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Shabnam Razeghian Jahromi
Portland State University

Anca-Alexandra Tudori
Delft University of Technology

Timothy R. Anderson
Portland State University, tim.anderson@pdx.edu

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Forecasting Hybrid Electric Vehicles using TFDEA

Shabnam Razeghian Jahromi[1], Anca-Alexandra Tudori[2], Timothy R. Anderson[1]
[1]Dept. of Engineering and Technology Management, Portland State University, Portland, OR - USA
[2]Delft University of Technology, Delft, Holland

***Abstract*--The Toyota Prius was introduced in Japan fifteen years ago and over 60 additional hybrid electric vehicles automobiles and redesigns have been brought to the market around the world since that time. There is major interest in future of the electric cars as using "the alternative fuel" can significantly decrease the environmental and fuel dependency concerns. This work has used data envelopment analysis to forecast the future of hybrid electric cars. It is based on a previous research on the same subject with an improvement in input-output model that has enhanced the outcomes to a great extent. The former study applied technology forecasting for both full-battery and hybrid electric cars. This research focuses on hybrid electric vehicles only and improving the model for battery electric cars will be a subject for future research. The dataset is the same as the one used in former research with some additional parameters that are gathered from manufacturers' websites and other relevant resources.**

I. INTRODUCTION

Pressing environmental concerns and increased dependency on oil imports have revived interest in developing electric vehicles in the 1960s and 1970s [1]. Increased manufacturing possibilities enabled by technological breakthroughs over the past two decades, combined with stringent environmental regulations, such as the 'Zero Emissions Vehicles (ZEV) Act' released by the California Air Resources Board in 1990, brought electric cars back on the market in the mid 1990s [2], [3]. Recent policies and goals set by U.S government like putting one million electric vehicles on the road by 2015 and significant tax credit for EV owners have brought attention to these vehicles more than ever [4].

Electric vehicles (EVs) can be broadly categorized as "full-electric" (i.e. using only a battery and an electric motor for propulsion) and "hybrid-electric" (i.e. combining the conventional internal combustion engine with an electric motor and battery). Most of the big car manufacturers will have released over the past 15 years battery electric (BEV) and/ or hybrid electric vehicles (HEV) which are commercially available under different purchasing and leasing conditions. Despite the increasing trend in number of electric vehicles on the market, the overall percentage of electric vehicles on the road is still very small [5] due, mostly, to price related factors, performance, infrequency in charging stations, and consumers' reluctance to embrace the new technology [2]. Electric vehicle technology is progressing every year in terms of better driving range and higher fuel economy. The range anxiety caused by pure electric vehicles has been eliminated by advent of hybrid electric cars. The fuel economy of the hybrid cars are greatly improved in plug-in hybrids that have the possibility of recharging their battery by an external grid.

The significant contribution of Electric vehicles in decreasing both oil dependency and CO2 emission have made them a hot topic and their technological trend in future is now one of the main discussions [6],[7],[8]. Although there are different opinions on when EVs will reach the point to replace gas engine vehicles in a greater scale, a common view point is that once EVs become less expensive, charging batteries become more convenient and performance factors like driving range improves, they will with no doubt have a disruptive impact on society and on the whole car manufacturing market [9].

What is the technology trend of electric vehicles and does any of the existing designs have the potential to dominate the electric vehicle market in future? The answers to these questions are now very critical for the main game players in the car industry.

In 2012, Alexandra Tudorie, as her Master thesis, applied Technology Forecasting using Data Envelopment Analysis (TFDEA) to predict the future of EV technology and determine whether any of the existing designs will be preferred over the others in market [16]. In her study the TFDEA model failed to provide acceptable results and the forecasts did not seem to be realistic. Similar to ill-chosen independent variables causing problems in linear regression [10], the accuracy of prediction in TFDEA is highly dependent on choosing the right parameters in the model [11]. However, unlike regression that has well-defined procedures like step wise regression to build the right model and also to diagnose its accuracy, there is no step by step method in selecting the proper parameters in TFDEA. Building the proper model in TFDEA is an iterative process in which the different sets of parameters proposed by the experts in the field are selected until the right model that yields acceptable results is built. The current study revises the model that Tudorie used, to find out whether enhancing the model can improve the accuracy of the TFDEA forecasts in EV industry. The results indicate that some changes in input and output parameters can significantly affect the accuracy of predictions and TFDEA can in fact be a reliable forecasting tool for the technological progress of electric vehicles.

II. RESEARCH METHODOLOGY

Technology forecasting is a method done by companies to predict the future trend of a specific product or technology in order to ensure their dominance in the market [11]. TFDEA is a forecasting tool that uses Data Envelopment Analysis

(DEA) and leverages the benefits that DEA brings. DEA is a powerful method for performance measurement and benchmarking using frontier method [11], [12] and has been extensively applied in organizational benchmarking [13]. DEA uses a dataset including data points or Decision Making Units (DMU), as in DEA terminology, and identifies the best performers by calculating the relative efficiency of the DMUs in the dataset. It then evaluates the performance of the other entities by comparing them against the best performers. This is a strong advantage compared to conventional methods like regression analysis that averages over all observations and does not allow identifying extreme points[11]. .Moreover, DEA can incorporate multiple parameters in measuring the performance which is very useful in fields like EVs where there are several performance measurements that are important e.g. high acceleration rate and high fuel economy. Such characteristics have made TFDEA a strong forecasting tool that can be applied in predicting the trend of products where multiple performance indicators are imposed by different markets of the technology under study. TFDEA is, however, very sensitive to selection of input and output parameters. Therefore it is essential to build a model with the proper set of parameters [11]. Figure 1 illustrates a general DEA model with multiple input and outputs and Equation 1 shows how efficiency is calculated.

