develop a comprehensive framework of the negation of driver's safety concerns regarding the hydrogen-fuelled EV, based on the results from the survey and a review of psychological effects. This proposed framework intends to explain the sociological barrier as well as a technological barrier while considering the concept of the innovative EV and is able to act as the baseline model of safety perception, especially for EVs.

2 METHODS

First of all, a questionnaire survey was developed and distributed to collect data regarding the safety concerns of three various powertrains, namely (1) the conventional IC engine vehicle powertrain which uses either petrol or diesel fuel, (2) the hybrid vehicle (HV) powertrain which combines the IC engine with an electrical motor and (3) the solely EV which utilises generated electricity to drive the wheel. In the construction of the questionnaire, in order to prevent participants from giving a preconceived perception of the specific power source (i.e. battery or hydrogen) in their minds, words such as batteries and hydrogen were deliberately avoided. A non-probability sampling method, known as a voluntary sample, was used. This is an easier way to collect data and gather ideas that make the best use of the Internet today. In addition, a snowball sampling method was also used to minimise the potential voluntary sample bias. The survey was specifically sent to participants with a wide range of occupations and asked the participants to disseminate the survey within their organisations, including engineers, designers, students, shop owners, academics and drivers; but overall, it was not limited to these occupations.

This developed questionnaire had two identical versions. One was in English and another in Chinese. The questionnaire was distributed in the Chinese language since this country has more than one-third of the total EVs in the world [17] and English is not an essential language for Chinese drivers. The Chinese version was developed to collect those drivers' opinions whilst minimising any uncertainties due to misunderstanding. The survey period was 3 weeks in June 2018, and a total of 96 responses were collected.

The data were then analysed using Pareto analysis to identify the most significant aspects to address, thereby making the development effort more effective. The Pareto analysis is a formal technique that is able to extract the salient points from where many possible causes are competing for attention. This analysis method was developed from the Pareto principle, which is also commonly referred to as the 80/20 rule. This rule states that 80% of the problems are generated from 20% of the causation factors. In other words, 80% of the safety concerns can be improved by solving the identified 20% of the significant causation factors.

In order to perform the analysis, the collected answers were sorted into various sub-groups according to the defined keywords. Then, the closely related sub-groups were gathered together to form a specific safety concern category. Figure 1 indicates the defined keywords and their associated safety categories.

In the end, the concerned frequency (CF) was calculated and compared among those three different vehicle types. During the calculations, 'Explosion/Fire', 'Battery Failure' and 'Fuel

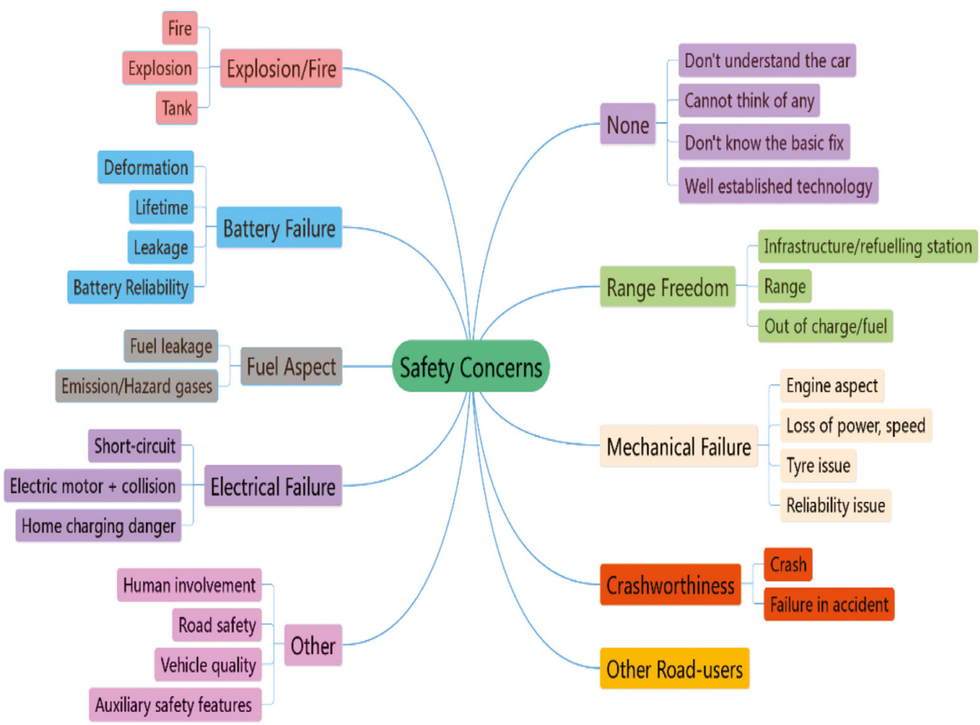

Figure 1: Safety concern categories and associated sub-groups for Pareto analysis.

