Hydrogen Fuel Cell Bus Driver Response in a Real World Setting: Study of a Northern California Transit Bus Fleet

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August 1st, 2014

Revised: November 15, 2014

Words: 3,080, Tables: 1, and Figures: 4
(Total: 4,330)

Abstract

This study examined the driver acceptance of a group of fuel cell-electric bus drivers with Alameda-Contra Costa Transit in the San Francisco Bay Area. A total of 48 drivers completed a written survey out of a total of 145 total surveys issued (i.e., a 33% response rate). The study focuses on a key attribute for potential success of alternative urban bus technology and that is the "driver acceptance" factor. Technology performance flaws that are undesirable or "annoying" to the bus drivers may also be disruptive to passengers. Furthermore, since drivers use the buses throughout their full duty cycle, they are in a unique position to identify key opportunities to improve the new technology options as they emerge and evolve.

Key findings from the study include that, in general, drivers rated the hydrogen fuel cell buses to be at the same or better performance in terms of handling, ride quality, acceleration, and braking. For quiet operation, they rated the new buses as excellent. When asked how they liked the experimental hydrogen fuel cell buses, the average response was just above neutral with the most common response being 'the same' as Diesel buses followed by 'much better'. Those drivers who consider fuel economy when purchasing a vehicle liked the fuel cell buses more. Older drivers preferred the Diesel buses while male drivers preferred the new fuel cell buses. Perceptions of safety were mixed, with some drivers expressing safety concerns irrespective of how much training they had received.

Key words: fuel cell, electric, transit bus, driver acceptance, energy, sustainability

Introduction

Various options for cleaner and more reliable propulsion systems for heavy-duty urban transit buses have emerged in recent years as alternatives to traditional Diesel engine buses. These include natural gas combustion engines, Diesel-electric hybrid systems, battery-electric drivetrains, and most recently fuel cell-electric drivetrains. Each has relative advantages and disadvantages, including the bus capital cost, emissions performance, maintenance cost and downtime, fueling requirements, and performance over the required duty cycle. For example, the combustion engine options tend to be lower capital cost but with higher lifecycle emissions, while the more advanced electric options tend to be higher capital cost and lower emission, and with potentially lower per-kilometer fuel costs [1]. However, previous studies have shown that driver acceptance can be variable among early adopters and experimenters for new vehicle technologies even if the overall experiences are positive (e.g., see [2] and [3]), and this may be important to their potential market uptake as those experiences are translated to larger groups of consumers.

This novel study focused on a key attribute for potential success of alternative urban bus technology, and that is the "driver acceptance" factor. Bus drivers are in contact with the bus technology for long periods of time and thus are uniquely positioned to understand key strengths and weaknesses in the technology, but curiously are rarely systematically surveyed with regard to new bus technologies. Technology performance flaws that are undesirable or "annoying" to the bus drivers may also be disruptive to bus passengers, and in any event do not bode well for the potential market uptake of the technology. Furthermore, since drivers actually use the buses throughout their full duty cycle, they are in a unique position to identify key opportunities to improve the "new technology" options as they emerge and evolve, to the extent possible relative to any key obstacles or issues for adoption.

The study examined the driver acceptance and opinions of a group of fuel cell-electric bus drivers with Alameda-Contra Costa Transit (AC Transit) in the San Francisco Bay Area. AC Transit has had a fleet of twelve hydrogen fuel cell buses in revenue service since 2008, building on an earlier program with three buses dating back to 2000 [4]. For this study 48 drivers completed a written survey with the assistance of university research personnel, out of a total of 145 total surveys issued (i.e., 33% response rate). The drivers were surveyed during the summer of 2013 and survey data were subsequently analyzed and reported here.