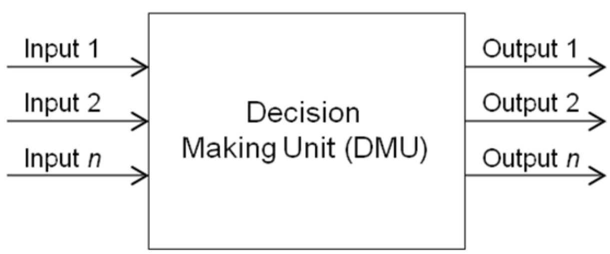

Figure 1 General DEA/TFDEA model with multiple input and output parameters

$$Efficiency\ DMU \quad = \frac{Weighted\ sum\ of\ outputs\ Y}{weighted\ sum\ of\ inputs\ X} \qquad (1)$$

In 2001, Anderson *et al.* first used TFDEA to forecast the trend of microprocessors and extended Moore's law by recognizing that the production and performance tradeoffs for state of the art microprocessors is richer than simply the number of transistors [14]. Since then, TFDEA has been applied in broad range of fields including telecommunication protocols [15], [16], fighter jets [17], commercial airplanes [18], and LCDs [19]. There are also other studies in improving and extending TFDEA [20], [21].

While DEA looks at the performance of the DMUs at one point in time, TFDEA looks into the change in the performance of the frontiers over a time period. TFDEA calculates a Rate of Change (RoC) by comparing the frontiers of each year with the ones in the previous year. The RoC is then used to predict the performance of the frontiers or State of the Art (SoA) in the future. The first step in this methodology is to build a model using the proper set of inputs and outputs through research and consults of experts in the field. This step is typically an iterative process until an appropriate set of parameters is ascertained. Once the accuracy of the model is determined, the calculated RoC will be used to project the trend of technology in the future years. The detailed mathematics of TFDEA can be found in [17].

Most of the data used in this study is from the original dataset used in the former research by Tudorie. Additional input and output parameters are obtained from vehicle manufactures' websites and other resources. The dataset includes two types of hybrid electric cars; the regular hybrid and the plug-in hybrid electric vehicles. A hybrid electric vehicle combines a conventional propulsion unit with a rechargeable energy storage system for a better fuel economy; yet batteries are charged using the internal fuel of the vehicle. A plug-in hybrid has the characteristics of a conventional hybrid electric car and in addition to the on-board electricity generation like HEVs, Plug-in hybrids can be plugged into electric outlets for recharging. They normally have a larger battery which allows them to drive in electric mode for a longer period of time. As such, PHEVs provide higher fuel efficiency [22].

III. TFDEA MODEL AND DATA COLLECTION

A. *Initial Model used*

Table 1 illustrates the initial TFDEA model that was used by Tudorie to forecast the future of hybrid electric vehicles and Table 2 defines each input and output parameter that was used in Tudorie's TFDEA model.

TABLE 1 INITIAL TFDEA MODEL USED BY TUDORIE

Number of HEVs	**Period**	**Initial TFDEA Model**					
		Inputs			Outputs		
64	1997-June 2012	Weight	Combined output power	Battery capacity	Acceleration rate	CO2 emissions	Fuel economy

TABLE 2 INPUT/OUTPUT PARAMETER DEFINITION OF THE INITIAL MODEL

Parameter	Definition
Weight (kg)	Total weight of the vehicle in kilogram
Combined output power (kw)	Combined output power delivered by electric motor and combustion engine together in kilowatts
Battery capacity(kwh)	The amount of electric charge a battery can store in kilowatthour.
Acceleration rate (km/h/s)	Indicates the speed in km/h a vehicle can reach in one second.
CO2 emissions	The amount of CO2 released while traveling 1 kilometer in grams per kilometer
Fuel economy (km/l)	Distance traveled per unit of fuel consumed on standard drive cycles in kilometers per liter

Tudorie thoroughly discusses the physics behind EVs' dynamics, the internal combustion unit and the battery technology. In her study, acceleration rate is selected as the main indicator of HEV's performance. Fuel economy and CO2 emission are the performance measurements imposed by government regulations and were included in the model.

The current paper extends this work to reflect the varying purposes of the different vehicles in the dataset. By definition the purpose of most vehicles is to transport people and goods and vehicles range from the large Chevy Tahoe sport utility HEV to small commuter vehicles. It is important to include an output that reflects the Tahoe's greater ability to transport people and goods – using a smaller commuter vehicle would require multiple trips. While interior volume would be a good measure, consistent measurement is difficult. As a proxy for this greater capacity, total seating capacity is used. For example, the Chevy Tahoe has a seating capacity of nine people while the Chevy Volt can only accommodate four. It is an admittedly imperfect proxy though as the two new variations of the Toyota Prius, the compact Prius C and the larger Prius V both are listed as being five passenger vehicles despite the Prius V being much larger.