Aspect' were considered as one specific safety category which refers to the power supply components (PSCs) of the vehicle.

3 RESULTS AND DISCUSSION

3.1 Socioeconomic status of the participants

Amongst the collect 96 responses, 4 were from non-drivers and therefore were considered as other road users. 29.2 % (n=28) of the total responses came from China. Figure 2 shows the number of participants in various age groups (left) and the socioeconomic status (SES) of the participants (right). The left figure shows that the majority of the participants are aged between 25 to 64 years; therefore, the survey results are able to identify the most important safety issues for the emerging future market as these people are the likely potential users of hydrogen-fuelled vehicle market in the near future. The figure on the right indicates the SES of the participants from the occupational aspect. This figure of occupational SES is assessed based on the skill required using modified Kuppuswamy scale [18]. Occupations, such as engineer, lawyer, academic professor and analysts, often require a higher level of skill set (e.g. decision-making ability and advanced numerical skills), and hence, are considered as a high SES classification. On the other hand, jobs, such as bartender and cleaner, often required a relatively low level of skill set, and hence are considered to be grouped in lower SES classification. These results indicate again that the survey had a wider range of coverage and was not representative of a particular group of people.

Figure 3 indicates the distribution of various safety aspects in descending order of CF with respect to the three types of vehicle powertrain: (a) ICE vehicle, (b) HV and (c) EV, respectively. The primary y-axis represents the CF of each individual safety aspect (x-axis) and the secondary y-axis represents the accumulative percentage of the concerned problems. By applying a vertical line at the intersection point between the accumulative percentage curve and the 80% boundary, the most important criteria of vehicle safety perception were identified regarding individual vehicle powertrain. The safety aspects on the left of the drawn line account for at least 80% of the safety concerns.

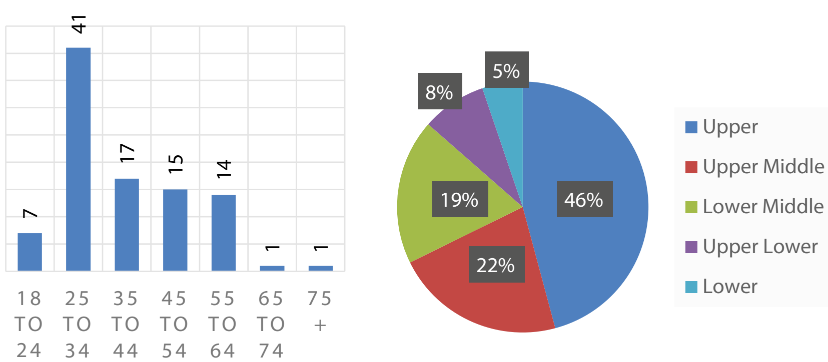

Figure 2: The number of participants in various age group (left) and the socioeconomic status of the participants (right).

