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Title: Hierarchical Decision Modeling (HDM) Applied to Alternative Powertrain Automobile Purchase

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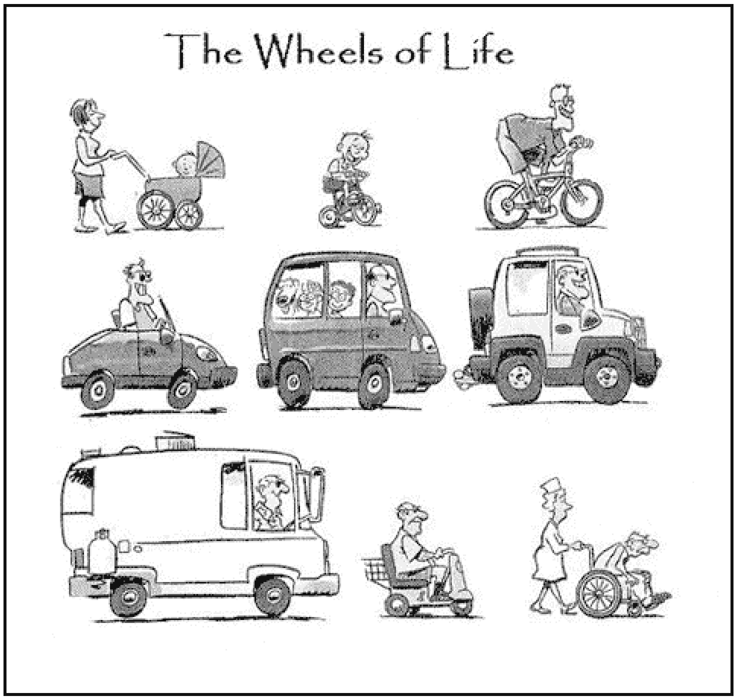

Figure 1 The Wheels of Life [1]

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1 Abstract

Over ten years ago, the decision to purchase a particular powertrain automobile was easy: one either chose gasoline or diesel, and gasoline was chosen over 98% of the time. Now there are two more marketable powertrain technologies available to consumers: hybrid and electric. Add this to the variety of other decisions that the average car purchaser has to make, and the implications are a dizzying array of choices. This paper attempts to alleviate those choices by utilizing the Hierarchical Decision Model along with pairwise comparisons that will assist a car purchaser to choose a powertrain technology that best fits their criteria. Whether the car purchaser is making the decision on his or her own, or with other important decision makers, the analytical decision tools will lead the purchasers to the right powertrain technology.

2 Introduction

The U.S. Department of Energy Lists over 200 carmakers from Acura to Yugo, each offering between ten to 80 different models per year [2]. This drives the number of alternatives for passenger vehicles to several thousand. In addition to the traditional car selection criteria of cost, size, safety, and style, the advent of alternative powertrain technologies brings an added level of complexity to the automotive purchase decision-making process. Alternative automotive powertrain technology is a fancy word for hybrid, electric and diesel-powered vehicles, among others [1]. Appendix 8.5 offers a detailed overview of the powertrain technologies discussed in this paper. Currently, gasoline-powered cars comprise the majority of vehicles on the road in the United States (see Table 1). However, new technologies such as hybrid, clean diesel and fully electric cars are entering the market. Their success in the market depends largely on the future price of gasoline, as higher fuel costs will make these vehicle technologies more attractive to consumers.

Table 1U.S. Market, Alternative and Advanced Powertrain Types, 2011 and 2015 (Percent total of U.S. Vehicle Sales) [3]

	$2.50/gallon		$6.00/gallon	
	2011	2015	2011	2015
Dedicated Gasoline	91.5%	83.8%	89.0%	69.0%
Hybrid Electric Vehicle	5.0%	10.5%	6.0%	20.0%
Diesel	3.0%	5.0%	4.0%	7.5%
Battery Electric Vehicle	0.1%	1.0%	0.5%	2.5%

The first hybrid car patent was granted at the turn of the last century, on March 2, 1909[2]. However, as so many times in history, the market was not ready for Henri Pieper's invention, and the affordable gasoline-powered Ford Model T soon crowded out the first hybrid car prototypes. In the 21st century, hybrid cars have seen a revival and are hailed as the solution to global warming, air pollution and skyrocketing fuel prices [4]. Figure 2 shows historic sales of hybrid vehicles over the last ten years. Clearly, hybrid technology is on the rise.

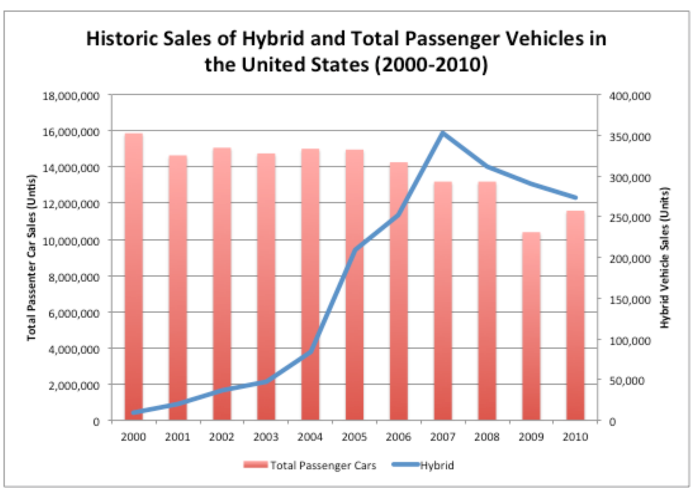


Figure 2 Historic Sales of Hybrid and Total Passenger Vehicles in the United States (2000-2010)[5]

The take-rate of hybrid vehicles, meaning the percentage of hybrid car sales compared to total sales of passenger cars, has dramatically increased from 0.06% in 2000 to 2.37% in 2010[5]. Ten years after the introduction of modern-day hybrid cars in the US, government tax credits for hybrid cars are running out[6]. The government is shifting funds towards subsidies of electric vehicles, offering tax credits of up to $7,500 for electric cars purchased in or after 2010[7]. There are a handful of models ready for mass-market adoption, and the Nissan Leaf is the most promising electric vehicle option for the average urban commuter[8]. The fourth technology discussed in this paper is clean-diesel. Diesel cars were thus far perceived as a “dirty” technology[9]. However, better-refined diesel fuels such as ultra-low sulfur diesel (ULSD) now offer a low-emission alternative and twice the fuel-efficiency compared to gasoline-powered engines[10].

This paper will answer the question “What is the right powertrain technology for me?” by providing a fact-based analytical decision-making model. It takes into account the relative importance of the buying criteria of the decision-maker, their subjective evaluation of qualitative criteria, and their expectation regarding future gasoline prices. The paper will first discuss existing literature on the car purchase decision-making process and car buying preferences of US consumers. Next, the paper will detail methods and measures used to obtain the data on car buying preferences for the selected sample. The discussion section will summarize the findings, outline academic and practical implications, discuss limitations of the research, and conclude with recommendations for future research.

3 Literature Review

3.1 Car Purchase Behavior of the US Consumer

For decades, car manufacturers and consumer research companies have studied how consumers decide to buy a car. This not only assists them to understand the purchasing behavior [11], [12],[13], and [14]; but most importantly it is used to determine the product development process. Studies show that women influence the majority of car purchase decisions, ranging from 80% to 86% depending on the study [14], [15]. While both men and women place a high importance on safety, performance, and design, the interpretation of these criteria varies across genders. “For men, safety means features that help avoid an accident, such as antilock brakes and responsive steering. For women, it's about features that help to survive an accident: passenger airbags, reinforced side panels, or a drop-down engine” [14]. Many women also consider rear curtain airbags, vehicles that don't roll over, and vehicles that are not too small when they think of safety. Therefore, men and women can be expected to place similar priorities on car purchase criteria. In fact, Barletta proposes, “if you can meet women's expectations, you generally exceed the expectations of men” [14]. Barletta also suggests that women “expressed interest in hybrids because of the environmental impact” and that for women the environmental impact of the car plays an important role in the car purchase decision [14].

In general, most consumers are predicted to be more environmentally conscious, not only women. A report published by Kelly Blue Book Market research in 2008, reported “66% of new-vehicle shoppers indicated that it is important to them to purchase a vehicle from a brand that is environmentally friendly”. Even more astounding is the fact that they would not revert back to old habits if gas prices dropped back to $1 per gallon [16]. This interest in hybrid and electric technology has spawned several research efforts to understand what distinguishes hybrid car drivers from vehicle owners overall [12] and [17].

