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**Conventional and Electric Vehicles In Terms of Fuel Economy, Annual Fuel Cost, and Maintenance**

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**Abstract**

In this study, conventional vehicles (CVs) and electric vehicles (EVs) were compared statistically at 95% confidence level in terms of fuel economy (FE), annual fuel cost (AFC), maintenance frequency, and maintenance intensity. Electric Vehicles were hybrid electric vehicles, plug-in electric vehicles, fuel cell electric vehicles, and battery electric vehicles. The study examined samples of 3,028 CVs and 282 EVs from 2016 to 2018 models for FE and AFC assessments. Also, CVs with 65 maintenance events and EVs with 348 maintenance events from 2000 to 2016 were studied for maintenance frequency and intensity assessments. The FE and AFC comparisons were based on the consumer-reported data from the US Department of Energy and Environmental Protection Agency. The maintenance data were obtained from Idaho National Laboratory.

The results found that the means for FE of CVs were not significantly different between 2016 and 2017, or between 2017 and 2018 models. For EVs, the mean 2017 FE was better than 2016, but the means FE of 2017 and 2018 models were not significantly different. In addition, the mean FE of EVs was overall 74.19% higher than that of CVs. Moreover, the mean AFC of EVs was significantly lower (i.e., 47.68% less) than that of CVs. This study also introduced a formula to compute miles-per-dollar (MPD) from miles-per-gallon (MPG) and miles-per-gallon-equivalent (MPGe) values. Further, the mean frequency and mean intensity of maintenance per year of EVs were found to be approximately the same as those of CVs. Maintenance intensity was a reflection of the maintenance cost. Although, annual maintenance cost of EVs was 1.236% and CVs was 1.707% of their respective MSRP, but MSRP of EVs was higher than that of CVs. These findings may be useful for automotive industry in order to improve vehicle design and performance.

**Keywords**: Technology Management, Conventional Vehicles, Electric Vehicles, Fuel Economy.

**Introduction**

Conventional vehicles (CVs) are vehicles with internal combustion engines. In the US, most of these vehicles use gasoline as fuel. These vehicles have been around for about 140 years. Electrical vehicles (EVs) run with internal combustion engines ICEs and/or electric motor engines with battery packs (Aasness & Odeck, 2015). Today, automotive industries and their consumers are demanding more information on electric vehicles (EVs) because they are becoming more and more adopted due to the rising cost of gasoline and the effects of emissions from gasoline-powered vehicles on the environment (EPA, 2018a; NHSTA, 2018; Lin & Greene, 2011; Thomas, Huff, West, & Chambon, 2017; Wang, Fan, Zhao, Yang, & Fu, 2016; El- Sharkawy, Mourad, Salem, & Youssef, 2011; NRC, 2011). Scientists and environmentalists mostly have been concentrating on emission aspect of conventional vehicles (CVs). However, consumers always have a concern on EVs fuel economy (FE) and annual fuel cost (AFC). They have also expected to know more about EVs maintenance requirements and their costs compared to those of gasoline-powered CVs.

Many previous studies were carried out on life-cycle assessment, emission analysis, and industrial performance, and they had consistently offered some indication of better fuel economy for EVs (Feng & Figliozzia, 2012; Nordelöf, Messagie, Tillman, Söderman, & Mierlo, 2014). However, FE, AFC and maintenance combined had rarely been studied using comparative statistical analysis in industrial technology management area. Usually the FE had been recorded and reported per vehicle make and model (Chen J. S., 2015) but AFC and maintenance data were usually not identified for consumers on CVs and EVs. Moreover, most previous studies had utilized small sample sizes as they had mainly used simulations or model vehicles (Mirchandania, Adlera, and Madsenb, 2014; Karaki, Dinnawi, Jabr, Chedid, & Panik, 2015; Wang, Fan, Zhao, Yang, & Fu, 2016).

Research Problem

The lack of assessment and comparative studies with substantial samples on the quality of real-world CVs and EVs in terms of FE, AFC, and maintenance has been a current research problem in the vehicle and transportation industry (Pelletier et al., 2014). Therefore, the purpose of this study was to assess and compare the quality of CVs and EVs using FE, AFC, and maintenance data with large sample sizes.