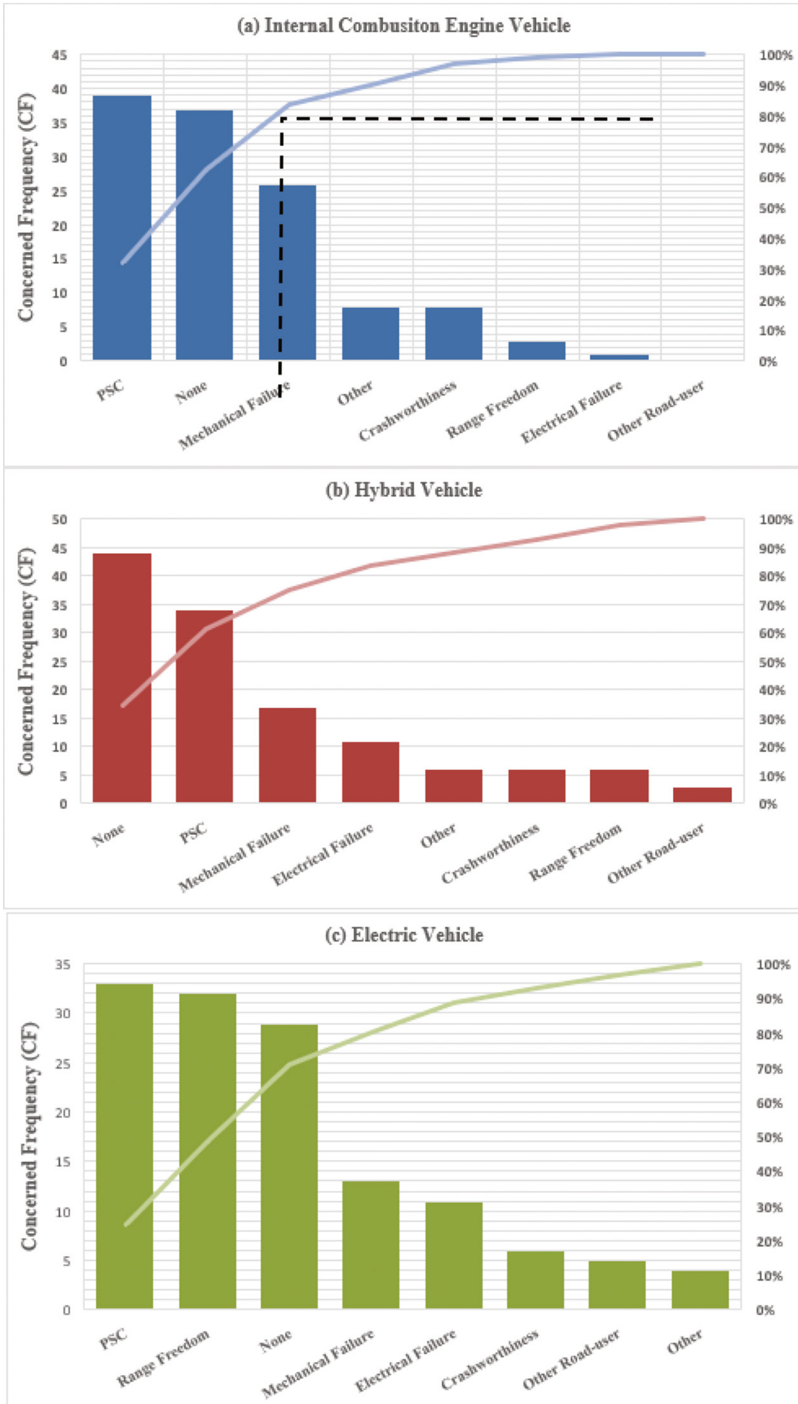

Figure 3: The concerned frequency of various safety concerns regarding (a) ICE vehicle, (b) HV and (c) EV.

3.2 Vehicle familiarity factor influences

First of all, the IC engine is a mature technology and has existed for many decades. Therefore, its working principle is not a mystery to the public. Hence, the breakdown of these vehicles due to mechanical failure is often expected to some extent. This factor is indicated in the 20% causation range in Fig. 3(a) and accounts for 21.3% (CF = 26) of the overall concerned safety. In the HV (Fig. 3(b)) and EV (Fig. 3(c)) powertrain, the CF of mechanical failure is CF = 17 (13.4%) and CF = 13 (9.8%), respectively. Safety concerns regarding traditional mechanical failures are diminishing, as the proportion of applied electronic systems in modern HV and EV is increasing, thus, leading to an increase in concerns about electronic failures rather than sole mechanical failure. With respect to the HV and EV, the electrical failure factor only accounts for 8.7% (CF = 11) and 8.3% (CF = 11) of the overall safety concerns, respectively. This is due to the fact that people's concerns about electric systems are mainly focused on battery fires, charging and electrolyte leakage, whereas the concerns about the actual electrical circuit have not received much attention. In addition, these numbers illustrate that the general electronic safety awareness of EVs is still at the level of battery failure and fire explosion. However, the more specific safety risks regarding electronic circuits (e.g. the high voltage of 350V) and other electronic components are not considered seriously.