Some studies suggest that hybrid car purchases are motivated by environmental concerns [17]. However, these are contradicted by several publications [12],[18], [19], [20]. A study published in the Journal of Consumer Marketing in 2010 examined the hybrid car purchase intentions of US consumers versus Korean consumers.   They found that "social value associated with green products, in general, has a negative relationship with US consumer hybrid purchase intentions" while Koreans are more likely to purchase hybrid cars for their associated status as environmentally friendly [19]. A survey published in Transport Policy in 2010 found that "respondents did not rate greenhouse gas emissions as crucial attributes when purchasing a new vehicle […] instead the most highly rated attributes were reliability, automobile safety, fuel costs, and price"[20]. A J.D. Power report also suggests that money is the primary reason for purchasing a hybrid vehicle: 70% of respondents in the 2008 Alternative Powertrain Study indicated "lower fuel cost" as the primary buying reason compared to only 16% who said "better for the environment" was the main purchasing factor [12]. This finding was confirmed in the 2011 J.D. Power report: "Fuel-Pump savings, not environmental benefits, inform most alternative-powertrain purchases" [9]. The economic downturn after 2008 further increased the importance of cost: "24% of Americans saying they considered getting a new car in the past six months but decided against it […] citing broad economic concerns" [18]. Irrespective of why consumers purchased their first hybrid car, once they own one, they are more likely to stay loyal: 46% of hybrid car owners buy the same make on their next purchase [17]. Lastly, research has found hybrid car owners tend to "have much higher levels of education and report much higher household income; they are also about four years older than the average new vehicle buyer (54 vs. 50)"[21].

3.2 Multi-Criteria Decision-Making Models Applied to Car Purchase Decision

While understanding how the average consumer in a certain demographic segment decides on a car is useful to the manufacturer, it does not help the individual looking to maximize their individual cost-benefit equation. Many automotive guides help with narrowing down the options. Some authors have applied multi-criteria decision-making models to this problem [22]. Multi-criteria decision tools lend themselves to the automotive purchase decision since they take into consideration customer preferences and yield a prioritized list of alternatives.

A paper published in Management Information Systems in 2001 uses the Analytic Hierarchical Process (AHP) to prioritize and analyze three mid-sized car models [22]. The authors analyzed seven main criteria (exterior, convenience, performance, safety, economic aspect, dealer, and warranty) and 39 sub-criteria. Questionnaires for pairwise comparison of the criteria were mailed to car dealers, and their responses were used to generate the weighting of each criterion. A second set of questionnaires was mailed to drivers, and they were asked to indicate their satisfaction with the car on a 5-point scale. They showed in their sensitivity analysis that the highest rated car is also the one with the highest sales volume in the market.

While car dealers are domain experts and know what is selling, the authors of this paper believe that the importance of each criterion for the individual decision-maker remains a highly personal attribute. The authors therefore propose to use a multi-criteria decision-making model, namely hierarchical decision modeling (HDM), to develop a decision-tool that can be used by an individual or group, to identify the best alternative based on the personal preferences and subjective evaluation of qualitative attributes.

4 Methods

This paper combines two analytical decision-making tools, namely Hierarchical Decision Modeling and Decisions under Risk, to derive a decision-making process that is practical, data-driven, and can be used to optimize the car purchase decision.

For the purpose of identifying purchase criteria, 28 graduate engineering management students were surveyed. A 5-point scale was used to measure the relative importance of each criterion (see Appendix 8.1 for a copy of the questionnaire). The criteria with the highest average scores were used for future analysis. Although "environment" did not score very high in the initial survey, this criterion was included in future analysis, as the authors were interested in the importance of environmental impact on the buying decision. Demographic information was also collected with the questionnaire, and the ranking of criteria was correlated against the respondent's background information. A hierarchical decision model (HDM) was developed, as described by Cleland and Kocaoglu [23]. The HDM is a valuable tool when analyzing multi-criteria decisions that have multiple hierarchical levels such as cost and benefit, followed by sub-criteria for cost and sub-criteria for benefits. Kocaoglu describes a method for obtaining priority weights by asking decision-makers to divide 100 points between two criteria at one time. As part of the pairwise comparison the authors calculated an inconsistency value [23]. An inconsistency value greater than 0.2 indicates that the decision-maker answered the questions randomly and the results cannot be used without further clarification. The model also requires selection of alternatives. One representative car model from each powertrain technology was selected: gasoline, diesel, hybrid and electric. All car models have a selling price of approximately US$30,000, are mid-sized sedans, and are the bestselling in their category. Another questionnaire was then distributed to a broader group of respondents (see Appendix 8.2 for a copy of the second questionnaire and Appendix 8.3 for a summary of the respondents' profiles). In total, 10 questionnaires were distributed and 8 were returned. The respondents were asked to provide a pairwise comparison of buying criteria to obtain weighting for each criterion. They were also asked to rank subjective buying criteria for the four automotive alternatives on a 10-point scale with 10 being their personal optimum preference. The rating for each cost-criterion is based on quantitative data available online for each car model (see section 7 of Appendix 8.2).Figure 3 shows the HDM for the car purchase decision.

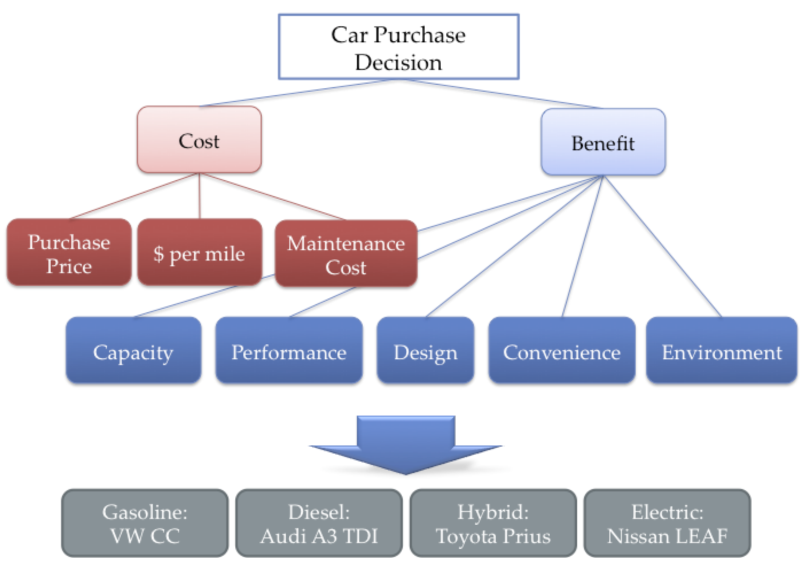


Figure 3 Multi-Criteria Decision Model for Alternative Powertrain Automotive Purchase

A temporal dimension was added to the decision problem. The literature suggests that car buyers are influenced by the future price of fuel. The authors therefore analyzed the alternatives using the decisions under risk model[23]. Subjective probabilities were determined by asking respondents to distribute 100 points among three states of nature: the average price of gas will be $2, $4 or $6 over the next five years. The total cost of ownership was then calculated over five years using the subjective probabilities for the average price of fuel.

5 Results

5.1 Ranking of Purchasing Criteria

The first questionnaire was used to identify which purchasing criteria are most important to the purchasing process. The authors surveyed 28 ETM students, of which 100% responded. The initial set of five cost criteria and eight benefit criteria were developed from the literature. Table 2 and Table 3 show the average scores obtained from the questionnaire responses. All cost criteria with an average value above 3.5 were used for future analysis (purchase price, dollar per mile and maintenance cost). Similarly, all benefit criteria with a value higher than 3.5 were used (capacity, performance, design, safety and brand). However, during testing of the second questionnaire, it was noticed that the subjective ranking for brand and safety were very close for each alternative. The benefit criteria were therefore modified by removing safety and brand, since they do not add information to the decision process. The criteria convenience and environment were added instead. Although the latter two scored low in the survey, they have been identified as important criteria by literature.

Table 2 Average scores of cost criteria

Cost Criteria	Purchase Price	Dollar per Mile	Resale Value	Maintenance Cost	Tax
Average	4.48	3.55	3.17	3.76	2.83

Table 3 Average scores of benefit criteria

Benefit Criteria	Capacity	Perfor-mance	Amenity	Design	Safety	Brand	Conve-nience	Environ ment
Average	4.24	4.10	3.41	3.93	4.14	3.48	3.38	2.93

The individual scores were then correlated to the demographic information. There was no statistically significant correlation between the ranking and any of the collected demographic criteria (gender, number of kids in household, education, employment, country of origin). Figure 4 shows two examples of correlation graphs. The first (on the left) shows that the importance of performance is slightly correlated with the level of education but not enough to be statistically relevant. The second (on the right) shows that the number of children in the household does not impact the importance of safety. The authors would have expected families to place higher value on safety. This leads to the conclusion that selecting a car is a highly individual process.