Fuel economy and CO2 emissions are two factors that can vary in different driving styles and weather conditions. The US Environmental Protection Agency (EPA) announces the fuel efficiency of vehicles in miles per gallon and the study uses EPA values for fuel efficiency of cars available in US market. The fuel economy value for cars outside of US market is obtained from manufacturer websites and test drive reviews. To avoid adding more inconsistency in parameter values, CO2 emission parameter is not included in the revised model. Moreover, CO2 and fuel economy are both addressing similar aspects in performance of hybrid vehicles.

Weight of the car, battery capacity and combined output power were the main variables affecting the acceleration rate of the car based on physical and mechanical principles of internal engines. While this argument is technically valid, whether these parameters are the right choices as input parameters in a TFDEA model is under question. The initial inputs might be valid choices in forecasting the technology of main subsystems in the vehicle like battery technology.

The main trade off that electric vehicle industry is facing to provide higher performance is the cost of manufacturing. Tudorie also recognized the importance of incorporating the cost of the car in the model, but she excluded that due to the complexities involved in obtaining such parameter. However, excluding the cost of manufacturing in the model results in unfair comparisons where a company that makes an inexpensive car has it deemed obsolete or uncompetitive compared to a much more expensive car. Many customers may enjoy driving a Fisker Karma with its luxury design and high acceleration rate, but they also should be willing to spend 100,000 US Dollars to purchase it. A solid model is the one that properly reflects such trade-offs by its input and output parameters. Manufacturers do not reveal their manufacturing costs and access to such information is not feasible, therefore this study has used Manufacturer's Suggested Retail Price (MSRP) as a proxy for manufacturing cost.

Figure 2 illustrates the initial TFDEA model and the revised one with different inputs and outputs. The revised model is thoroughly explained in the next section.

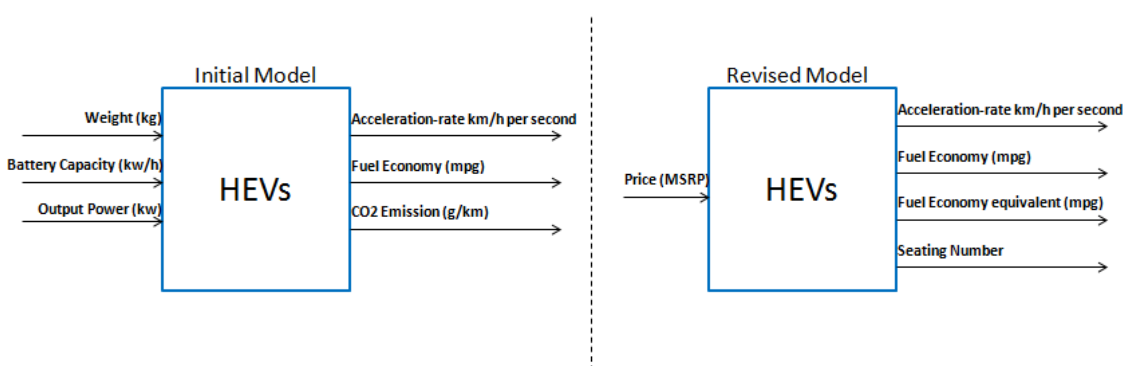

Figure 2 Initial TFDEA Model vs. Revised Model

TABLE 3 REVISED TFDEA MODEL FOR HYBRID ELECTRIC VEHICLES

Number of HEVs	Period	Revised TFDEA Model				
		Inputs	Outputs			
64	1997-June 2012	Price (MSRP) (2012 equivalent US Dollars)	Acceleration rate (km/h per second)	Fuel economy (mpg)	MAX of MPG and MPGequivalent (mpg)	Seating capacity

B. The revised TFDEA Model

Table 3 illustrates the revised TFDEA model and the new input and output parameters based on the discussion in the previous section.

Input parameters

Price: price is the only input parameter in the revised model. Manufacturer's Suggested Retail Price (MSRP) is considered as a reasonable proxy for manufacturing cost due to a high presumed correlation.

The vehicles in the dataset are from five different countries and are released in different years therefore the actual MSRP for each car was converted into 2012 US Dollar equivalent through the following steps:

1. The car's MSRP in the year of release is found through the manufacturers' website or car review websites.
2. If the MSRP is in foreign currency, the value is converted to the equivalent amount in US Dollars using the exchange rate of the year of release. This study used the historical exchange rates provided by OANDA to do the conversions [18]. Equation 2 shows the formula to convert the MSRPs in the original currency to the US Dollar equivalent:
$$\text{MSRP}_{US\ Dollar\ equivalent} = \text{Exchange rate}_{year\ of\ release} * \text{MSRP}_{in\ original\ currency}. \quad (2)$$
3. To inflate a past dollar value into present value the formula in Equation 3 is used by applying the historical Consumer Price Index (CPI) and the CPI of the current year. The CPI values are obtained from the Bureau of Labor Statistics [19] and the formula is described in [20]:
$$\text{MSRP}_{2012\ equivalent} = \text{MSRP}_{year\ of\ release} * (2012\ \text{CPI})/(\text{Year of release CPI}) \ . \quad (3)$$

Output Parameters

Acceleration rate: The same output as in the initial model. This value indicates the speed the vehicle can reach in one second. Equation 4 shows the formula that was used in the thesis to calculate the acceleration rate value:

$$\text{accelaration rate}\left(\frac{\text{km}}{\text{hour}}\text{per second}\right) = \frac{\text{speed range}\left(\frac{\text{km}}{\text{h}}\right)}{time(second)}. \quad (4)$$

Fuel economy: The same output as in the initial model. Fuel economy shows the distance a vehicle can travel in one unit of fuel. A higher value indicates a more sustainable vehicle that is aligned with green environment regulations. The value of fuel economy may vary in different traffic conditions and is dependent on individual driving habits [16]. The fuel economy values are collected from EPA, and from manufacturers' web site for cars outside US market.