Background

A few previous fuel cell bus acceptance studies have been conducted including some related to passenger perceptions but also with at least two previous bus driver acceptance studies. In a "Clean Urban Transport for Europe" (CUTE) demonstration project, 5% of Stockholm bus drivers and 2% of Luxembourg, Hamburg, and London drivers considered the hydrogen fuel cell buses to be less safe than their Diesel engine counterpart. They also reported the braking to be of lesser quality by 59% in Stockholm and by 28% in Luxembourg, Hamburg, and London. The acceleration was found worse by 19% of drivers in Stockholm and 54% of drivers in Luxembourg, Hamburg, and London [5].

Second, in a study of "Midibus" fuel cell bus drivers in Germany, 22% were overall not satisfied with the performance of the vehicles while 44% were satisfied [6]. Drivers of Connecticut Transit fuel cell buses responded with a majority that found the braking to be comparable to Diesel engine buses. The majority also rated the acceleration as better or the same,

but one third found it to be worse. Vibration and noise were considered better or the same by nearly all [7].

Study Methodology

Survey data were collected through a written survey and results tabulated during the Summer and Fall of 2013. Descriptive statistics were generated using frequency breakdowns and means. Statistical tests were performed using regression for continuous outcomes and generalized linear models for discrete outcomes unless otherwise indicated. The software used for the statistical analysis is Data Desk by Data Description Inc. of Ithaca, New York.

The three-page written survey was distributed to drivers who had driven a hydrogen fuel cell bus in the last three months for AC Transit. This resulted in a study population of 145 fuel cell bus drivers that were eligible to participate. To some extent, it is clear that eligibility for the study is based on the drivers' voluntary decision to drive a fuel cell bus on a particular route. There is thus a potential "self selection bias" associated with this feature of the study, but this is mitigated by the fact that drivers are believed to have selected to drive the fuel cell buses based more on scheduling and routing considerations than their particular desire to drive a fuel cell bus rather than a conventional diesel bus. The authors are unsure of the impact of this potential self-selection bias on the results of the study.

Survey packets included a consent form that was to be read and initialed by the driver upon being given the packet. Completed surveys were either handed in or mailed in by the bus drivers. Drivers were provided with 15 minutes of pay for taking the survey, as a small incentive. The majority of the questions in the survey were of the multiple-choice type. Questions covered the route driven, the driver's perception of how passengers viewed the hydrogen buses, the driver's perception of safety, bus performance (handling, ride quality, acceleration, braking, quiet operation, and overall comparison of fuel cell buses to other buses driven), driver environmental perceptions, technology, and demographics.

The environment questions were designed to determine how important the environment was to bus drivers and how much effort they put into reducing their environmental footprint. The technology question was designed to reveal how knowledgeable and "ready to adapt" the drivers would be about recent technological advancements based on their purchase of new technology. A five-digit number was associated with each survey in order to ensure that no personal identifiers were attached to the surveys. There was an overall response rate of 33%, with 47 of the 145 drivers returning their surveys. This is a reasonable response rate by general survey standards, but we note that our study in the summer of 2013 coincided with a labor dispute between drivers and the agency and this likely depressed the response rate somewhat. Also the drivers only received a small incentive for participating (see "Study Limitations" below).

Study Results

The demographics of survey respondents are shown in Table 1 below, with regard to key personal and household characteristics. As shown, the study population is: 1) more male than female (heavily); 2) significantly older than is average in California and the U.S.; 3) with slightly larger households; and 4) a higher than average "high school or higher" but lower than average "Bachelor's degree or higher" rate than in California and the U.S. overall.

TABLE 1 Demographic results for drivers of hydrogen fuel cell buses

	Survey Sample	CA	U.S.
Percent female	28.9%	50.3%	50.8%
Age 50 or higher	63.6%	29.1%	32.1%
Average number of people living in household	3.3	2.9	2.6
Percent married	59.1%	48.6%	56.5%
Graduated high school or have higher level of education	95.6%	81.0%	85.7%
Bachelor's degree or higher	8.9%	30.5%	28.5%

Note: Based on 2010 U.S. Census data for California and U.S. figures.