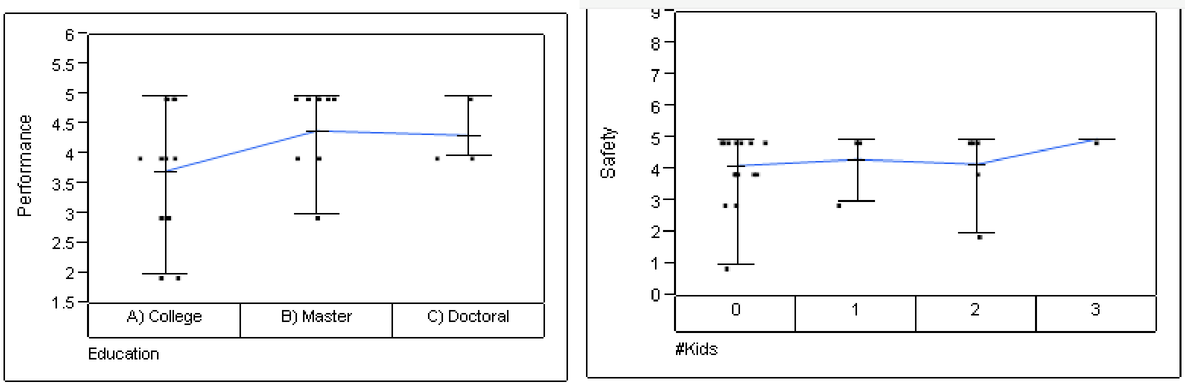


Figure 4 Correlation of performance to education (left) and safety to number of kids in household (right)

5.2 Hierarchical Decision Modeling

The results for the Hierarchical Decision Modeling include weighted values for each cost and benefit criterion, normalized cost evaluation, and normalized benefit evaluation. The weighted values and benefit evaluation are subjective criteria and different for each decision-maker.

Appendix 8.4 shows the evaluation of alternatives based on the cost criteria. Based on average prices of regular gas the authors assumed $4 for the costing model. The price for premium and diesel was adjusted as a percentage of regular gasoline. The electricity price was assumed at 11 cents per kilowatt hour [24] (see Appendix 8.6 for data on historic prices for regular gasoline and electricity).

Table 4 and Table 5 below show the subjective benefit evaluation for two of the eight respondents. It is evident that Tracy really likes her Toyota Prius. Surprisingly, she assigned a score of 10 (ideal) to the Nissan LEAF for convenience. Since this will be her secondary vehicle, a range of 100 miles and overnight charging is deemed perfect for this respondent. By contrast, Ben likes the Volkswagen and Audi for their performance and design and is not impressed with the Nissan LEAF, except for its environmental friendliness.

Table 4 Benefit Evaluation for Tracy

Tracy	Capacity	Performance	Design	Convenience	Environment
VW	5	8	4	6	5
Audi	10	9	5	6	5
Toyota	10	9	9	10	9
Nissan	8	7	3	10	10

Table 5 Benefit Evaluation for Ben

Ben	Capacity	Performance	Design	Convenience	Environment
VW	4	6	7	8	5
Audi	8	7	8	8	6
Toyota	7	5	6	8	7
Nissan	6	4	3	2	8

Based on the data discussed above, an HDM tree was constructed for each respondent. Figure 5 shows the HDM tree for Tracy. The most important cost criterion for Tracy was maintenance cost (0.43), and the most important benefit criterion was capacity (0.27). Overall benefits are more important than costs (0.7 versus 0.3). Even though the Nissan costs less, the best choice for Tracy is the Toyota Prius with a score of 0.3 followed closely by the Nissan LEAF (0.28).

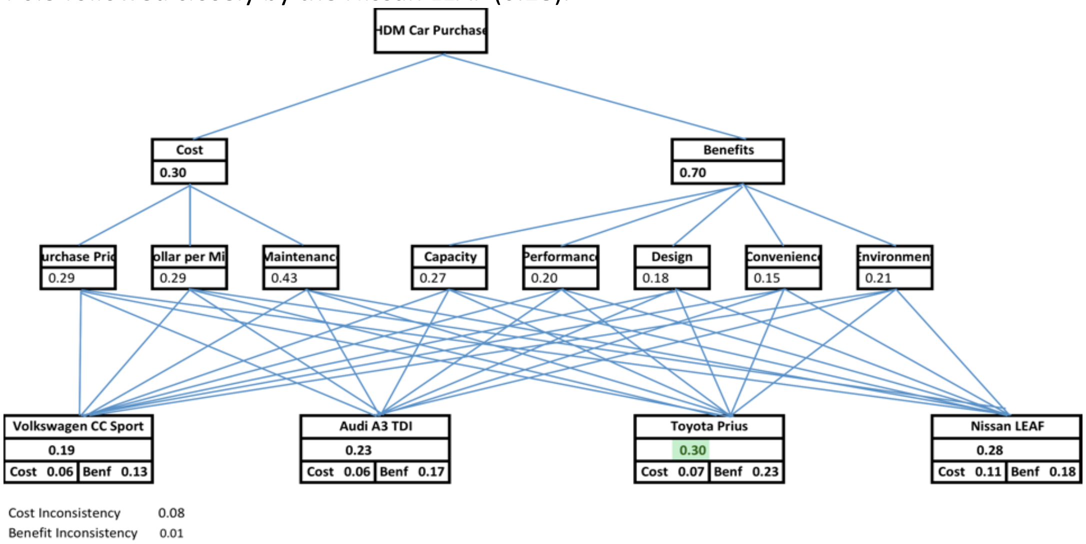


Figure 5 HDM for Tracy

Table 6 shows the final HDM scores for all respondents. Note that for respondents who value cost more than benefits (cost > 0.5) the Nissan LEAF is the best alternative. For respondents that value benefits more than cost, the subjective evaluation of benefits plays an important role. For instance, Ben ranked the Audi very high on four out of the five criteria (see Table 5). Thus, the Audi is the best alternative for Ben.

Table 6 Summary of HDM scores for all respondents

	VW	Audi	Toyota	Nissan	Cost/ Benefit
R1	0.22	0.22	0.25	0.31	**0.60**
R2	0.19	0.21	0.28	0.32	**0.50**
R3	0.22	0.24	0.29	0.25	**0.30**
R4	0.20	0.22	0.25	0.33	**0.50**
R5	0.19	0.24	0.29	0.29	**0.40**
R6	0.22	0.23	0.25	0.31	**0.80**
Ben	0.23	0.27	0.26	0.23	**0.35**
Tracy	0.19	0.23	0.30	0.28	**0.30**

5.3 Decisions under Risk

Table 7 below shows the analysis of alternatives based on the subjective probability of lower, constant, or higher gas prices of Tracy. It is evident that the electric car is the best choice no matter how fuel prices will develop; however, only for the duration of tax credits. If the $7,500 rebate for the Nissan Leaf was removed, the expected value for Tracy drops for the electric car and the hybrid becomes the best option for minimizing cost (see Table 8). The total cost of ownership at $4 is different for Tracy than the cost data shown in the Appendix due to the fact that Tracy only travels 5K miles per year. The Appendix assumes 15K miles per year based on average data on US car drivers.

Table 7Expected Value for Tracy

	Probability	Volkswagen CC	Audi A3 TDI	Toyota Prius	Nissan LEAF
$2	0.10	US$40,417.00	US$40,119.82	US$36,566.00	US$35,104.50
$4	0.30	US$42,517.00	US$41,678.65	US$37,566.00	US$35,104.50
$6	0.60	US$44,617.00	US$43,237.47	US$38,566.00	US$35,104.50
	Expected Value	**US$43,567.00**	**US$42,458.06**	**US$38,066.00**	**US$35,104.50**

Table 8 Expected Value for Tracy (no tax credits)

	Probability	Volkswagen CC	Audi A3 TDI	Toyota Prius	Nissan LEAF
$2	0.10	US$40,417.00	US$40,119.82	US$36,566.00	US$42,604.50
$4	0.30	US$42,517.00	US$41,678.65	US$37,566.00	US$42,604.50
$6	0.60	US$44,617.00	US$43,237.47	US$38,566.00	US$42,604.50
	Expected Value	US$43,567.00	US$42,458.06	US$38,066.00	US$42,604.50

6 Discussion

6.1 Implications

The purpose of the paper was to describe and apply an analytical decision-making model for the purchase of a car depending on the powertrain. The model is useful in externalizing priorities and subjective evaluations and could be especially useful in situations of multiple decision-makers, as in the case of a family debating on the best car.