Objectives of the Study

Specific objectives of the study were as follows:

1. to determine if FE of CVs had improved from one year to another as each year, technology of vehicles had been slightly advanced.

2. to investigate if FE of EVs had improved from year to year.

3. to see if AFC of EVs was less than that of CVs.

4. to find if the maintenance frequency (f) of EVs was less than that of CVs.

5. to determine if the maintenance intensity (I) in terms of cost of EVs was less than that of CVs.

Importance of the Study

The current study is significant as it used real-world consumer-reported data for fuel economy and annual fuel cost studies (see Fuel Economy Study, Annual Fuel Cost Study, and Inclusion and Exclusion Criteria sub-headings in the Methodology section). All reported data were used making sufficiently large samples. For maintenance study, a different data set was used. Vehicles with records of 1-4 years of accelerated driving that were systematically tracked, were used (see Maintenance Study and Inclusion and Exclusion Criteria sub-headings in the Methodology section). A novel and common consumer-friendly measuring unit miles per U.S. dollar (MPD) was used, which could be easily converted from both miles per gallon (MPG) and miles per gallon equivalence (MPGe).

**Methodology**

The study collected open-access consumer reported fuel economy data from the US Department of Energy and US Environmental Protection Agency (DOE, 2018), and maintenance data from Idaho National Laboratory (INL, 2018). The research population was passenger vehicles released from domestic and foreign automotive manufacturers in the United States of America to consumers. Three different studies were designed in this research. These were FE study, AFC study and maintenance study. FE study had two objectives; objective 1 for CVs and 2 for EVs (see above), AFC study was as per objective 3, and maintenance study had two objectives; objective 4 for maintenance f and objective 5 maintenance intensity (I) (see above).

For the hypothesis testing (Bader & Badar, 2017), following hypotheses were set.

Fuel Economy (FE) study as per objective 1

|  |
| --- |
| 1a: H0: $μ\_{CV 2016}-μ\_{CV 2017}\geq 0$ H1: $μ\_{CV 2016}-μ\_{CV 2017 }<0$ |
| 1b: H0: $μ\_{CV 2017}-μ\_{CV 2018}\geq 0$ H1: $μ\_{CV 2017}-μ\_{CV 2018 }<0$ |
| FE as per objective 22a: H0: $μ\_{EV 2016}-μ\_{EV 2017 }\geq 0$ H1: $μ\_{EV 2016}-μ\_{EV 2017}<0$ |
| 2b: H0: $μ\_{EV 2017}-μ\_{EV 2018 }\geq 0$ H1: $μ\_{EV 2017}-μ\_{EV 2018 }<0$ |

Annual Fuel Cost (AFC) study as per objective 3

3: H0: $μ\_{EV}-μ\_{CV}\geq 0$

 H1: $μ\_{EV }- μ\_{CV }<0$

Maintenance study

4: Maintenance Frequency:

 H0: $μ\_{f\_{EV failures}}- μ\_{f\_{CV failures}}\geq 0$

 H1: $μ\_{f\_{EV failures}}- μ\_{f\_{CV failures}}<0$

5: Maintenance Intensity:

 H0:$ μ\_{I\_{EV failures}}- μ\_{I\_{CV failures}}\geq 0$

 H1: $μ\_{I\_{EV failures}}- μ\_{I\_{CV failures}}<0$

Fuel Economy StudyThe samples for FE study were the consumer-reported fuel economy data of model years 2016, 2017, and 2018 conventional and electric vehicles (DOE, 2018). The target population of N2016 FE = 2585, N2017 FE = 2573, and N2018 FE = 2648 was comprised of vehicle types – gasoline-run conventional vehicles (CVG), hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), fuel cell electric vehicles (FCEV), and all electric or battery electric vehicles (EVBEV). The open-access fuel economy data came from a website (DOE, 2018), which is a part of DOE and EPA both, thus reliable and valid. The target population was with three FE estimates: a city estimate, a highway estimate, and a combined estimate. Fuel economy estimates were measured in MPG or MPGe as formulated by EPA (DOE, 2018). The population did not include sport utility vehicles (SUVs) and passenger vans with a gross vehicles weight rating (GVWR) i.e. vehicle weight plus carrying capacity of more than 10,000 lb (DOE, 2018). The inclusion and exclusion criteria have been explained after the FE, AFC, and maintenance studies data.