Study results reveal that the bus drivers who responded to the survey are relatively conscientious about fuel economy with their personal vehicles. About 68% of the survey respondents take fuel economy into account at least somewhat when considering a vehicle purchase for themselves. They also appear to be willing to perform household recycling as 76% reported recycling regularly. Drivers generally agree that vehicle fumes and climate change are problems, as 86% agreed that these are significant issues.

The survey revealed that there is good driver approval for the handling, ride quality, and especially for the quiet operation of the fuel cell buses (Figure 1). The majority of drivers also approve of the acceleration and braking, but these were not rated as highly as the other bus characteristics (Figure 2).

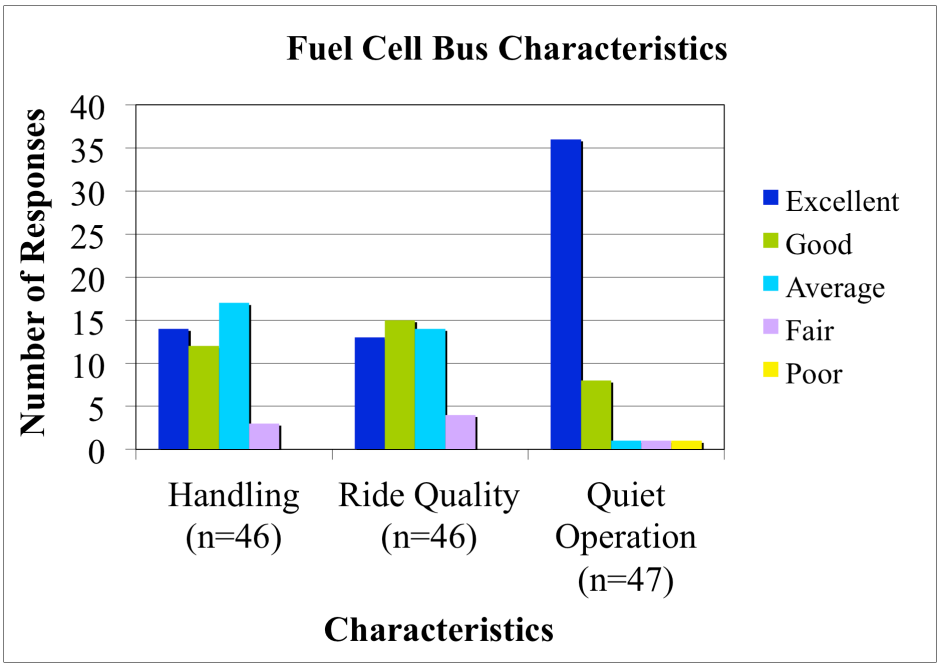

FIGURE 1 Driver evaluation of fuel cell bus handling, ride quality, and quiet operation