The HDM model does not take future gas prices into consideration nor does it account for the number of miles driven per year. Both of these variables are part of the expected value (decisions under risk). Thus, these two models complement each other well. The authors have shown that the car purchase decision is a very personal decision based on subjective evaluation of multiple criteria. This model lends itself for application beyond the field of academia. For example, in the form of an iPhone app. The Internet offers many websites for comparing objective criteria such as cost. What is lacking is a way to track subjective impressions after test driving a car, for example, driving fun, convenience, etc.

6.2 Limitations

During the selection of alternatives, the authors picked cars with a similar purchase price. However, hybrid car models are typically more expensive than the gasoline versions of the same make and model. Appendix 8.7 shows the purchase price and annual fuel cost for a selection of hybrid and gasoline vehicles. The authors accounted for the fact that hybrid models are typically sold with more extras than the base versions of the same gasoline model. By selecting the appropriate trim and add-ons for the gasoline version, the authors were able to select comparable models for both powertrain types. Still, hybrid cars are sold at a 10 percent premium compared to the gasoline equivalents. Thus, it takes on average four years to recoup the hybrid adder through fuel cost savings. In this paper the gasoline and diesel vehicles had a higher purchase price than the hybrid car, which is not a reflection of reality, except for the Ford Lincoln MKZ which was the first manufacturer to introduce the gasoline and hybrid versions at the same price. Therefore, future analysis of comparable models would be beneficial.

7 References

[1] “The Wheels of Life.” [Online]. Available: http://www.homeofficehighway.com/wp-content/uploads/2008/08/wheel-life-cartoon.gif.

[2] “Car Models by Make,” *Department of Energy*.[Online]. Available: http://www.fueleconomy.gov/feg/advancedSearch.htm. [Accessed: 17-May-2011].

[3] *Automotive Technology: Greener Products, Changing Skills, Powertrain &FueL report*. Center for Automotive Research, 2011.

[4] S. Ramesh, “The Growing Importance of Alternative Automotive Powertrain Technologies,” *Frost and Sullivan*, 04-Feb-2009.[Online]. Available: http://www.frost.com/prod/servlet/market-insight-top.pag?docid=157704512. [Accessed: 17-May-2011].

[5] “History of Hybrid Vehicles | Hybrid Cars.” [Online]. Available: http://www.hybridcars.com/history/history-of-hybrid-vehicles.html. [Accessed: 15-May-2011].

[6] “Hybrid Car Tax Credits: Incentives Fade into Memory,” *Hybrid Cars*, 07-Feb-2011. [Online]. Available: http://www.hybridcars.com/federal-incentives.html. [Accessed: 17-May-2011].

[7] “Federal Tax Credit for Electric Vehicles Purchased in or after 2010,” *U.S. Department of Energy*, 04-May-2011.[Online]. Available: http://www.fueleconomy.gov/feg/taxevb.shtml. [Accessed: 17-May-2011].

[8] “2011 Electric Cars in the USA: Here’s the Lineup.” [Online]. Available: http://www.practicalenvironmentalist.com/automobiles/2011-electric-cars-usa.htm. [Accessed: 13-Apr-2011].

[9] *2011 U.S. Green Automotive Study*. J.D. Power and Associates, 2011.

[10] “HowStuffWorks ‘How Diesel Engines Work’.”[Online]. Available: http://www.howstuffworks.com/diesel.htm. [Accessed: 15-May-2011].

[11] “Car Shoppers More Environmentally Aware Than Once Thought,” *Hybrid Cars*, 24-Sep-2008. [Online]. Available: http://www.hybridcars.com/news/car-shoppers-more-environmentally-aware-once-thought-25045.html. [Accessed: 17-May-2011].

[12] *2008 Alternative Powertrain Study*. J.D. Power and Associates, 2008.

[13] D. Zetu, M. J. Jay, J. Cheng, and B. Lo, “When will a Consumer Consider Buying Another Car?,” *Information Technology: Research and Education, 2003. Proceedings. ITRE2003. International Conference on*, pp. 530-534, Aug. 2003.

[14] M. Barletta, “Who’s Really Buying that Car? Ask Her.,” *Brandweek*, vol. 47, no. 32, p. 20, Sep. 2006.

[15] T. Warren, “What Women Want….,”*AutoWeek*, vol. 56, no. 5, pp. 20-21, Jan. 2006.

[16] *Eco Watch September 2008*. Kelly Blue Book Marketing Research.

[17] “Fickle Hybrid Shoppers and Loyal Hybrid Drivers,” *Hybrid Cars*, 14-Aug-2008.[Online]. Available: http://www.hybridcars.com/hybrid-drivers/fickle-hybrid-shoppers-and-loyal-hybrid-drivers-0814.html. [Accessed: 20-May-2011].

[18] C. Devitt, “Automaker Woes Threaten Midwest Ratings.,” *Bond Buyer*, vol. 368, no. 33106, pp. 1-8, Apr. 2009.

[19] J. D. Oliver and Seung-Hee Lee, “Hybrid car purchase intentions: a cross-cultural analysis.,” *Journal of Consumer Marketing*, vol. 27, no. 2, pp. 96-103, Mar. 2010.

[20] B. Caulfield, S. Farrell, and B. McMahon, “Examining individuals preferences for hybrid electric and alternatively fuelled vehicles.,” *Transport Policy*, vol. 17, no. 6, pp. 381-387, Nov. 2010.

[21] *2008 Power Auto Offline Media Report*. J.D. Power and Associates, 2008.

[22] D.-H. Byun, “The AHP approach for selecting an automobile purchase model,” *Information & Management*, vol. 38, no. 5, pp. 289-297, Apr. 2001.

[23] D. I. Cleland and D. F. Kocaoglu, “10 - Decision-Making Methodologies,” in *Engineering Management*, McGraw-Hill, 1981, pp. 297-338.
[24] “Electric Power Annual Data Tables.” .
[25] “Total Cost to Own - 2011 Volkswagen CC Sport - Yahoo! Autos,” *Yahoo Autos*. [Online]. Available: http://autos.yahoo.com/volkswagen/cc/2011/sport/cost.html. [Accessed: 03-Jun-2011].
[26] “Hybrid Center□:: How Hybrid Cars work□:: under the hood 2.” [Online]. Available: http://www.hybridcenter.org/hybrid-center-how-hybrid-cars-work-under-the-hood-2.html. [Accessed: 15-May-2011].
[27] “A Student’s Guide to Alternative Fuel Vehicles - Electric Vehicles,” *California Engergy Commission*, 03-Jun-2002.[Online]. Available: http://www.energyquest.ca.gov/transportation/electric.html. [Accessed: 15-May-2011].
[28] “HowStuffWorks ‘Inside an Electric Car’.”[Online]. Available: http://auto.howstuffworks.com/electric-car2.htm. [Accessed: 15-May-2011].
[29] “Electric Cars: How They Work.” [Online]. Available: http://library.thinkquest.org/20463/howtheywork.html. [Accessed: 15-May-2011].
[30] “HowStuffWorks ‘How Car Engines Work’.”[Online]. Available: http://www.howstuffworks.com/engine.htm. [Accessed: 15-May-2011].
[31] “U.S. Retail Gasoline Historical Prices.” [Online]. Available: http://www.eia.doe.gov/oil_gas/petroleum/data_publications/wrgp/mogas_history.html. [Accessed: 13-Apr-2011].

8 Appendices

8.1 Survey I: Importance of Financial and Benefit Criteria

Assume that you are in the market for a car. Your budget is $30K, you are only looking at sedan options, and your average daily round trip takes 20 miles.

1. Please indicate which of the following factors influence your buying decision. Please rank them on a scale from 1 to 5, with 1 being not important at all, and 5 very important

Financial Criteria	Not important				Very Important
	1	2	3	4	5
Purchase price					
Dollar per mile*					
Resale value					
Maintenance cost (insurance, oil change)					
Tax (credits, road tax)					
Other financial criteria (please specify):					

* Dollar per mile is a function calculated using current gas price/electricity price and miles per gallon (MPG) or miles per charge (MPC) for gasoline and electric vehicles respectively.