Regarding the PSCs, this is a specific category that includes the tank and battery-related fire explosions as well as leakage of all forms, because these terms frequently appeared in the survey. Figure 4 indicates these safety concerns with respect to each individual powertrain. The safety concerns are discussed regarding three different categories: (1) 'Explosion/Fire' which represents the concerns of fuel tank explosion or fire and battery fire; (2) 'Battery Failure' factor represents the remaining phenomena of battery failure, such as battery deformation, leakage, state-of-health, etc. and (3) concerns regarding fuel leakage and hazard exhaust gases.

In the IC engine vehicle, one-third (CF = 13) of the concerned safety is related to the fuel tank explosion and fire and the remaining two-third (CF = 26) of concerns are related to fuel leakage and hazard gases. The failures associated with batteries contained in IC powertrain are neglected by all participants. In the case of the HV, the CF of explosion and fire

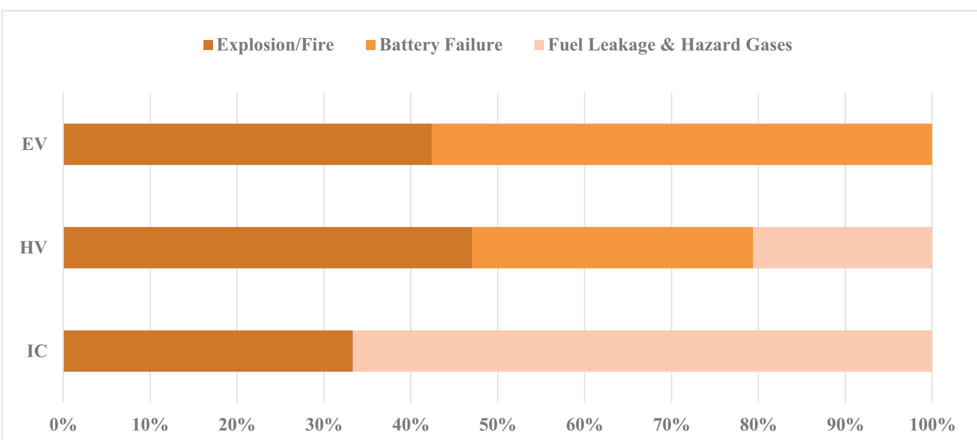

Figure 4: Percentage of various power supply component safety concerns.

is increased to 47.1% (CF=16). This is because the public has become more familiar with Tesla EVs recently, and its battery technologies have been mentioned regularly. In addition, the CF of fuel aspect issues is reduced to 20.6% (CF=7) to compensate for the increase in battery failure. Regarding the EV, the CF of battery fire and explosion is 42.4% (CF=14), and the battery failure CF is 57.6% (CF=19). These two numbers clarify an interesting phenomenon, which illustrates that hydrogen-fuelled EVs (e.g. hydrogen or methane) are not widely accepted by the public yet all the participants consider that battery is the only power source. This is because the questions are carefully stated in such a way that the term battery, hydrogen, methane or other forms of power sources did not appear while building the questionnaire. This is to prevent the participants from having a preconceived perception of a specific power source in their mind (i.e. battery or hydrogen), while they are asked to assess the safety concern of EV. Hence, the answers from this survey can also represent the public awareness level of the hydrogen fuel vehicle.

In reality, the hydrogen fuel vehicle consists of a fuel tank to store the hydrogen and pass it to the fuel cell to generate electricity for the motor that powers the wheel. Therefore, it can be proposed that providing the state information regarding the hydrogen tank and the fuel cell to the driver is an effective way to negate the safety concern of such vehicle type, and hence effectively increase the public acceptance as well.

3.3 Drivers' knowledge factor influences

It can also be seen that driver's knowledge level is another major contribution to the safety perception regardless of vehicle types. Figure 3 indicates this phenomenon through the high frequency of the 'None' factor. The majority of participants claimed that it was difficult for them to come up with specific safety issues as they did not know/understand the vehicle itself as well as the integrated technologies well enough. Amongst all three types of vehicles, a proportion of these participants consider that the brand reputation reflects the safety and reliability of the vehicles to some extent.