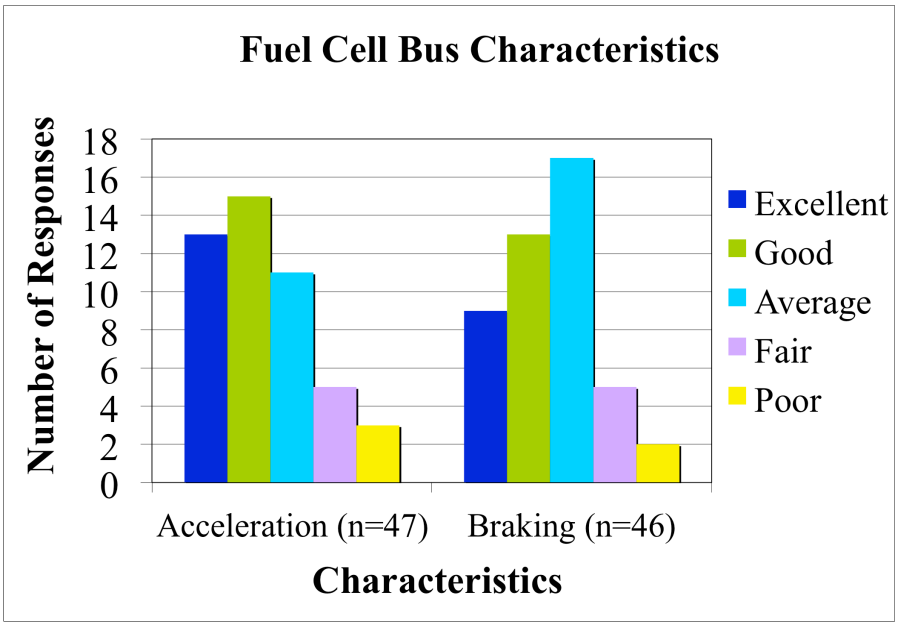

FIGURE 2 Driver evaluation of fuel cell bus acceleration and braking

Driver Perceptions of Hydrogen Fuel Cell Bus Safety

The driver responses to the environmental and technology questions were compared to responses to the question regarding driver perception of safety ('I feel as safe driving the fuel cell buses as I do driving the standard Diesel buses'). The most common or "mode" response for the safety question was "4", which correlates to an 'agree' response, but there is an average response of 3.1 that is more neutral (Figure 3).

We note that here and in the sections below we provide the "average" response to these ordinal Likert-scale responses as a general indicator but caution that there are issues with reporting averages across ordinal response scales. This is because the distances between the response categories on the Likert scale may not be consistent, depending on how each participant interprets the response categories. This is a common issue with ordinal-scale data analysis. However, given this caveat we believe the average response scores are still meaningful and generally the most useful from an interpretation perspective, along with graphs of data results showing the modal and overall distributions.

With regard to other correlations seen in the data set, when compared to responses for the question 'Traffic fumes are major contributor to global warming/climate change, smog, and/or other environmental problems' we find that the more drivers are concerned about the traffic fumes, the less safe they feel in the hydrogen fuel cell bus as compared to Diesel, even after adjusting for age, income, education, and gender (p=0.016). For example, those drivers that responded to traffic fumes with 'strongly agree' had an average response to the safety question of 2.5 (corresponding to feeling less safe), while drivers that responded with 'agree' had an average of 3.3 (corresponding to feeling more safe).