Other Criteria	Not important				Very Important
	1	2	3	4	5
Capacity (passenger seating, trunk space, number of doors)					
Performance (horsepower, torque, 0-60MPS)					
Amenities (heated seats, back-seat entertainment, satellite radio, parking camera)					
Design					
Safety (front/side airbag, crash test rating)					
Brand (import, US-made, Japanese, etc.)					
Convenience (access to fuel, range)					
Environmental impact (CO2 emissions, alternative technologies)					
Other (please specify):					

2. How important are costs relative to other car buying criteria? Please distribute 100 points between costs and other criteria to indicate how important one is relative to the other.

   Cost ____ ____ Other (total of 100 points)

Now, please imagine that gas prices will double over the next year.

3. Would your judgment of buying criteria change?
   - ☐ Yes
   - ☐ No

4. If yes, please repeat the ranking of buying criteria under the assumption that gas prices will double.

Financial Criteria	Not important				Very Important
	1	2	3	4	5
Purchase price					
Dollar per mile*					
Resale value					
Maintenance cost (insurance, oil change)					
Tax (credits, road tax)					
Other financial criteria(please specify):					

* Dollar per mile is a function calculated using current gas price/electricity price and miles per gallon (MPG) or miles per charge (MPC) for gasoline and electric vehicles respectively.

Other Criteria	Not important				Very Important
	1	2	3	4	5
Capacity (passenger seating, trunk space, number of doors)					
Performance (horsepower, torque, 0-60MPS)					
Amenities (heated seats, back-seat entertainment, satellite radio, parking camera)					
Design					
Safety (front/side airbag, crash test rating)					
Brand (import, US-made, Japanese, etc.)					
Convenience (access to fuel, range)					
Environmental impact (CO2 emissions, alternative technologies)					
Other (please specify):					

5. How important are costs relative to other car buying criteria? Please distribute 100 points between costs and other criteria to indicate how important one is relative to the other.
   Cost ____ ____ Other (total of 100 points)

Demographic Information

6. Gender
   - ☐ Male
   - ☐ Female
7. Number of adults in household: ___
8. Number of children (<18 years): _____
9. What is the highest level of education you have completed?
   - ☐ High school
   - ☐ Some College
   - ☐ College Degree (BS, BA)
   - ☐ Master's degree
   - ☐ Doctoral degree
10. What was/is your major?
    ____
11. I currently (multiple choice)
    - ☐ Work
    - ☐ Study
12. Please select your region of origin (citizenship)
    - ☐ USA

☐ Other, please specify___

8.2 Survey II: Pairwise Comparison of Criteria and Subjective Assessment of Alternatives

1. Have you purchased/do you intend to purchase a car in the last/next two years?
   ☐ Yes – please continue with the survey
   ☐ No – thank you very much for your time

2. What car make/model did/will you purchase?

   2.1. ________________________________

3. Please compare the following criteria by distributing 100 points between each pair

3.1. Cost pairwise comparison

Purchase Price			Dollar per Mile
Purchase Price			Maintenance cost
Dollar per Mile			Maintenance cost

3.2. Benefits pairwise comparison

Capacity			Performance
Capacity			Design
Capacity			Convenience*
Capacity			Environment**
Performance			Design
Performance			Convenience*
Performance			Environment**
Design			Convenience*
Design			Environment**
Convenience*			Environment**

*Convenience = access to fuel stations, charging time
**Environment = better for the environment

3.3. Cost/Benefit pairwise comparison

Total Cost			Total Benefits

3.4. How will gas prices change over the next five years? Please assign probabilities to falling, staying and rising gas prices (the probabilities should add up to 100%):
   ☐ Fall to $2 ________ (% probability)
   ☐ Stay at $4 ________ (% probability)
   ☐ Rise to $6 ________ (% probability)

4. If gas prices were to rise, would your judgment of the cost criteria change?
   ☐ Yes – Please answer question 4
   ☐ No – Please continue to question 5

5. If gas prices were to rise how would your judgment of cost criteria change? Please assign 100 points between each pair.

5.1. Cost/Benefit pairwise comparison

Total Cost			Total Benefits

5.2. Cost pairwise comparison

Purchase Price			Dollar per Mile
Purchase Price			Maintenance cost
Dollar per Mile			Maintenance cost

Personal Information

6. Please provide some background information.

6.1. Gender
☐ Male
☐ Female

6.2. Age
☐ <25
☐ 26-30
☐ 31-40
☐ 41-50
☐ 51-60
☐ over 60

6.3. What is the highest level of education you have completed?
☐ High school
☐ Some College
☐ College Degree (BS, BA)
☐ Master's degree
☐ Doctoral degree

6.4. What was/is your major?
☐ Engineering
☐ Business
☐ Liberal arts
☐ Other: please specify: ___________________

6.5. If you work, what industry do you work in?
☐ Agriculture, forestry, fishing, hunting, mining
☐ Creative and marketing
☐ Educational, health and social services
☐ Finance, insurance, real estate, rental
☐ High-Tech
☐ Public administration
☐ Other: please specify ___________________

6.6. What is your total annual household income?
☐ Less than $35,000
☐ $35,000 – $99,999
☐ $100,000 – $199,999
☐ $200,000 or more

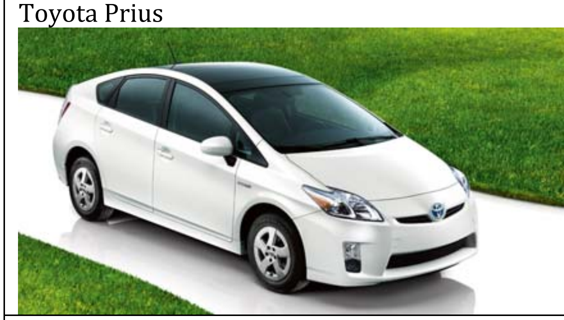
6.7. What type of vehicle do you currently own?
☐ Gasoline
☐ Diesel
☐ Hybrid
☐ Electric
☐ None
☐ Other

6.8. Will the new vehicle be your
☐ Primary mode of transportation?
☐ Second car for short trips
☐ Other:___________________

6.9. How many miles did you drive last year?
☐ <10K
☐ 10K-15K
☐ >15K

7. Please rank the following car models on a scale from 1 to 10, 10 being your personal optimum.

Car Model	Capacity	Performance	Design	Convenience	Environment
Volkswagen CC					
Audi A3 TDI					
Toyota Prius					
Nissan LEAF					
Your car (question 2.1)					

Volkswagon Comfort Coupe (CC) 	**Technology** Premium Gasoline **Performance** 2.0 Liter, 4 cylinder 7.4s 0-60 time 200 horsepower **Range** 416m per tank	**Capacity** Passengers: 4 Passenger: 94 ft3 Trunk: 13 ft3 **Environment** 162.4 average CO2 output g/kg
Audi A3 TDI 	**Technology** Diesel **Performance** 2.0 Liter, 4 cylinder 8.9s 0-60 time 140 horsepower (turbocharger) **Range** 450m per tank	**Capacity** Passengers: 5 Trunk (cubic feet): 20 **Environment** 143 average CO2 output g/kg
Toyota Prius 	**Technology** Hybrid, regular gasoline **Performance** 1.8 Liter, 4 cylinder 10.1s 0-60 time 134 horsepower **Range** 590m per tank	**Capacity** Passengers: 5 Trunk (cubic feet): 21.6 **Environment** 92.0 average CO2 output g/kg
Nissan LEAF 	**Technology** 100% electric **Performance** 90 mph max speed 80 kW AC motor 7s 0-60 time 107 horsepower **Range** 100m per charge	**Capacity** Passengers: 5 Trunk (cubic feet): 14.5 **Charge Time** 16 hours @ 120V 8 hours @ 240V **Environment** 0 average CO2 output g/kg (while driving)

8.3 Respondent Profile Survey II

The second survey was conducted outside of the ETM program to get a wider variety of respondents in terms of educational background.

Respondent Profile Survey II

	Miles	Gender	Education	Major	Industry	Old Car	New Car	New Car
R1	20,000	M	College Degree	Business	Health Care	Gas	Nissan Altima	Primary
R2	5,000	F	Some College	Liberal Arts	Health Care	Gas	Toyota Corrolla	Primary
R3	12,500	F	Some College	Engineering	Health Care	Gas	Toyota FJ Cruiser	Primary
R4	5,000	M	High School	Business	Health Care	Hybrid	Prius	Primary
R5	20,000	F	High School	Business	Health Care	Hybrid	Prius	Primary
R6	12,500	F	Some College	Criminal Justice	Health Care	Gas	VW Beetle	Primary
Ben	10,000	M	Doctoral Degree	Engineering	High-Tech	Gas	Lexus RXh	Primary
Tracy	5,000	F	Some College	Interior Design	N/A	Hybrid	Prius	Secondary

8.4 Cost Data for Alternatives

The table below shows the cost data obtained for each vehicle. The value for each alternative was normalized and used for the HDM.