Fuel economy values from the original thesis are converted to their miles per gallon equivalent and are used in this study with an adjustment to the plug-in hybrid values.

The concept of fuel economy is more complicated in plug-in hybrids as they can drive in pure electric mode from having being charged off the grid. While this pure electric mode range is limited, it is often sufficient for commuting city vehicles. The original values in the dataset for plug-in hybrid vehicles have been replaced by their fuel economy in hybrid mode only. To recognize the additional dimension of plug-in hybrids' performance when driving in pure electric mode, another output of fuel economy is included in the model as described in the following.

Max of MPG and MPGequivalnet: EPA is announcing a Mile per Gallon equivalent (MPGe) for the plug-in hybrids like Opel Ampra (also known as Chevrolet Volt in US). This value is based on the gasoline-equivalent energy of electricity [23]. Equation 5 is showing the kilo watt-hours of energy per gallon of gasoline:

$$1 \text{ gallon of gasoline} = 33.7 \text{ kwh} \ . \quad (5)$$

For vehicles like BYD F3DM that are not available in US market and EPA has not announced an MPGe value for them, the MPGe is calculated using the electricity driving range in mile, the battery capacity in kwh and Equation 5. Equation 6 shows the calculation:

$$\text{MPGequivalent} = \frac{33.7 * \text{drivingrange}}{\text{batterycapacity}}. \quad (6)$$

An additional column "MPG equivalent" is added by gathering and calculating MPGe values for Plug-in vehicles. "Max of MPG and MPGequivalent" output parameter maximizes the values for fuel economy and fuel economy equivalent. In the case of conventional hybrids, the Max of MPG and MPGe will be the same value as their fuel economy. Adding this parameter incorporates the advantage that plug-in hybrids have over the conventional hybrid cars. Plug-in hybrids can recharge their battery through external outlets and normally have bigger size of batteries. Therefore, compare to regular hybrids, they can travel a longer distance in electric mode without consuming fuel.

Seating capacity: The previous section discussed the importance of including a measurement of the capacity for the vehicles. Adding this parameter can make vehicles like the Chevrolet Tahoe which recognizes the benefit of more space but lower acceleration rate than sports cars like the Fisker Karma.

C. DATA SET

The current study uses the dataset gathered by Tudorie in the original Master thesis.

The dataset is a collection of 64 hybrid electric vehicles from 1997 to 2012. Appendix A shows the dataset used in this study. Figure 3 illustrates the number of hybrid vehicle DMUs per year.

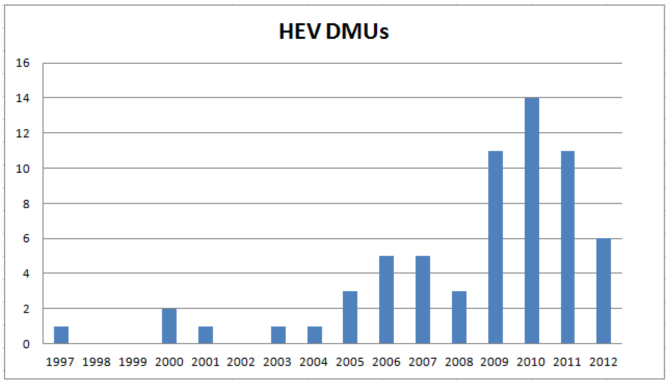

Figure 3 Number of HEV DMUs per year

IV. TFDEA IMPLEMENTATION

The revised TFDEA model is implemented using the tool developed by Lim and Anderson [24]. As Equation 1 shows, the efficiency of DMUs in data envelopment analysis can be improved either by minimizing the inputs or maximizing the outputs. Such concept determines the input or output orientation in TFDEA. As in the case of electrical vehicles, the market is more interested in increasing acceleration rate and better fuel economy with minimal changes in the price. Therefore an output orientation has been chosen for the TFDEA implementation in the initial study as well as in the current research.

The model is validated using a back testing approach. In order to back test the results of the forecast, a frontier year is selected and the dataset is divided into two parts at the frontier year. The vehicle DMUs released before the frontier year are used to calculate the RoC and the DMUs after the frontier year are used to verify the forecasts made by calculated RoC. The dividing point should be chosen properly to have enough historical data for the calculations.

Figure 3 shows that 2009 is the first year that can be chosen as a frontier year in terms of having enough DMUs for a forecast. Until 2009, the only plug-in hybrid available was the 2008 BYD F3DM from china. Most of the Plug-in hybrids in dataset like the Besturn B50, the Jeep Patriot and the Chevrolet Volt were released in 2010. Plug-in hybrids have slightly different design from conventional hybrids and are becoming more popular every year. Therefore, this study has chosen 2010 as a frontier year to include Plug-in technology in calculating the RoC. A variable returns to scale and dynamic RoC calculation were used in implementing the TFDEA model.