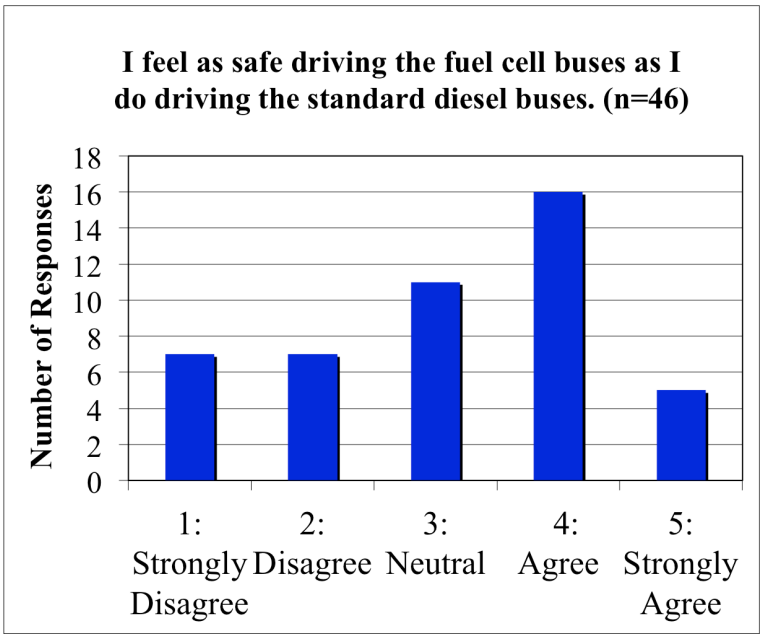

FIGURE 3 Driver perceptions of fuel cell bus safety

Furthermore, the more a driver was open to purchasing new technology, the safer they felt in the new hydrogen fuel cell buses, even when adjusting for age, income, education, gender, and vehicle fumes beliefs (p=0.016). For example, drivers that responded to the new technology question; 'When a new technology that I am interested in becomes available for purchase', with 'I rarely purchase new technologies before they become well established', had an average of 2.6 to the safety question (corresponding to feeling less safe). Drivers that responded with 'I am among the first people to purchase it', 'I buy it after reading a favorable review', or 'I buy it if a friend or colleague buys one first and likes it', had an average of 3.7 (corresponding to feeling more safe). The other environmental questions did not have a significant difference in response when compared to the safety question.

An important result is that there was no statistical relation at all to the perceived quality of driver training received and perceptions of safety in the hydrogen fuel cell bus (p=0.37). Thus, although much of the training was educational about the new hydrogen and fuel cell technology and its safety features, it was (apparently) largely ineffective in overcoming preconceived notions and perceptions. The result is somewhat in contrast to the findings in [2] where safety perceptions on refueling private vehicles were improved after a ride in the vehicle and witnessing a refueling. Thus there is a need to do systematic experiments on the effectiveness of specific hydrogen vehicle training programs and curriculum for both the commercial and private sectors of the transportation industry.

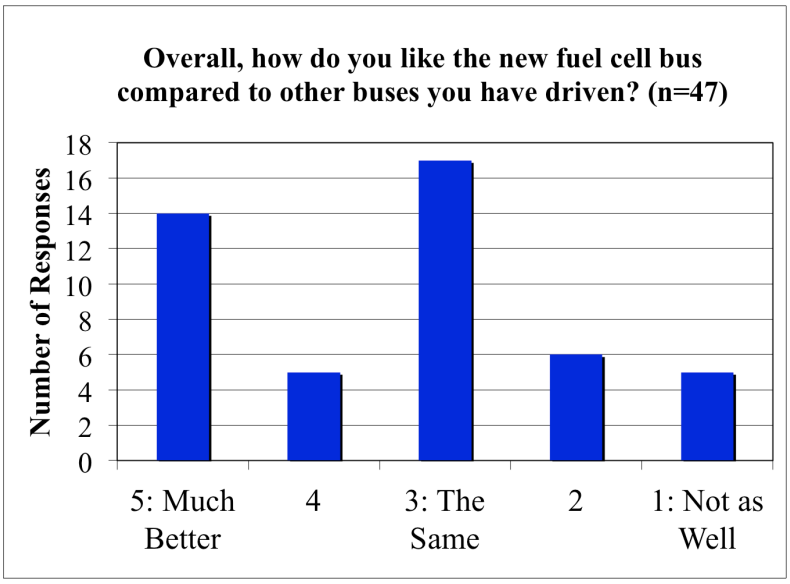

FIGURE 4 Driver responses to overall preference of hydrogen fuel cell buses to Diesel

Driver Perceptions of Overall Preference of Hydrogen Fuel Cell Buses

Responses to the question 'Overall, how do you like the fuel cell buses compared to other buses you have driven?' were also compared to responses to the environmental and technology questions. The overall bus performance question had an average response of 3.4 (Figure 4). Drivers who responded with 'strongly agree' to the 'traffic fumes' question had an average response to the overall bus preference question of 3.7, and drivers that responded with 'agree' had an average response of 3.0 (corresponding to neutral). However, this difference only suggests a trend, as there is no statistical significance (p=0.13, F-test).