Cost Data for Alternatives

	VW CC sport	Audi A3 TDI	Toyota Prius Four	Nissan LEAF
Base price[25]	US$28,400.00	US$28,100.00	US$27,000.00	US$33,720.00
Tax Credit[7]				US$7,500.00
Adjusted price	US$28,400.00	US$28,100.00	US$27,000.00	US$26,220.00
1/cost	3.521E-05	3.559E-05	3.704E-05	3.814E-05
Purchase price	0.241	0.244	0.254	0.261
Fuel type[25]	Premium Gas	Diesel	Regular	Electricity
Fuel price[25]	US$4.20	US$4.24	US$4.00	US$0.11
MPG/kWhpm[25]	25	34	50	0.25
Dollar per mile	US$0.17	US$0.12	US$0.08	US$0.03
Total per year	US$252.00	US$187.06	US$120.00	US$41.25
1/cost	5.952	8.019	12.500	36.364
Annual fuel cost	0.095	0.128	0.199	0.579
Repair [25]	US$1,983.00	US$2,378.00	US$1,488.00	US$1,488.00
Insurance[25]	US$5,691.00	US$5,158.00	US$4,969.00	US$5,051.00
Maintenance[25]	US$2,243.00	US$2,925.00	US$2,109.00	US$1,658.00
Total 5 years	US$9,917.00	US$10,461.00	US$8,566.00	US$8,197.00
1/cost	1.008E-04	9.559E-05	1.167E-04	1.220E-04
Maintenance (5 years)	0.232	0.220	0.268	0.280
Total Cost to Own	US$39,577.00	US$39,496.29	US$36,166.00	US$34,623.25
1/cost	2.527E-05	2.532E-05	2.765E-05	2.888E-05
	0.236	0.236	0.258	0.270

Assumptions:

Miles per year	15000
Ownership periods (yrs):	5

8.5 Details on Alternative Powertrain Technologies

8.5.1 The Hybrid Vehicle

In 1898 a German inventor, the 23-year-old Ferdinand Porsche, built his first car the Lohner Electric Chaise (see Figure 6). It was the world's first front-wheel-drive. Porsche's second car was a hybrid, using an internal combustion engine to spin a generator that provided power to electric motors located in the wheel hubs. On battery alone, the car could travel nearly 40 miles [5].

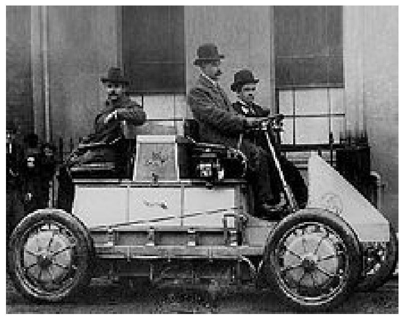


Figure 6The Lohner-Porsche Mixte Hybrid was the first gasoline-electric hybrid automobile.

Today's hybrid vehicles employ one of three different types of drivetrains: the series drivetrain, the parallel drivetrain, and the series/parallel drivetrain [26].The series drivetrain is the least complicated of the drivetrains (see Figure 7 for an illustration). In a series hybrid, the electric motor is the only means of providing power to get the wheels turning. The motor receives electric power from either the battery pack or from a generator run by a gasoline engine. A computer determines how much of the power comes from the battery or the engine/generator set. Both the engine/generator and regenerative braking recharge the battery pack. The engine is typically smaller in a series drivetrain because it only has to meet average driving power demands; the battery pack is generally more powerful than the one in parallel hybrids, in order to provide remaining peak driving power needs. This larger battery and motor, along with the generator, add to the cost, making series hybrids more expensive than parallel hybrids. Because series drivetrains perform best in stop-and-go driving, they are primarily being considered for buses and other urban work vehicles [26].

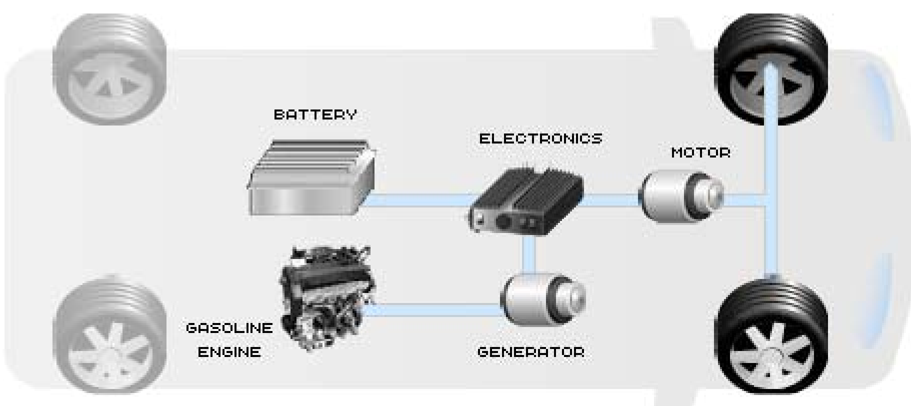


Figure 7 The Series Drivetrain Hybrid Technology **[26]**

With a parallel hybrid electric vehicle, both the engine and the electric motor generate the power that drives the wheels (see Figure 8 for detailed illustration). The addition of computer controls and a transmission allow these components to work together. Parallel hybrids can use a smaller battery pack and therefore rely mainly on regenerative braking to keep it recharged. However, when power demands are low, parallel hybrids also utilize the drive motor as a generator for supplemental recharging, much like an alternator in conventional cars. Since, the engine is connected directly to the wheels in this setup, it eliminates the inefficiency of converting mechanical power to electricity and back, which makes these hybrids quite efficient on the highway. Yet the same direct connection between the engine and the wheels that increases highway efficiency compared to a series hybrid does reduce, but not eliminate, the city driving efficiency benefits (i.e. the engine operates inefficiently in stop-and-go driving because it is forced to meet the associated widely varying power demands) [26].

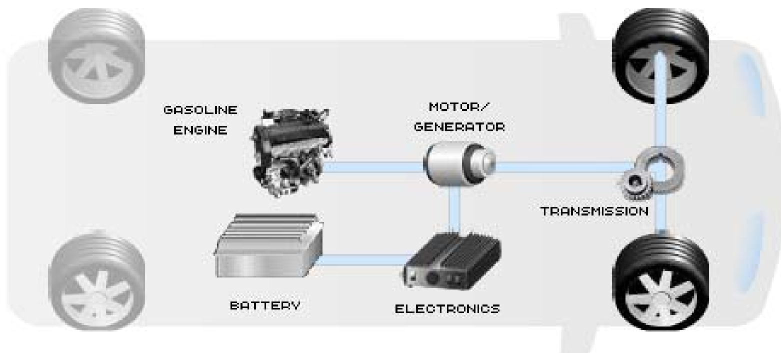


Figure 8 The Parallel Drivetrain Hybrid Technology **[26]**

The series-parallel drivetrain merges the advantages and complications of the parallel and series drivetrains (see Figure 9 for detailed illustration). By combining the two designs, the engine can both drive the wheels directly (as in the parallel drivetrain) and be effectively disconnected from the wheels so that only the electric motor powers the wheels (as in the series drivetrain). The Toyota Prius has made this concept popular, and a similar technology is also in the new Ford Escape Hybrid. As a result of this dual drivetrain, the engine operates at near optimum efficiency more often. At lower speeds it operates more as a series vehicle, while at high speeds, where the series drivetrain is less efficient, the engine takes over and energy loss is minimized. This system incurs higher costs than a pure parallel hybrid since it needs a generator, a larger battery pack, and more computing power to control the dual system. However, the series/parallel drivetrain has the potential to perform better than either of the systems alone. [26]

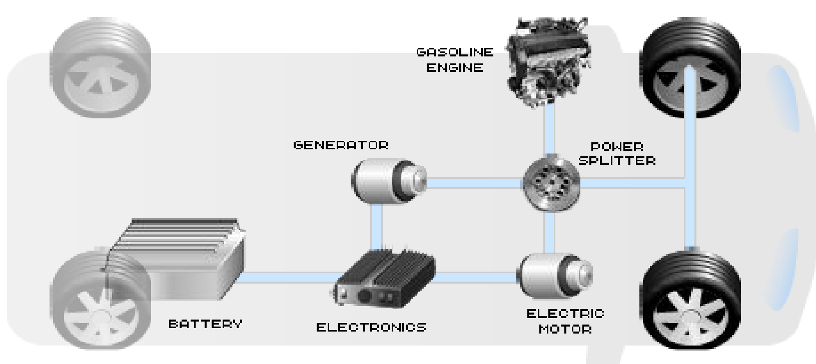


Figure 9 The Series-Parallel Drivetrain Hybrid Technology **[26]**

8.5.2 The Electric Vehicle

In 1839, Robert Anderson of Aberdeen, Scotland built the first electric vehicle [5].In the early 1900s there were more electric vehicles than there were gasoline-powered cars. Figure 10 shows the Rauch and Lang Electric Sedan, built in 1922, as an example of an early electric vehicle [27].