The target populations of vehicles have been mentioned above. However, not all consumers report their fuel economy data. Hence, the samples used in this study consisted of the consumer-reported data, which were for 973 CVs and 92 EVs from 2016, 1015 CVs and 90 EVs from 2017, and 1,040 CVs and 100 EVs from 2018. Thus, a total of 3,028 CVs and 282 EVs were analyzed. The collected samples were organized by model, type, size, class, mode, city FE, highway FE, and combined FE. Finally, CVs and EVs in terms of combined FE for each of the three model years were used for comparison in this study. Overall the data were comprising the number of conventional and electric vehicles as follows.

1. 2018 (CVG = 1040, EV = 100 = [HEV = 40+PHEV = 33+ FCEV = 4+EVBEV = 23])

2. 2017 (CVG = 1015, EV = 90 = [HEV = 37+PHEV = 19+FCEV = 5+EVBEV = 29])

3. 2016 (CVG = 973, EV = 92 = [HEV = 40+PHEV = 18+FCEV = 4+EVBEV = 30])

The FE for CVs was measured in miles per gallon (MPG), and for EVs in MPG and/or miles per gallon equivalent (MPGe) depending on the mode of driving. In case of driving on electrical charging, kWh per 100 miles is recorded and is converted to MPGe as per the formula in EPA (2018b). As the measurement units differed by type of vehicle, it was necessary to transform them into a common measurement unit, MPD. The average MPGe/MPG factor was first calculated from combined FE samples. The factor was then first used to transform MPG to MPGe units. MPGe units for EVs were subsequently transformed to MPD using the equation derived in Morgan (2019).

$MPG or MPGe×\frac{1}{fuel price/gallon}= miles per dollar= MPD$

Refer to ‘Inclusion and Exclusion Criteria’ sub-heading later to note that the fuel price was $2.86 per gallon based on Arizona. The MPGe/MPG factors for 2016, 2017, and 2018 data set were as shown in Table 1. For CVs, MPG divided by fuel price per gallon yielded MPD. For electric vehicles, two units MPG and MPGe both were used depending on the mode. For EVs, MPG was converted to MPGe by the factor in Table 1.

**Table 1.** MPGe/MPG Factors

|  |  |
| --- | --- |
| Sample | MPGe/MPG |
| 2016 | 2.3430 |
| 2017 | 2.3938 |
| 2018 | 2.4107 |

The FE data measured in MPD were analyzed in Minitab 18 for descriptive statistics, normality, outlier threat for distribution, equal variances, and two-sample t-test with hypothesis testing at 95% confidence level. A summary of the results of these analyses are shown in the results section. For in-depth results including normality, outlier, and variance tests, refer to Morgan (2019).

Annual Fuel Cost Study

This study utilized the same samples described in the fuel economy study, where the combined highway and city FE values were converted to MPD. From the MPD, annual fuel cost (AFC) values for CVs and EVs for 2016, 2017, and 2018 were obtained. The AFC data were then analyzed in Minitab 18 for descriptive statistics, normality, outlier threat for distribution, equal variances, and two-sample t-test with hypothesis testing at 95% confidence level. Also, average manufacturer suggested retail price (MSRP) and vehicle depreciation (VD) were calculated. A summary of the results of these analyses are shown in the results section. For in-depth results including normality, outlier, and variance tests, refer to Morgan (2019).