V. ANALYSIS OF THE RESULTS

Figure 4 shows the results of the forecast using the initial model and Figure 5 depicts the results of revised model using frontier year 2010.

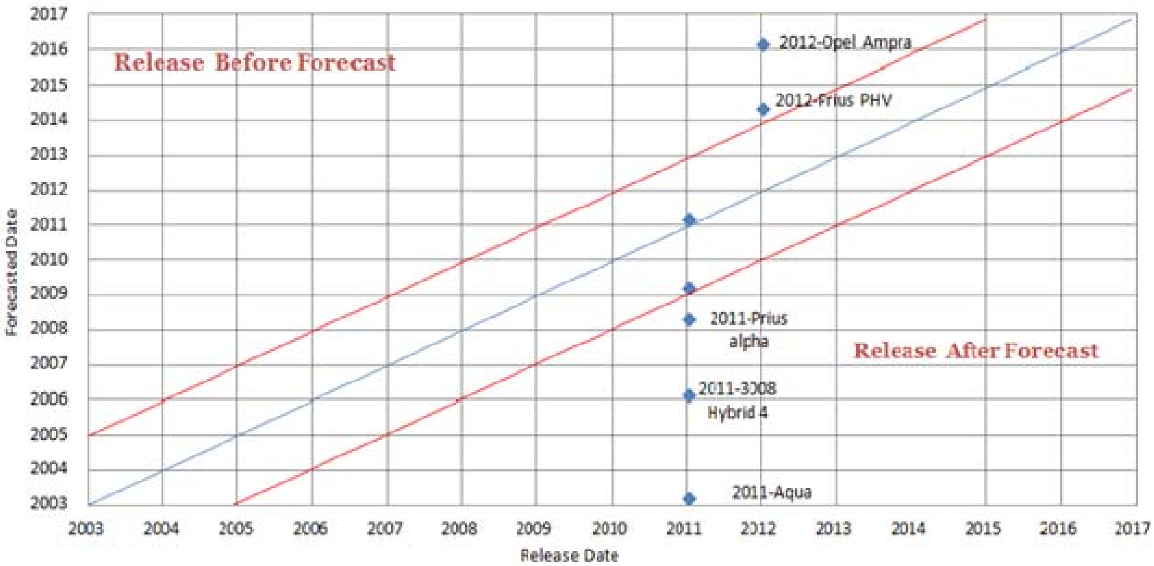

Figure 4 Release Date vs. Forecasted Date Initial model, Frontier year 2010

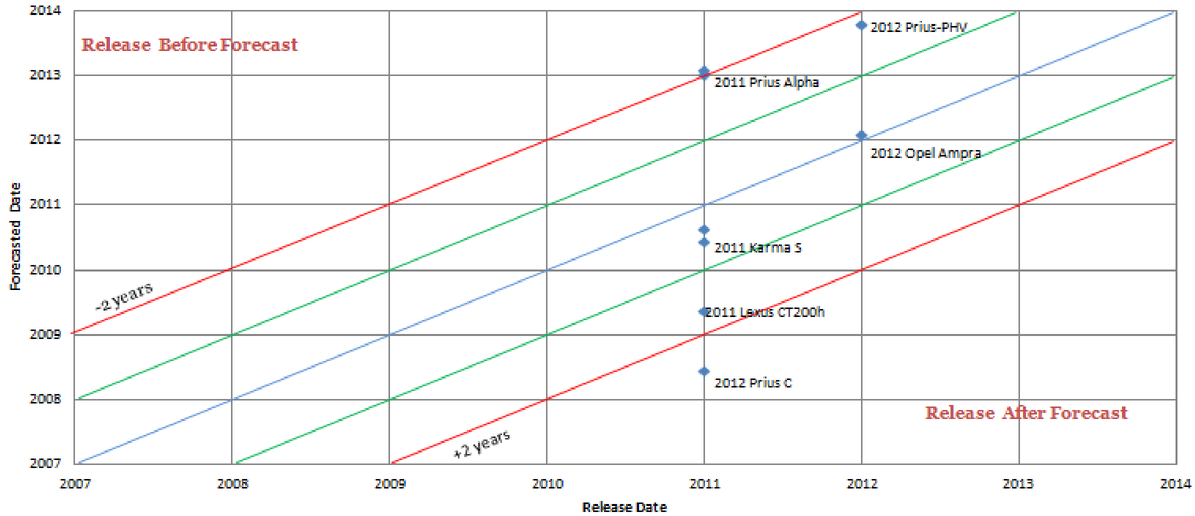

Figure 5 Release Date vs. Forecasted Date-Revised model, Frontier year 2010

The blue line is the perfect forecast which is never the case. The red lines show the forecasts that are within two years of the release date. The two figures illustrate the difference in accuracy of the initial and revised TFDEA models. As the figures show, except for 2012 Prius C, the rest of the forecasts by the revised model fall within two years of the actual release date which is not the case for the former model.