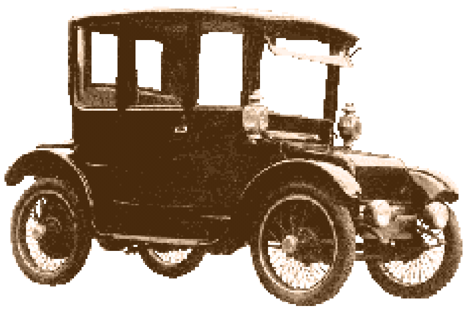


Figure 10 Rauch and Lang Electric Sedan Built in 1922 [27]

The "engine" of an electric car consists of the batteries, DC controller, and DC motor. The controller takes power from the batteries and delivers it to the motor. The accelerator pedal hooks to a pair of potentiometers (variable resistors), and these potentiometers provide the signal that tells the controller how much power it is supposed to deliver. Figure 11 depicts the operation of a simple DC controller. The controller can deliver zero power (when the car is stopped), full power (when the driver floors the accelerator pedal), or any power level in between [28].

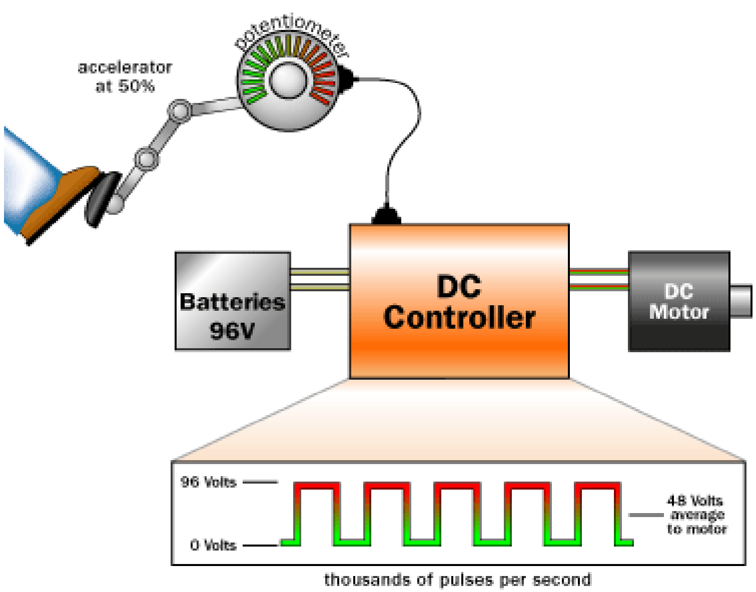


Figure 11 Operation of an Electric Vehicle [28]

Most controllers pulse the power more than 15,000 times per second, in order to keep the pulsation outside the range of human hearing. The pulsed current causes the motor housing to vibrate at that frequency, so by pulsing at more than 15,000 cycles per second, the controller and motor are silent to human ears[28].Everything else in the electric car is basically the same as in its gas-powered equivalent: transmission, brakes, air conditioning, and airbags. In fact, many newer electric cars actually have a single battery under the hood in addition to the battery pack. This solitary battery is constantly recharged by the main pack and it powers all of the electronic devices in the car, just like the battery in a gas-powered car[29]. There are three major types of electric motors in electric cars: DC Brushless, AC Induction, and the Permanent Magnet motor. Each has its advantages and disadvantages. The DC Brushless will offer the highest top speed, but the lowest acceleration. The AC Induction motor has the highest acceleration and an average top speed, but also has a higher price tag. The Permanent Magnet motor falls right in between the other two in both categories. There are also three different types of batteries: Lead Acid, Nickel-Metal Hydride, and Lithium. Lead Acid batteries are the most popular, the least expensive, and 97% recyclable. The Nickel-Metal Hydride batteries are smaller than the Lead Acid batteries, provide higher performance, and cost more. The Lithium Ion batteries provide the best performance, are smaller that the Lead Acid batteries, and are the most expensive. All three batteries have to be completely replaced every 3 or 4 years[29].

8.5.3 **The Gasoline Engine Vehicle**

In the early 1900's the gasoline engine car was not desirable, as gasoline was very expensive, and in order to start a gasoline engine one had to turn a crank on the front of the car. The cars were also noisy and produced lots of smoke from the exhaust. Once the electric starter was invented and gasoline was less expensive, the gasoline engine vehicle was the most popular vehicle sold[27]. In 1904 Henry Ford overcame the challenges posed by gasoline-powered cars — noise, vibration, and odor — and began assembly-line production of low-priced, lightweight, gas-powered vehicles. The purpose of a gasoline car engine is to convert gasoline into motion. Currently, the easiest way to create motion from gasoline is to burn the gasoline inside an engine. Almost all cars currently use what is called a four-stroke combustion cycle to convert gasoline into motion. The four-stroke approach is also known as the Otto cycle**,** in honor of Nikolaus Otto, who invented it in 1867. The core of the engine is the cylinder, with the pistons moving up and down inside the cylinder. In a multi-cylinder engine, the cylinders usually are arranged in one of three ways: inline**,** V or flat (see Figure 12). In the inline, the cylinders are arranged in a line in a single bank. In the V, the cylinders are arranged in two banks set at an angle to one another. In the flat, the cylinders are arranged in two banks on opposite sides of the engine[30].

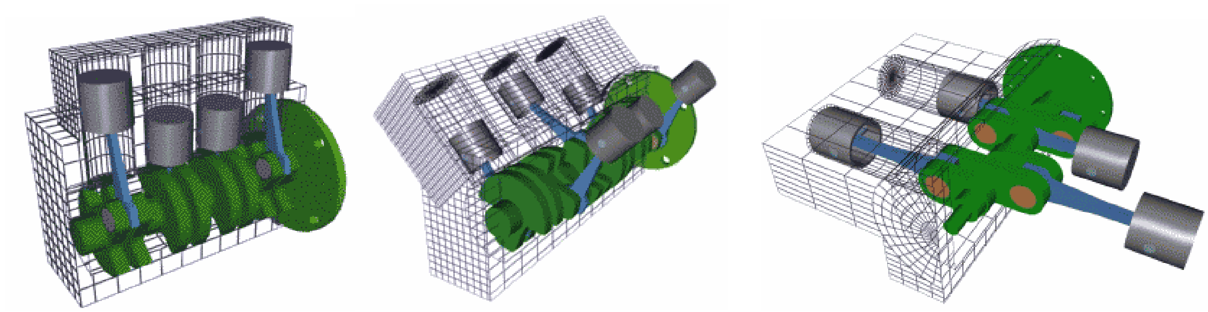


Figure 12 Arrangement of Multi-cylinder Engine: inline, V and flat (from left to right) [30]

The number of cylinders that an engine contains is an important factor in the overall performance of the engine. Each cylinder contains a piston that pumps inside of it and those pistons connect to and turn the crankshaft. The more pistons there are pumping, the more combustive events are taking place during any given moment. That means that more power can be generated in less time. The other key components of the gasoline engine include the spark plugs, valves, exhaust, and various liquids to keep everything running smoothly.