Maintenance Study

The samples were collected from Idaho National Laboratory (INL, 2018), which is a part of DOE having CVs with 65 maintenance events and EVs with 348 maintenance events from 2000 to 2016. Thus, maintenance incidents n = 65 for CVs and n = 348 for EVs were tracked under accelerated driving and normal environmental patterns. The data were organized by model, type, size, class, frequency, and intensity according to tracked years. The collected frequency (f) and intensity (I) data came from tracked maintenance of failures and costs of failures on accelerated driven vehicles at the rate of one accelerated-driven year was equal to three normally driven years. The frequency referred to the number of failures or maintenance events. The intensity referred to the impact of the failures or maintenance events on the vehicle system, measured by cost. Cost is a better measure of failure (Guinot, Sinn, Badar, & Ulmer, 2017). The higher the cost of maintenance of a failure in a vehicle system, the higher the intensity or impact of the failure is on that system.

Inclusion and Exclusion Criteria

Only CVs using gasoline fuel, HEVs and PHEVs using gasoline and electrofuel, FCEVs using hydrogen fuel, and EVs (i.e., BEVs) using electrofuel were considered. Conventional vehicles using diesel fuel (CVD); natural gas vehicles (NGVs) using natural gas fuel, also known as compressed natural gas (CNG); flexible fuel vehicles (FFVs) using ethanol; and propane vehicles (PVs) using propane gas were not considered in the FE and AFC studies (DOE, 2018). But in the maintenance study some of these types were also included (INL, 2018).

Only common market vehicle classes for EVs and CVs were used in the FE and AFC studies since they showed smaller standard deviations (DOE, 2018). The common market vehicle classes were small cars, family sedans, upscale sedans, luxury sedans, hatch backs, coupes, convertibles, sports, station wagons, SUV under 10,000 lbs., and minivans.

The average fuel price was used as $2.86/gallon for regular unleaded gasoline in the state of Arizona (DOE, 2018).

For maintenance study, data were obtained from Advanced Vehicle Testing (INL, 2018). The tracking period for maintenance and repair varied from one to four years during 2000-2016 period. The vehicles went through accelerated driving (one-year accelerated driving was equivalent to three-year normal driving) with driven mileages from 36,000 to 225,740 miles, depending on the engine or battery system. Therefore, 1-4 years of systematically tracked accelerated driven cars’ maintenance data were equivalent to a 3-12 years of normally driven cars’ maintenance data with 12000 – 18000 miles a year.

Results

This research analyzed 3,028 CVs and 282 EVs using self-reported data by consumers, adjusted by the EPA and DOE for 2016-2018 vehicle models. It also examined data of 65 maintenance events of CVs and 348 of EVs selected within accelerated driving and normal environmental conditions that were tracked from 1 to 4 years by the Idaho National Laboratory from 2000-2016 for the maintenance study. Hypothesis 1, 2, 3, 4, and 5 were tested at the 95% confidence level and findings were as follows. The hypothesis testing results are also summarized in Table 2.

* Hypotheses 1(a) and 1(b) tested whether there was significant improvement of mean FE in newer CV models over that of older CV models comparing 2016 vs 2017 and 2017 vs 2018. The null hypotheses 1(a) and 1(b) were not rejected; the means of FE of CVs of older models were approximately the same or slightly greater than that of newer models with no statistically significant difference.
* Hypotheses 2(a) and 2(b) examined whether there was significant improvement of mean FE in newer EV models over that of older EV models comparing 2016 vs 2017 and 2017 vs 2018. Null hypothesis 2(a) was rejected; the mean FE of 2016 EVs was significantly less than that of 2017. However, null hypothesis 2(b) was not rejected; the mean FE of 2018 EV models was approximately the same or slightly greater than that of 2017 EV models with no statistically significance difference
* Hypothesis 3 tested if the mean AFC of EVs was less than that of CVs from the customer perspective with consideration to MSRP and vehicle depreciation. Null hypothesis 3 was rejected; the mean AFC of EVs was significantly lower than that of CVs.
* Hypothesis 4 examined whether the failure modes of EVs and their effects were less frequent than those of CVs. Null hypothesis 4 was not rejected; the failure modes and their effects for EVs were relatively more frequent or equal to those of CVs.
* Hypothesis 5 tested if the failure modes and their effects for EVs were less intense than those of CVs. Null hypothesis 5 was not rejected; the failure modes and their effects for EVs were more intense or equal in terms of repair cost to those of CVs.