The Opel Ampra is predicted to come into market in 2012 and the Prius PHV is forecasted with almost one year deviation. This shows that Plug-in hybrid technology has been reflected better in the revised model. The revised model is showing the Lexus CT200h has been a bit behind the market which can be justified by the fact that the luxury parameters of Lexus were not considered in the model. Lexus CT200h is an expensive car compare to the other vehicles and its advantages like the fancy design or luxuries interior were not incorporated in the model. Table 4 shows the Mean Absolute Deviation (MAD) of the forecasted dates and the RoC of both initial and revised models. MAD of the revised model is almost 2 years less than the MAD calculated for the former model.

TABLE 4.MAD AND ROC OF THE INITIAL AND REVISED MODELS

Model	RoC	MAD [years]
Initial	1.13	3.41
Revised	1.03	1.51

Another improvement that the new model has provided in the results of TFDEA is shown in figures 6 and 7. The Efficiency_R is the efficiency score of the car at the year of Release and the Efficiency_F is the efficiency score of the car at the Frontier year which in this case is 2010. The results of the initial model is indicating that the vehicles like 1st generation Prius released more than 10 years ago are still efficient in the 2010 which is not realistic. The 1st generation Prius C is less efficient compare to vehicles like Opel Ampera, BYD F3DM with higher MPGes and improved acceleration rates.

The revised model is showing that the cars which were once State of the Art are not anymore efficient in 2010. This is more realistic and indicates that the revised model has improved the outcomes significantly.

DMU	Name	Date	Efficiency_R	Efficiency_F
1	Prius(1st gen.)	1997	1	1
2	Tino Hybrid	2000	1	1
3	Prius(2nd gen.)	2000	1	1
4	Civic Hybrid 1st gen.	2001	1	1

Figure 6 TFDEA Results-Initial Model

DMU	Name	Date	Efficiency_R	Efficiency_F
1	Prius(1st gen.)	1997	1	1.1473753
2	Tino Hybrid	2000	1	1.124154906
3	Prius(2nd gen.)	2000	1	1.128641844
4	Civic Hybrid 1st gen.	2001	1	1.095644768

Figure 7 TFDEA Results-Revised Model

Once the accuracy of the TFDEA model is verified the final RoC for the future prediction is calculated by setting the frontier year to the most recent release date which in this case is 2012.

The RoC of 1.042 means that the State of the Arts in 2012 will improve by 4.2% each year either by increasing their outputs or decreasing their input with the same rate.

TABLE 5: ROC AND SD OF FRONTIER YEAR 2012

Rate of Change	1.042
Standard Deviation	0.02167
95% Confidence Level	1.042 ± 0.042467

VI. IMPLICATIONS

Figure 8 shows the efficiency scores of the hybrid electric cars released in 2012. According to the TFDEA results, Prius PHV and Opel Ampra are the best performers in 2012. Such outcomes are aligned with success of Opel Ampra as the 2012 European Car of the Year [25].

DMU	Make	Model	Release Year	Efficiency at Release Year
60	Toyota	Prius PHV	2012	1
61	Opel	Opel Ampra	2012	1
62	BMW	ActiveHybrid 5 Series	2012	1.096624546
63	Lexus	Lexus GS450h (2013 MY)	2012	1.062203863
64	Honda	Insight	2012	1.135328482

Figure 8 Efficiency score of HEVs in 2012 as calculated by TFDEA

The final Rate of Change can be applied to calculate the performance measurements of the future frontiers in the market. Such predictions can give the manufacturers an insight into the future expectations of HEV market and how they can assure their dominance in the market. This information can be applied in setting the proper road maps and making the right decisions in designing their products. Knowing that the future frontiers of electric vehicles are expected to have an acceleration of 15 km/h per second will allow manufacturers to design a vehicle with proper subsystem characteristics that is capable of providing such acceleration. Figures 9 and10 show the expected performance of the frontiers in hybrid electric industry in the coming years using the values of the frontiers in 2012, the Opel Ampra and the Toyota Prius-PHV. The expected characteristics of the best performers within one, two and five years are calculated. For each year the aggressive and conservative values are illustrated based on the 95% confidence level of final RoC shown in Table 5.

The conservative RoC is very close to 1 and therefore the performance measurements are very close to the current performance values of the Opel Ampra and the Prius-PHV. The aggressive measurements are showing the expected output parameters of the future frontiers in the coming years. The Opel Ampra has high acceleration rate and the Prius-PHV has a significantly high fuel economy of 50 MPG in hybrid mode. According to the figures above, manufacturers should improve the acceleration rate to around 16 km/h/s or the fuel economy to 75 MPG within five years without significant increase in the price. The MPGe is also expected to reach around 142 MPG. This means that for regular hybrid cars to remain frontier they should provide very high acceleration rate or have very low price to compete with plug-in hybrids. Another way for manufacturers to stay frontier in the market is to offer the same performance as Opel Ampra or Prius-PHV currently have but decrease the price by 4.02% each year. This is a strategy that was used by Nissan to boost their sales for Nissan Leaf [26].

VII. CONCLUSION

This study revisited the former application of forecasting the technological progress in hybrid electric industry and improved the initial model by changing the input and output parameters based on the main performance indicators in hybrid electric vehicles' market in the past years. The results of the revised model were greatly improved and the final RoC was used to project the characteristics of the best performers in the coming years.