8.5.4 **The Diesel Engine Vehicle**

In 1878, Rudolf Diesel was attending the Polytechnic High School of Germany when he learned about the low efficiency of gasoline and steam engines. This inspired him to create an engine with a higher efficiency, and he devoted much of his time to developing a "Combustion Power Engine" [10]. By 1892 Diesel had obtained a patent for what is now call the diesel engine. Production of the diesel car started in 1933 with the Citroen Rosalie (see Figure 13)

Figure 13 Citroen Rosalie, 1933 [10]

In a diesel engine, there is no spark plug. Instead, diesel fuel is injected into the cylinder, and the heat and pressure of the compression stroke cause the fuel to ignite. Diesel fuel has a higher energy density than gasoline, so a diesel engine gets better mileage. In theory, diesel engines and gasoline engines are quite similar. They are both internal combustion engines designed to convert the chemical energy available in fuel into mechanical energy. This mechanical energy moves pistons up and down inside cylinders. The pistons are connected to a crankshaft, and the up-and-down motion of the pistons, known as linear motion, creates the rotary motion needed to turn the wheels of a car forward [10]. The major difference between diesel and gasoline is the way the explosions happen inside the cylinders. In a gasoline engine, fuel is mixed with air, compressed by pistons and ignited by sparks from spark plugs. In a diesel engine, however, the air is compressed first, and then the fuel is injected. Because air heats up when it's compressed, the fuel ignites. Diesel fuel is heavier and oilier than gasoline, and it evaporates much more slowly. It contains more carbon atoms in longer chains than gasoline does, and it takes less to refine it[10]. Over the past 30 to 40 years, vast improvements have been made on diesel engine performance and fuel cleanliness. Direct injection devices are now controlled by advanced computers that monitor fuel combustion, increasing efficiency and reducing emissions. Better-refined diesel fuels such as ultra-low sulfur diesel (ULSD) will lower the amount of harmful emissions and upgrading engines to make them compatible with cleaner fuel is becoming a simpler process [10].

8.6 Historic Gasoline and Electricity Prices

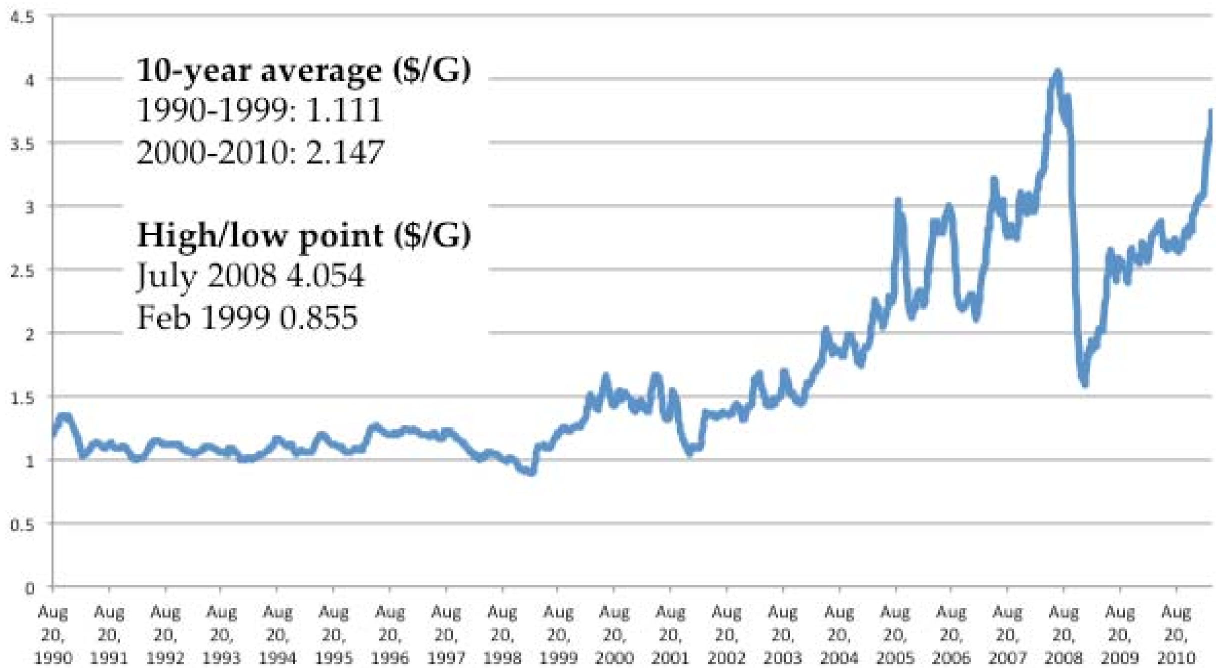


Figure 14Average Gasoline Price (Regular) in the US from 1990 to 2010[31]

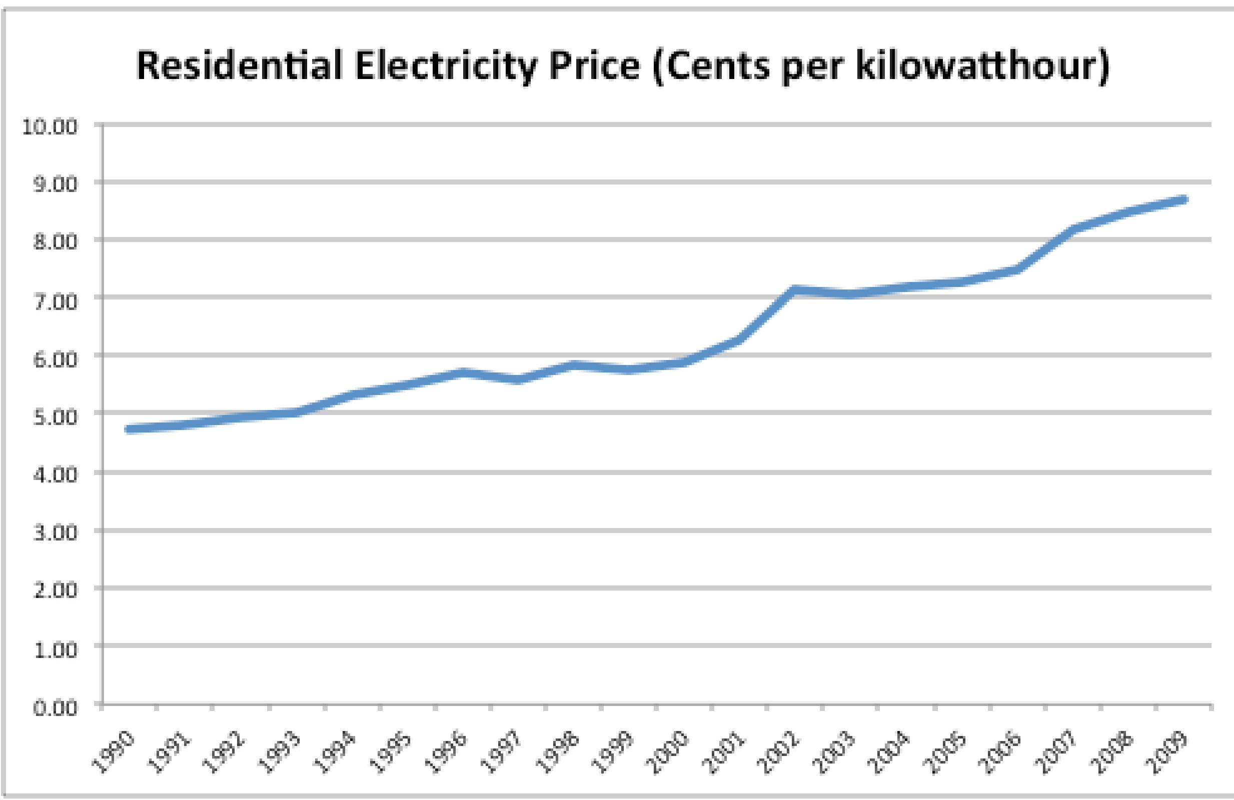


Figure 15Residential Electricity Price (Cents per Kilowatt hour) [24]

8.7 Hybrid vs. Gasoline Car Models

	Gasoline			Hybrid					
	MSRP	MPG	Annual fuel cost	MSRP	MPG	Annual fuel cost	Hybrid adder %	Fuel cost delta	Break-even (years)
Lexus RX 350/RX450h	$39,075	21.5	$2,930	$44,735	30	$2,100	114%	-$830	7
Ford Fusion SE/Hybrid	$25,405	25	$2,520	$28,675	39	$1,615	113%	-$905	4
Lexus IS/HS 250h	$33,295	23	$2,739	$36,330	34.5	$1,826	109%	-$913	3
Hyundai Sonata SE	$22,795	28.5	$2,211	$25,800	37.5	$1,680	113%	-$531	6
Nissan Altima	$20,270	27.5	$2,291	$22,348	34	$1,853	110%	-$438	5
Honda Civic EX/Hybrid	$22,405	30	$2,100	$23,950	41.5	$1,518	107%	-$582	3
Ford Lincoln MKZ	$35,000	22.5	$2,800	$35,000	38.5	$1,636	100%	-$1,164	0
Average:							**110%**	**-$766**	**4**

Assumptions:
15K miles per year
Dollar per gallon:

Regular	4
Premium	4.2
Diesel	4.24