Figure 5 shows that 74% (n=71) of the total participants considered the 'Make/Model' of the car as an important factor. Regarding general vehicle safety concerns, 58.3% (n=56) of the total participants concerned safety and 57.1% (n=32) of participants considered purchasing either German brands or brands that use German technologies (e.g. Volvo for safety reason). This shows that people tend to rely on brand reputation to judge the quality of the vehicles.

In addition to the common safety concerns (i.e. 'None', 'PSC' and 'Mechanical failure'), the 'Range Freedom' also has a significant influence of safety concerns for the solely EV (CF=32). This number is 5 times higher than for the HV (CF=6) and 10 times higher than for the IC vehicle (CF=3). This is due to the fact that the risk of out of charge/electricity and ease of recharging availability are considered under this factor. The results indicate that participants are mainly afraid of running out of charge for the EV and find difficulties in gaining access to a recharging port during their journey. This type of awareness and worry is based on the fact that the EV is powered by a battery (BEV) and although the current EVs meet the technical daily driving distance requirement already, the long-range journey has to be still planned carefully according to the charging infrastructure for BEV. On the other hand, the modern hydrogen-powered EV is able to easily reach a range of 300+ miles and has had a 5-min refuelling time since 2014. This shows that most participants are less sensitive to emerging technologies due to knowledge gap, and therefore this leads to an increase in worry and anxiety of the drivers while driving EVs.

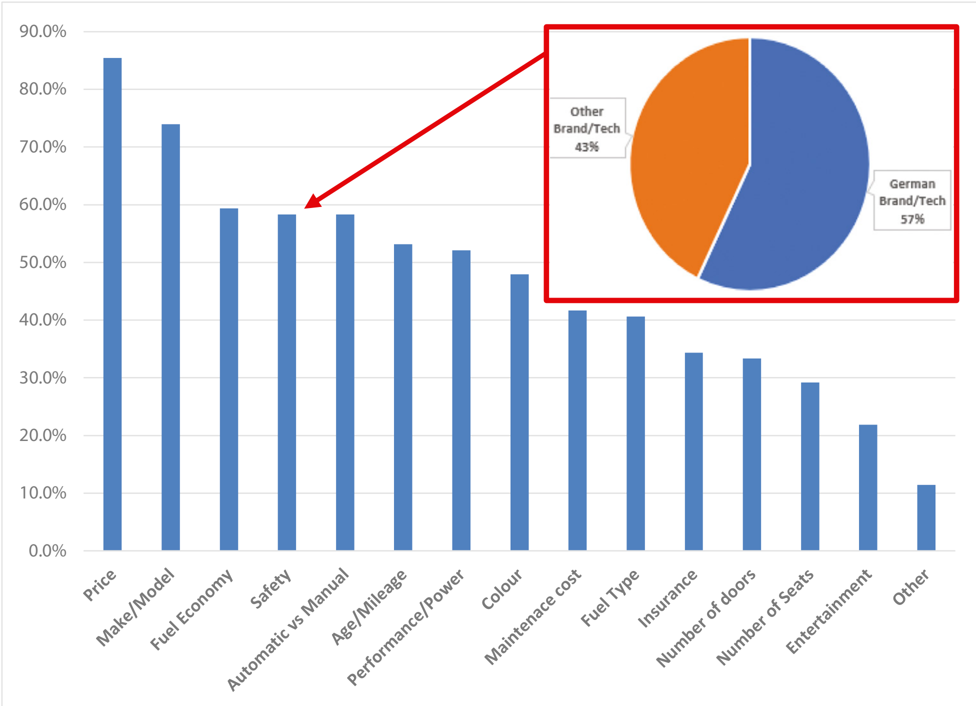

Figure 5: Participants' rating of the general purchase concerns in a descending order.

4 EV SAFETY PERCEPTION FRAMEWORK

4.1 Driver's evaluation chain of safety perception

The conducted survey results faintly suggest that there is a logical line behind the evaluation of the safety perception regarding hydrogen-fuelled vehicles. Figure 6 clearly illustrates this logic line in sequential order with respect to the events at each stage, from the driver's point of view.