**Table 2.** Summary Findings of Hypothesis Testing: T-Test

|  |  |  |  |
| --- | --- | --- | --- |
| Hypotheses | P Value | Result | Interpretation |
| 1a: FEH0: $μ\_{CV 2016}-μ\_{CV 2017}\geq 0$H1: $μ\_{CV 2016}-μ\_{CV 2017 }<0$ | **0.350** | Not enough evidence to reject H0 | Not significantly less |
| 1b: FEH0: $μ\_{CV 2017}-μ\_{CV 2018}\geq 0$H1: $μ\_{CV 2017}-μ\_{CV 2018 }<0$ | **0.473** | Not enough evidence to reject H0 | Not significantly less |
| 2a: FEH0: $μ\_{EV 2016}-μ\_{EV 2017 }\geq 0$H1: $μ\_{EV 2016}-μ\_{EV 2017}<0$ | **0.030** | Enough evidence to reject H0 | Significantly less |
| 2b: FEH0: $μ\_{EV 2017}-μ\_{EV 2018 }\geq 0$H1: $μ\_{EV 2017}-μ\_{EV 2018 }<0$ | **0.845** | Not enough evidence to reject H0 | Not significantly less |
| 3: AFCH0: $μ\_{EV}-μ\_{CV}\geq 0$H1: $μ\_{EV }- μ\_{CV }<0$ | **0.000** | Enough evidence to reject H0 | Significantly less |
| 4: Maintenance FrequencyH0: $μ\_{f\_{EV failures}}- μ\_{f\_{CV failures}}\geq 0$H1: $μ\_{f\_{EV failures}}- μ\_{f\_{CV failures}}<0$ | **0.752** | Not enough evidence to reject H0 | Not significantly less |
| 5: Maintenance IntensityH0:$ μ\_{I\_{EV failures}}- μ\_{I\_{CV failures}}\geq 0$H1: $μ\_{I\_{EV failures}}- μ\_{I\_{CV failures}}<0$ | **0.571** | Not enough evidence to reject H0 | Not significantly less |

Tests of these hypotheses served to fulfill objectives 1 through 5. Concerning objective 1, the FE finding revealed that the means of CV FE displayed a slight positive trend from 2016 to 2017, and from 2017 to 2018, as shown in Figure 1, but these were not significantly different (see Table 2). In the case of objective 2 for EVs, there was a significant positive trend in FE from 2016 to 2017, followed by a non-significant negative trend from 2017 to 2018, as displayed in Figure 2. Comparing CV vs EV in terms of FE: as demonstrated in the MPD data shown in Table 3, the CVs averaged eight miles per dollar spent for fuel, whereas EVs averaged 31 miles per dollar spent on fuel. In other words, CVs demonstrated only 25.81% of EVs’ fuel economy. See Figures 3 and 4.



**Figure 1**. Line Plot of Mean CV FE Trend



**Figure 2**. Line plot of mean EV FE trend

**Table 3.** Descriptive statistics: 2016, 2017, and 2018 CV and EV MPD

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable | Total Count |  | Mean | StDev | Variance |
| 2016 CV MPD | 973 |  | **8.0779** | 1.6905 | 2.8576 |
| 2016 EV MPD | 92 |  | **30.674** | 7.249 | 52.542 |
| 2017 CV MPD | 1015 |  | **8.1074** | 1.7245 | 2.9740 |
| 2017 EV MPD | 90 |  | **32.915** | 8.672 | 75.197 |
| 2018 CV MPD | 1040 |  | **8.1126** | 1.6756 | 2.8077 |
| 2018 EV MPD | 100 |  | **31.671** | 9.717 | 94.411 |

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |



**Figure 3.** Interval plot of 2016, 2017 and 2018 CV MPD



**Figure 4.** Interval plot of 2016, 2017, and 2018 EV MPD

Objective 3: Determine if the AFC of EVs was less than that of CVs.