As a future work, the current model can be extended for forecasting the technological trend of Battery Electric Vehicle (BEVs). Further, the model can be improved to cover both BEVs and HEVs to predict the future of electric vehicles using a broader dataset that includes all the electric vehicles released over the past years.

Output Parameter	2012 Opel Ampra values	Future Frontier Expected Values					
		2013		2014		2017	
		Conservative	Aggressive	Conservative	Aggressive	Conservative	Aggressive
Accelaration rate	11.11	11.10	12.05	11.10	13.07	11.08	16.66
Fuel economy	37	36.98	40.13	36.97	43.51	36.91	55.50
Fuel economy equivalent	98	97.95	106.28	97.91	115.25	97.77	147.00
Seating	4	4.00	4.34	4.00	4.70	3.99	6.00

Figure 9 Expected performance values of best performers in coming years based on 2012 Opel Ampra

Output Parameter	2012 Prius-PHV values	Future Frontier Expected Values					
		2013		2014		2017	
		Conservative	Aggressive	Conservative	Aggressive	Conservative	Aggressive
Accelaration rate	8.82	8.82	9.56	8.81	10.37	8.80	13.23
Fuel economy	50	49.98	54.22	49.95	58.80	49.88	75.00
Fuel economy equivalent	95	94.96	103.02	94.91	111.73	94.78	142.50
Seating	5	5.00	5.42	5.00	5.88	4.99	7.50

Figure 10 Expected performance values of best performers in coming years based on 2012 Prius PHV

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APPENDIX A: HEV DATASET

DMU	Maker	Name	Date	Type	Y_Acceleration_rate	X_Price_2012	Y_Seating	Y_Fuel_Economy	MPGe	Y_MPG_MAX	Original MSRP	Country of Price	US Dollar Equivalent	Country of Price
1	Toyota	Prius(1st gen.)	1997	HEV	7.46	24436.7	5	41.26		41.26	16929	US	16929	US
2	Nissan	Tino Hybrid	2000	HEV	8.2	35249.7	5	54.1		54.1	26200	US	26200	
3	Toyota	Prius(2nd gen.)	2000	HEV	7.97	26752.3	5	45.23		45.23	20450	US	20450	US
4	Honda	Civic Hybrid 1st gen.	2001	HEV	7.04	25756.4	5	47.04		47.04	20000	USA	20000	USA
5	Toyota	Alphard Hybrid	2003	HEV	8.33	37971.3	8	40.46		40.46	3600000	Japan	30960	Japan
6	Ford	Escape Hybrid	2004	HEV	10.32	36566.8	5	31.99		31.99	30825	USA	30825	USA
7	Lexus	Lexus RX400h	2005	HEV	12.76	58346.8	5	28.23		28.23	49185	USA	49185	USA
8	Honda	Civic Hybrid 2nd gen.	2005	HEV	7.63	26275.9	5	39.99		39.99	22150	USA	22150	USA
9	Toyota	Highlander Hybrid	2005	HEV	12.76	29099.3	7	29.4		29.4	24530	USA	24530	USA
10	Mercury	Mercury Mariner Hybrid	2006	HEV	8.98	34668.8	5	32.93		32.93	29225		29225	
11	Toyota	Camry Hybrid	2006	HEV	11.28	29764.3	5	33.64		33.64	25900	USA	25900	USA
12	Lexus	Lexus GS450h	2006	HEV	18.65	6435.53	5	33.4		33.4	56000	USA	56000	USA
13	Toyota	Estima Hybrid	2006	HEV	9.26	35905.4	7	47.04		47.04	3633000	Japan	31243.8	Japan
14	Nissan	Altima Hybrid	2006	HEV	13.29	29436.8	5	32.93		32.93	25615	USA	25615	USA
15	Chevrolet	Chevrolet Tahoe Hybrid	2007	HEV	10.91	42796.5	9	22.35		22.35	50490	USA	50490	USA
16	Toyota	Kluger Hybrid	2007	HEV	12.76	46091.8	7	25.87		25.87	41250	USA	41250	USA
17	Toyota	Lexus LS600h/hL	2007	HEV	17.54	118190	5	28.7		28.7	105775	USA	105775	USA
18	Mazda	Tribute Hybrid	2007	HEV	11.28	24749.9	5	31.75		31.75	22150	USA	22150	USA
19	GMC	GMC Yukon Hybrid	2007	HEV	12.28	56924.7	8	21.78		21.78	50945	USA	50945	USA
20	Toyota	Crown Hybrid	2008	HEV	8.7	62104.8	5	37.16		37.16	5950000	Japan	57715	Japan
21	Cadillac	Cadillac Escalade Hybrid	2008	HEV	9.09	78697.7	8	22.35		22.35	73135	USA	73135	USA
22	BYD	F3DM	2008	PHEV	9.52	23673.3	5	30.11	85	85	22000	USA	22000	USA
23	Chery	A5 BSG	2009	HEV	7.87	11814.1	5	35.28		35.28	10940	USA	10940	USA
24	Lexus	Lexus RX450h	2009	HEV	13.47	46095.6	5	31.99		31.99	42685	USA	42685	USA
25	Mercedes	ML450 Blue HV	2009	HEV	12.6	60339.5	5	23.99		23.99	55875	USA	55875	USA
26	Toyota	Prius (3rd gen.)	2009	HEV	9.6	24567.8	5	47.98		47.98	22750	USA	22750	USA
27	Mercedes	S400 Hybrid/ Hybrid Long	2009	HEV	13.89	95922.3	5	26.34		26.34	88825	USA	88825	USA