Regarding the technology aspect, engineers are considered to be responsible for vehicle safety at the design and manufacture stage. In fact, engineers are more interested in achieving various standards (e.g. SAE-J2579 for vehicle electrical safety), and safety is considered as the risk for vehicle reliability. Therefore, an engineer's perception of safety is a numerically defined probability that can be measured. From the point of view of drivers, they are more interested in the potential safety margin whilst driving the vehicle. Hence, drivers consider

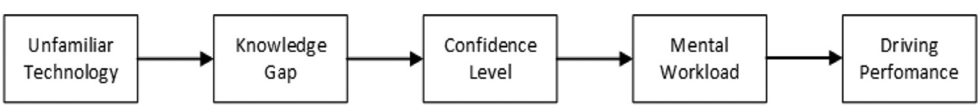

Figure 6: Safety perception evaluation chain.

safety as freedom from unacceptable risk, which is psychologically orientated. Therefore, a driver's safety perception begins with low technology familiarity compared to the engineers.

In the case of HV and EV, certain participants commented that they did not understand vehicle-related technologies, and thus, they lack the basic fix skills when considering the electrical aspect. As a result, these drivers have no confidence regarding EV safety. On the other hand, brand reputation will play an important role in terms of driver's confidence level. Previous studies stated that acceptance of an innovative technology depends on the trust in the providers who are responsible when the technology is not well-known by the public [19, 20]. Those dominated companies have professional developers and follow relatively high and restricted standards, and hence, they deserve a better trust and credibility. Expanding this trust concept, social-political acceptance can be increased by an increase in the advertisement investment and celebrity effect. Also, the official propaganda will not only increase the social acceptance but the trust and credibility of the EV technologies. All these factors will result in an enhanced familiarity of the technology to the public, and therefore, the root causes of the insufficient safety perception can be improved. As a result, the safety concerns of the hydrogen-fuelled vehicle will be negated.

The magnitudes of the negation depend on the performance improvement, which depends on the level of drivers' mental workload. The driver's mental workload will be improved if the confidence level is improved due to the increase in knowledge and familiarity with the technology. Therefore, the safety perception evaluation chain (Fig. 6) consists of a sequence of potential events in which the state of each event depends only on the state attained in the previous event.

4.2 Proposed safety perception framework

4.2.1 Applied Markov theory

The previous section summarised the psychological factors that affect the driver's confidence level. In this section, the identified factors are linked together to form a comprehensive framework in a format which is able to be analysed through the Markov theory. The framework is developed based on the theory of Markov chain, which is a famous probability theory developed by a Russian mathematician, Andrey Markov. He proposed and investigated a general schema that can be used to study natural processes using mathematical analysis methods. This theory has been proved to work well throughout a wide diversity of applications [21, 22].

This theory states that in a chain of event, such as the evaluation chain indicated in Fig. 6, each event (box) is memoryless, and the state of the next event depends only on the state of the current event, not the previous event. Therefore, in a Markov model, by knowing the state solely of a present event, a prediction can be made for the future state of a defined process. This is a complex mathematic theory, and only the fundamental level is applied to this study. In the case of the safety perception model, the state of a present event is represented by a matrix in the form as follows:

$$P = \begin{bmatrix} a_1 \\ \dots \\ a_n \end{bmatrix} \tag{1}$$

where P is the state matrix, 'a' represents the state while the subscripts '1' to 'n' indicate the number of possible states. In order to predict the next state, a transition probability matrix needs to be obtained, known as the Markov transition matrix, as eqn (2) indicates:

$$A = \begin{bmatrix} b_1 & \dots & n_1 \\ \dots & & \dots \\ b_n & \dots & n_n \end{bmatrix} \tag{2}$$

This transition probability matrix indicates that the probability of the present state is becoming one of the possible future states. The size of this matrix depends on potential future possibilities. Then the possibility of the future state can be determined by:

$$P_n = A \bullet P_{n-1} \tag{3}$$

4.2.2 Quantification procedure of the safety score

From the survey analysis, it can be seen that the 'trust and credibility' factor is affected by three aspects: the manufacturer's brand reputation, the technology developer reputation and the driver's familiarity of the developed technologies. Hence, 'trust and credibility' can be quantified through the following equation:

$$Trust\,score = Brand\,Reputation + Developer\,Reputation + Technology\,Familiarity \tag{4}$$

Each term on the left-hand side of the eqn (4) is calculated using eqns (1)–(3), respectively. The Markov transition probability matrix is obtained by post-processing the collected survey data and listed below:

$$A_{BR} = \begin{bmatrix} 0.61 & 0.48 \\ 0.39 & 0.52 \end{bmatrix}; A_{DR} = \begin{bmatrix} 0.57 & 0.53 \\ 0.43 & 0.47 \end{bmatrix}; A_{TF} = \begin{bmatrix} 0.54 & 0.55 \\ 0.46 & 0.45 \end{bmatrix}; \tag{5}$$

where the subscripts 'BR', 'DR' and TF' stand for 'Brand Reputation', 'Developer Reputation' and 'Technology Familiarity', respectively.