We find that drivers that are more likely to consider fuel economy when purchasing personal vehicles are more likely to favorably rate the overall performance of the fuel cell buses. The more a driver considers fuel economy 'When purchasing a new or used personal vehicle', the more they like the hydrogen fuel cell buses over Diesel (p=0.031). This affect persists even when adjusting for age, education, gender, and feeling safe (p=0.026). Drivers that 'strongly agreed' to fuel economy being a 'major factor in choosing a vehicle' had an average response of 4.2 (corresponds to likes fuel cell bus better) to the overall like hydrogen fuel cell bus question, drivers that responded with 'agree' had an average response of 3.1 (corresponds to neutral), and drivers that responded with 'neutral', had an average response of 3.3 (just a bit above neutral).

Finally, age and gender are also predictive of preferring the fuel cell buses to conventional Diesel buses. Older drivers tend to prefer Diesel buses (p=0.011) and male drivers prefer the fuel cell buses over the Diesel buses by almost a full point more than females on the "1 to 5" rating scale (p=0.032).

Study Limitations and Caveats

This study entailed only a modest incentive for participation (15 minutes of paid time for the drivers who completed the surveys) and thus is a self-selected set of the population of drivers of hydrogen fuel cell buses. As shown in Table 1, the demographics of the sample differ significantly from California and the United States (U.S.) as a whole, and we do not know how

representative this sample of bus drivers is relative to the overall population of bus drivers in California or the U.S. To further limit the study's generalizability, these drivers are all from one small part of the world all driving only one model bus by one manufacturer.

Also, we note that the sample size is small with "n<100" and thus not very powerful. Although several findings are statistically significant, we suspect that more of the findings would have been significant with even a slightly larger sample size. Also due to the small sample size, statistical tests were done with the assumptions that the Likert responses are continuous, with equal distance between them, and that they are normally distributed (common assumptions for ordinal scale statistical analysis).

Conclusions

A survey of AC Transit drivers of twelve experimental hydrogen fuel cell electric drive buses was conducted and analyzed in this study. The survey contained questions about respondent demographics, attitudes, and perceptions of hydrogen fuel cell bus performance and safety. Most of the respondents were male, over 50, living with at least two other people, and at least graduated from high school. They also tended to consider fuel mileage when purchasing their own vehicle, recycle at home, and believed that vehicle fumes caused environmental and climate change issues. In general, they rated the hydrogen fuel cell buses to be at the same or better performance compared to conventional Diesel buses in terms of handling, ride quality, acceleration, and braking. For quiet operation, they rated the new buses as excellent.

In perceptions of hydrogen bus safety, the respondents have mixed reviews with almost an even distribution from the worst to the best. The average response correlates with the neutral response. Those who believed that traffic fumes are an environmental problem also rated the safety of the buses more poorly, but with no clear explanation for this correlation. Those who characterized themselves as early adopters of new technology felt safer in the hydrogen buses than the Diesel buses, an interesting and not entirely expected finding. There was no statistical relation for the perceived quality of driver training received and perceptions of safety in the hydrogen fuel cell bus (p=0.37). Thus, although much of the training was educational about the features of the new hydrogen/fuel cell technology and its safety features, it appears this was largely ineffective in overcoming preconceived notions. This indicates a need to do systematic experiments on the effectiveness of specific hydrogen vehicle training programs and curriculum for both the commercial and private sectors of the transportation industry.

When asked if the drivers liked the experimental hydrogen fuel cell buses more than their Diesel counterpart, the average response was just above neutral with the most common response being 'the same' and the second most common being 'much better.' Belief in vehicle exhaust being a significant environmental issue had no effect on how much a driver liked or disliked the fuel cell bus compared to Diesel buses. However, those who consider fuel economy when purchasing a vehicle tended to like the fuel cell buses more. In general, older drivers preferred the Diesel buses and male drivers preferred the new fuel cell buses.

Acknowledgements

The authors would like to thank Alameda-Contra Costa Transit, and Jaimie Levin and James Lair in particular, for their cooperation and assistance. Research funding support from the California Multi-Campus Research Programs and Initiatives (MRPI) program is also gratefully acknowledged.

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