Hypothesis 3 tested whether the mean AFC of EVs was less than that of CVs from the customer perspective if MSRP and vehicle depreciation were considered. Null hypothesis 3 was rejected (see Table 2); the mean AFC of EVs was significantly less than that of CVs (see Figure 5). The AFC finding further revealed that EVs on average saved 47.68% of AFC when compared to CVs. However, the average EV MSRP was 27.40% higher than that of average CV MSRP, which also indicated that EVs would maintain the same percentage of vehicle value higher than CVs even 10 years after the date of sales, as shown in Tables 4 and 5.



**Figure 5.** Interval plot of EV and CV AFC

**Table 4.** Descriptive statistics: EV and CV MSRP

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable | Total Count | Mean | StDev | SE Mean |
| EV MSRP | 282 | **87734** | 593229 | 35326 |
| CV MSRP | 3028 | **63697** | 103504 | 1881 |

**Table 5.** Descriptive statistics: EV and CV vehicle depreciation in 10 years

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable | Total Count | Mean | StDev | SE Mean |
| EV VD 10 Yrs. | 282 | **8773** | 59323 | 3533 |
|  |  |  |  |  |
| CV VD 10 Yrs. | 3028 | **6485** | 10583 | 192 |

It has been described in the methodology section that the data for maintenance study to test hypotheses 4 and 5 were different and taken from INL (2018). The mean MSRP for EVs was $28,482 according to the maintenance study data (see Figure 6). This study determined the mean EV maintenance cost to be $1,056 per accelerated year (see Table 6, 2nd column, intensity converted to cost). Thus, the maintenance cost of EV presented 3.7076% of their investment value per one accelerated-driving year or 1.2359% per normal-driving year (see Figure 6). In 10 years, EVs would spend 12.359% of MSRP. Meanwhile, for CVs, mean MSRP was $23,530, with annual accelerated maintenance costs of $1,205 (see Table 6, 2nd column). Thus, the maintenance cost per accelerated-driving year for CVs was 5.1211% of investment value or 1.7070% of investment per normal-driving year (see Figure 7). In 10 years, a CV would spend 17.070% of MSRP.

**Table 6.** Descriptive statistics: EV and CV frequency and intensity of failures

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable | Total Count | Mean | StDev | CoefV |
| EV Frequency (f) of Failures | 348 | **6.152** | 4.807 | 78.14 |
| CV Frequency (f) of Failures | 65 | **5.738** | 4.417 | 76.97 |
| EV Intensity (I) of Failures | 348 | **1056.2** | 1178.3 | 111.56 |
| CV Intensity (I) of Failures | 65 | **1205** | 1265 | 105.00 |



**Figure 6.** Pie chart for electric vehicles MSRP and maintenance cost



**Figure 7.** Pie chart for conventional vehicles MSRP and maintenance cost

Objectives 4 and 5: Investigate if the maintenance frequency and intensity of EVs were less than that of CVs.

Hypothesis 4 tested whether the failure incidents for EVs were less frequent than those of CVs. Null hypothesis 4 was not rejected; the failure incidents for EVs were not less frequent than those of CVs (see Figure 8). Null hypothesis 5 concerning maintenance intensity or cost was not rejected; the failure incidents for EVs were not less intense than those of CVs (see Figure 8).



**Figure 8.** Interval plots of EV and CV maintenance intensity and frequency

Conclusions

This research studied the real data reported randomly by consumers on fuel economy and statistically compared across all available vehicle types. The samples were derived from the common market vehicle classes. The novel and common measuring unit, MPD, offers the consumers a clear understanding of their investment in fuel per dollar and a great convenience in comparing CVs and EVs, as MPG and MPGe can now convert into one single unit. For maintenance study, a different data set comprising vehicles with records of 1-4 years of accelerated driving were used.