Based on the obtained transition probability, the following state-steady probabilities are calculated using eqn (3):

$$P_{BR} = \begin{bmatrix} 0.5517 & 0.4483 \end{bmatrix}; P_{DR} = \begin{bmatrix} 0.5521 & 0.4479 \end{bmatrix}; P_{TF} = \begin{bmatrix} 0.5455 & 0.4545 \end{bmatrix}; \tag{6}$$

At this stage, various meanings are assigned to each matrix with respect to safety scoring. For instance, P_{BR} matrix means that high-end brand vehicle scores 0.5517, and low-end vehicle scores 0.4483; P_{DR} matrix means that vehicles with better developer reputation scores 0.5521, and 0.447 9 is scored for vehicle with lower developer reputation; P_{TF} matrix states that driver who is familiar with the technologies scores higher while considering safety, and thus scores 0.5455. Those drivers who did not know the technologies have a lower score (i.e. 0.4545). It should be noted that in the automotive industry, car manufacturers are also often the technology developers. Hence, the calculated scores for the brand reputation and the developer reputations are very similar due to this fact.

In the end, the overall trust score can be calculated by adding the scores together according to the variously defined situations. To give an extreme example, if a driver knows nothing about vehicle technologies and driving a low-end brand car with integrated technologies from a developer who has a lower reputation, then the overall trust score is 1.3507 (i.e. 0.4483+0.4479+0.4545). In addition to this extreme case, there are seven additional combinations of eqn (6) that can accurately quantify the trust score for different situations.

4.2.3 Developing the overall safety perception framework

In section 4.2.2, the development procedure is demonstrated by applying the Markov transition probability to the 'trust and credibility' aspect. This concept can be expanded even further by considering a wide range of factors that affect safety performance. Figure 7 indicates the overall safety perception framework by considering and gathering various factors that have influences on safety performance. The orange text boxes indicate the two major aspects that influence the final safety perception score, and the green text boxes are the categories that need to be considered within these two aspects. Finally, light brown text boxes represent the individual factors that have been identified from the conducted survey.

Regarding the psychological confidence aspect, both social-political acceptance and appropriate knowledge level affects the overall assessment in addition to the demonstrated trust and credibility aspect. Well-established propaganda could be a good way to improve the knowledge level, and the social-political acceptance of hydrogen-fuelled vehicle will also be improved. Besides, an increase in the advertisements and celebrity effect will positively improve social acceptance.

In addition to the driver, vehicle reliability is another major aspect that needs to be taken into account while considering safety. In fact, most people believe today that automotive engineers should be responsible for vehicle safety, and manufacturers should provide safer and more reliable vehicles. From the conducted survey, it can be seen that the judgement of vehicle reliability from the general public relies on the design/model of the car, including powertrain, electrical and mechanical elements. Also, the survey results show that, for