28	Mercury	Mercury Milan Hybrid	2009	HEV	11.55	30431.6	5	40.69		40.69	28180	USA	28180	USA
29	Lexus	Lexus HS250h	2009	HEV	11.55	38363.5	5	54.1		54.1	35525	USA	35525	USA
30	Hyundai	Avante/ Elantra LPI	2009	HEV	10.21	21807.5	5	41.87		41.87	20194	USA	20194	USA
31	Kia	Forte LPI	2009	HEV	14.06	20856.2	5	40.46		40.46	19313		19313	
32	BMW	ActiveHybrid X6	2009	HEV	17.96	96948.2	4	18.82		18.82	89775	USA	89775	USA
33	Toyota	SAI	2009	HEV	11.55	39055.7	5	54.1		54.1	3380000	Japan	36166	Japan
34	Toyota	Auris HSD	2010	HEV	8.85	35680.7	5	68.21		68.21	21325	UK	33582.6	UK
35	Honda	CR-Z	2010	HEV	9.24	21371.7	2	60.69		60.69	20115	USA	20115	USA
36	BYD	F3DM PHEV	2010	PHEV	9.24	23055.7	5	30.15	85	85	21700	USA	21700	USA
37	Volkswagen	Touareg HV	2010	HEV	15.38	64007.7	5	28.7		28.7	38255	UK	60244	UK
38	Audi	Audi Q5	2010	HEV	14.08	37399.1	5	33.64		33.64	35200	USA	35200	USA
39	Jeep	Jeep Patriot EV	2010	PHEV	12.05	16994.3	5	29.4	38	38	15995	USA	15995	USA
40	FAW	Besturn B50	2010	PHEV	7.14	14543.2	5	31.28		31.28	92800	China	13688	China
41	BMW	ActiveHybrid 7 Series	2010	Mild-HEV	20.41	103990	5	22.11		22.11	97875	USA	97875	USA
42	Lincoln	Lincoln MKZ Hybrid	2010	HEV	11.15	36926.3	5	37.63		37.63	34755	USA	34755	USA
43	Honda	Fit/ Jazz Hybrid	2010	HEV	8.26	16861.5	5	30		30	15870	USA	15870	USA
44	Hyundai	Sonata HV	2010	HEV	14.7	28203.4	5	37		37	26545	USA	26545	USA
45	Porsche	Cayenne S HV	2010	HEV	14.71	72965.5	5	26.11		26.11	68675	USA	68675	USA
46	Nissan	Fuga Hybrid/ Infiniti M35h	2010	HEV	18.65	69948	5	33.64		33.64	5775000	Japan-Yen	65835	Japan-Yen
47	Chevrolet	Chevrolet Volt	2010	PHEV	10.78	42796.5	4	35	93	93	40280	USA	40280	USA
48	Toyota	Aqua	2011	HEV	9.35	22782.8	5	50		50	22120	USA	22120	USA
49	Lexus	Lexus CT200h	2011	HEV	9.71	29992.5	5	61.86		61.86	29120	USA	29120	USA
50	Honda	Civic Hybrid 3rd gen	2011	HEV	9.6	24925.1	5	44.36		44.36	24200	USA	24200	USA
51	Toyota	Prius alpha	2011	HEV	10	30497.2	5	72.92		72.92	2350000	Japan	29610	Japan
52	Peugeot	3008 Hybrid4	2011	HEV	11.36	44967.2	5	61.16		61.16	43659	USA	43659	USA
53	Honda	Fit Shuttle Hybrid	2011	HEV	7.52	16345.5	5	58.8		58.8	15870	USA	15870	USA
54	Fisker	Karma S	2011	PHEV	16.67	105056	4	20	54	54	102000	USA	102000	USA
55	Buick	Buick Regal eAssist	2011	Mild-HEV	12.05	27865.7	5	25.99		25.99	27055	USA	27055	USA
56	Toyota	Prius v	2011	HEV	9.51	27191	5	32.93		32.93	26400	USA	26400	USA
57	Honda	Freed Spike Hybrid	2011	HEV	6.29	27888.7	5	50.81		50.81	2149000	Japan	27077.4	Japan
58	Kia	Optima K5 HV	2011	HEV	10.54	26470.1	5	35.99		35.99	25700	USA	25700	USA
59	Toyota	Prius c	2012	HEV	9.35	18950	5	50		50	32000	USA	32000	USA
60	Toyota	Prius PHV	2012	PHEV	8.82	32000	5	50	95	95	31645	Europe	58718	Europe
61	Opel	Ampera	2012	EREV	11.11	31645	4	37	98	98	61995	USA	61995	USA
62	BMW	ActiveHybrid 5 Series	2012	HEV	16.67	61995	5	26		26	18950	USA	18950	USA
63	Lexus	Lexus GS450h (2013 MY)	2012	HEV	16.95	58950	5	31		31	58950	USA	58950	USA
64	Honda	Insight	2012	HEV	9.42	18500	5	42		42	18500	USA	18500	USA