Conventional vehicles have improved in fuel economy (FE) along with their improvement in vehicle technology as reported in (Gustafsson & Johansson, 2015). The finding in this research, however, concluded that the FE did not improve in CVs. The fuel economy trend for CVs from 2016 to 2018 increased overtime, but these increments were minor and not statistically significant. The FE of EVs was also expected to have improved with their technology (Galus, Zima, & Andersson, 2010). The results revealed that there was a significant increase in FE of EVs from 2016 to 2017; however, the difference between 2017 to 2018 EV models was not statistically significant. Comparing EVs vs CVs, it is important to note that EVs demonstrated a fuel economy benefit of 74.19% over CVs in miles per dollar spent on fuel. With advancement in technology, conventional and electrical both vehicles should improve in fuel economy (i.e. should give better miles per dollar) from a model year to next model year. The findings based on the consumer-reported data in this work for model year 2016 to model year 2018 were different and in disagreement with fuel economy improvements reported in (EPA, 2018a; NHSTA, 2018). This opens up a possibility for further study to investigate the reasons. The data collected for this study were reported randomly by consumers and may not be representative of the two model year populations of vehicle drivers. Also, self-reported fuel economy values are highly variable, and at least some values are suspect (Lin & Greene, 2011). Part of the variability could be differences in climate, terrain, city/highway fraction of distance driven, difference in the mix of makes/models/trim levels.

Average annual fuel cost (AFC) of EVs should be less than that of CVs (DOE, 2018). This study confirmed that this expectation was statistically true. EVs were spending 47.68% less on fuel for driving than CVs, nearly half of CVs’ fuel expense. This finding is in agreement with NRC (2011) that hybrids and plug-in vehicles are more efficient than comparable conventional vehicles powered by internal combustion engines. However, the current work observed that the average MSRPs for EVs were 27.40% greater than that of CVs.

Concerning maintenance study, frequency of failures for EVs is expected to be less than that of CVs due to lack of ICE (internal combustion engine) in BEVs, or alternative use of ICE in HEVs, or PHEVs. Previous studies have suggested that the intensity of failures of EVs might be greater than that of CVs due to expensive high voltage batteries (Carroll, 2010). The research findings concluded that they were as frequent and as intense as those of CVs statistically. This may be because maintenance centers scheduled EVs at the same rate as CVs, or the greater number of electric control modules for EVs could create the same amount of complications as in CVs’ ICE. Previous studies have assumed the maintenance cost for an EV to be 40% of the investment cost, and 30% less than that of CVs (Salisa, Walker, Zhang, & Zhu, 2015; Mitropoulos, Prevedouros, & Kopelias, 2017). This study found that the maintenance cost of EVs was 1.2359% of the investment value per year. Meanwhile, for CVs, the maintenance cost per year was 1.7070% of the investment value per year. Accelerated annual maintenance cost for EV was $1056 while for CV it was $1205.

In conclusion, overall, the average fuel economy of electric vehicles was 74.19% higher than that of conventional vehicles. The average annual fuel cost of electric vehicles was 47.68% less than that of conventional vehicles. However, the average frequency and intensity of maintenance of electric vehicles were found to be approximately the same as those of conventional vehicles. This research offers important findings that can benefit vehicle manufacturers, maintenance centers, vehicle dealerships, consumers, applied engineering and technology students and professionals, and quality programs. These findings can also help consumer awareness and future transportation transitions from CVs to EVs (Jin & Slowik, 2017).

In this work aggregate data were compared for fuel economy and annual fuel cost. The study has tried to address an important research question concerning the maintenance costs too. However, in the future work, comparison should be made in terms of highway, city, etc. for each class and model of vehicles separately. Also, it would be better to normalize in terms of MSRP and then compare. Comparisons between CVs, HEVs, and plug-in electric vehicles should be made pair-wise, comparing comparable CVs and HEVs, comparable CVs and PHEVs, comparable CVs and FCEVs, or comparable CVs and BEVs, at the make/model/trim levels or within size class/body styles, not comparing averages of fuel economy, fuel costs or maintenance costs of CVs and HEVs, etc. The range of fuel economy and fuel costs between different makes/model/trims can be wider than the difference between averages. When comparing across model years, values for each individual make/model/trim level (or size class/body syle) should be compared across years, not averages of many makes/models/trims.

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