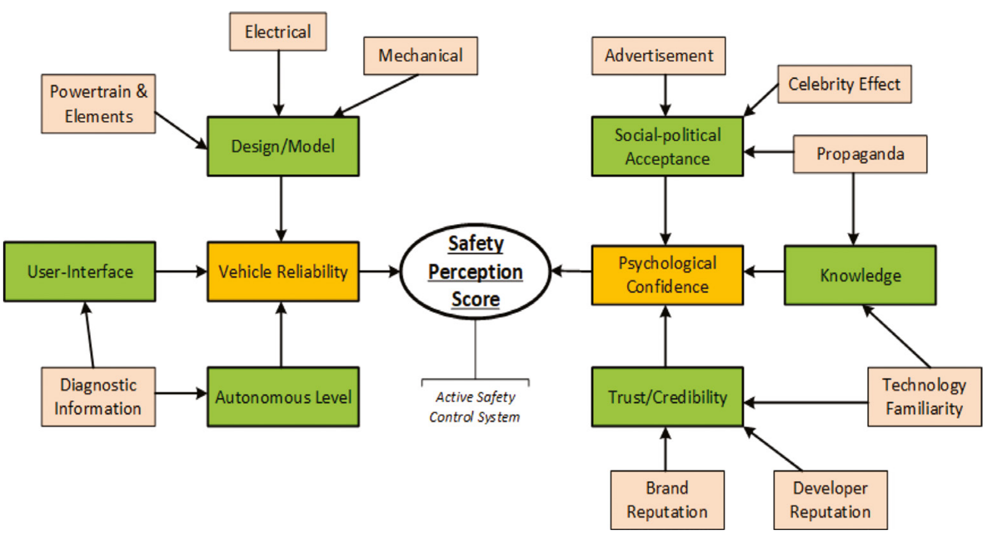

Figure 7: Proposed safety perception framework.

those drivers who do not really understand how a car functions, sufficient vehicle diagnostic information would enable an accurate assessment of the potential risks and the appropriate presentation of this information as well as the corresponding actions to help to negate the driver's safety concerns. Since autonomous vehicles are the future trend in the automotive industry, the level of autonomy also influences vehicle reliability. Therefore, this factor is included in the overall safety framework as well. For non-automated vehicle case, the score from this part is equal to zero.

Finally, a safety score can be calculated based on the present state of those identified factors. The proposed safety perception analysis could potentially become the foundation and backbone of an active safety control system.

4.3 Practical and policy implications

Nowadays, the concepts of smart transportation and smart mobility are becoming more and more familiar to the general public as well as the automotive industry. Road safety, at the moment, is an unavoidable topic that needs to carefully be considered as drivers themselves cause more than 90% of the road accidents. The design of the various active safety systems is on top of the research agenda. However, in order to develop a computation model that can predict and eliminate potential accidents, the numerical quantification of the term 'safety' and the correspondent factors is crucial. The proposed framework is able to determine a numerical value for the term 'safety' based on various factors, and thus, enables the potential ability to develop various computational models, such as driver's behaviour model.

Furthermore, due to the rapid growth of alternative fuelled vehicles, the policymakers need to modify the related policies to compensate for the potential safety issues caused by these alternative fuelled vehicles. In addition to the statistical data, these authorities also need some numerical simulation data to validate their decisions clearly. Also, it would be very beneficial for the decision-makers to access a model that is able to forecast the influence of applied rules or standards on road safety performance. All of these requirements need a numerical quantification of 'safety' in addition to the statistical data. Therefore, this proposed framework is able to act as the baseline prediction model of safety perception as it considers the sociological aspect as well as the technological aspect.

5 CONCLUSION

In this article, a quantitative survey was developed to investigate the public safety concerns of three types of vehicle powertrain: the IC engine, the hybrid electric and the solely EV. The root cause is the low familiarity with innovative vehicle technology. In terms of EVs, two specific aspects are ignored by the public at the moment: one is the specific safety risks regarding electronic circuits (e.g. high voltage of 350V) and other is that electronic components are not considered seriously; another potential aspect is that hydrogen-fuelled EVs (e.g. hydrogen or methane) are not widely accepted by the public and yet all the participants consider battery as the only power source.

The survey results also indicate that driving freedom is nowadays not just a problem of infrastructure only, but is gradually becoming a psychological issue in terms of increased driver's mental stress, and thus, the overall driving safety is affected. This is because of the lack of confidence whilst driving an EV, which also reflects the knowledge issue.

Furthermore, this article states the existence of an evaluation chain to determine the driver's safety perception. Within the evaluation chain, a sequence of potential factors appears, and the state of each factor depends only on the state attained in the previous factor. This characteristic of the chain enables the use of a Markov model to quantify the present and predict the future safety perception of the hydrogen-fuelled EV.

Last but not least, a comprehensive framework is developed to understand the negation of driver's safety concerns regarding the hydrogen-fuelled EV, based on the results from the survey and a review of psychological effects. This proposed framework explains the sociological barrier as well as the technological barrier and is able to act as the baseline prediction model of safety perception, especially for EVs.

ACKNOWLEDGEMENTS

This research is funded by the Engineering and Physical Science Research Council (EPSRC) through the Centre for Doctoral Training in Fuel Cells and Their Fuels at Loughborough University.

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