Economic and Environmental Optimization of Vehicle Fleets: A Case Study of the Impacts of Policy, Market, Utilization, and Technological Factors

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ABSTRACT

This paper focuses on the economic and environmental optimization of vehicle replacement decisions. A new type of vehicle replacement model (VRM) that minimizes purchase, operating, maintenance, and emissions costs is proposed. An integer programming VRM is adapted from literature to represent current environmental and policy issues such as greenhouse gas (GHG) taxes and incentives for electric vehicle purchases. This research also analyzes the impacts of utilization (mileage per year per vehicle) and gasoline prices on fleet management decisions estimating energy and emissions reductions for a variety of fleet replacement scenarios using real-world data in the United States. Findings include: (a) fuel efficient vehicles such as hybrid and electric vehicles are purchased only in scenarios with high gasoline prices and/or utilization, (b) current European CO_2 cap and trade emissions price (around $18.7/ton) do not significantly alter fleet management decisions, and (c) electric vehicle incentives (i.e., tax credits) do increase the rate of purchases of hybrid or electric vehicles in scenarios with high gasoline prices and vehicle utilization. This research indicates that the proposed model can be effectively used to inform environmental and fiscal policies regarding vehicle regulations, tax incentives, and GHG emissions.

Keywords: Vehicle Replacement Models, Greenhouse Gas (GHG) Emissions, Hybrid Vehicles, Electric Vehicles, Vehicle Characteristics, Emissions Price, Cost Comparison.

1. Introduction

The recent volatility of fossil fuel prices and the growing concern regarding the environmental costs of fossil fuel production have drawn attention to the need to reduce energy consumption and diversify into cleaner energy sources. Simultaneously, vehicle technologies are rapidly evolving and the automobile market is changing accordingly. In particular, electric vehicle technology is considered by many environmental advocates as a promising solution to reduce fossil fuel consumption and GHG emission levels [1]. In this research, the following convention is used to denote different types of vehicles and engine technologies. Internal combustion engine vehicles, also called *conventional vehicles*, use gasoline or a fossil fuel as the only source of energy. *Hybrid vehicles* (HV) or (HEV) have an internal combustion engine but also a battery that can be used to power the vehicle wheels. *Plug-in-Hybrid Electric Vehicles* (PHEV) are similar to HVs but usually with a higher capacity battery. Additionally, PHEVs can be *plugged in* to the electrical grid, hence, the PHEV battery is mostly recharged using the grid. Finally, *electric vehicles* (EV) only have an electrical engine and no combustion engine.

Although still a small share of the automobile marketplace, hybrid vehicle models and sales have been growing steadily. It is now possible to buy several kinds of HVs such as the Toyota Prius, Honda Civic, or Ford Escape. Even luxury brands such Lexus and Porsche are working on sporty hybrid vehicles[1]. At the time this writing (October 2010), Mitsubishi has already launched the i-MiEV in Japan (April 2010) and several car makers are about to release into the market new EV or PHEV models; for example, the Nissan EV Leaf (December 2010) and the Toyota PHEV Prius (2012)[2]. An intermediate alternative between EVs and conventional vehicles is the Chevrolet Volt that can be powered by an electric motor for 40 miles and a battery that can be recharged by an internal combustion engine or at a charging station.

Economic conditions are also evolving rapidly. After the growth and expansion observed in the middle of the decade, the current economic crisis that started in late 2007 is limiting the consumer's disposable income and access to credit. At the fleet level, private companies and state agencies have been forced to adopt comprehensive planning approaches that seek to reduce operating costs, maintain customers' service levels, and whenever possible, continue sustainable practices or cap GHG emissions.

Decision makers are faced with complex tradeoffs involving economic, environmental, or policy impacts of fleet management decisions or regulations. This research aims to provide a better understanding of the monetary, emissions, and energy consumption tradeoffs associated with distinct vehicle technologies (conventional fossil fuel based vehicles, hybrid, and electric vehicles) utilizing

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[1] http://www.hybridcars.com/carmakers.html, accessed October 10, 2010.
[2] http://www.economist.com, "A sparky new motor", The Economist, October 9th, 2010, online and printed edition

current real-world data. From a private company perspective, natural questions to ask include: What kind of new engine/vehicle technologies are cost-competitive? What is the impact of fuel prices on vehicle replacement decisions? Given an existing conventional vehicle fleet, what are policy best practices for replacing vehicles in the future? From the government perspective, natural questions to ask include: What type of fuel will provide the greatest GHG reduction for typical commercial vehicle fleet utilization? What type of incentives provides the greatest rate of return in term of GHG and costs? What level of incentives are necessary to encourage private companies adopt new greener technologies?

The specific contributions of this research include: (a) incorporation of GHG costs into fleet vehicle replacement-type models, (b) analysis of the competitiveness of new engine technologies, and (c) evaluation of the impacts of policies (tax credits), usage (miles per year), environmental conditions (CO_2 costs), and market conditions (fuel prices) on the competitiveness of new technologies.

This paper is organized as follows. Section two presents a literature review. Section three introduces the notation and formulation of the fleet management model employed in this research. Section four describes data sources and model inputs. Section five describes the base case scenario and the alternative fifteen scenarios utilized to study the tradeoffs among technologies, GHG costs, fiscal policies, and fuel prices. Section six highlights key results and section seven ends with conclusions.

2. Literature and Data Review

Since GHG emissions are largely dependent on the level of consumption of the available forms of gasoline or diesel fuels, private companies have natural economic incentives to use vehicles that are more fuel efficient or powered by less expensive and cleaner energy sources. Incentives to use greener technologies may be compounded by the fact that government incentives exist, e.g. a type of "cash for clunkers" program or tax breaks for new electric vehicles. However, more energy efficient PHEV or EVs have higher upfront purchase prices than conventional gasoline engines in the same vehicle class. This is clearly the case for EVs; a Nissan Leaf has a purchase price of approximately $33,720 whereas a similar size conventional Ford Fiesta has a purchase price of approximately $13,200[3]. In addition, as vehicles age, their value decreases (depreciation) and operating and maintenance (O&M) costs tend to increase. Depreciation and maintenance costs are dependent on the vehicle/engine type as well as utilization and maintenance policies.

The Management Science and Operations Research (MS/OR) literature pioneered the usage of vehicle replacement models (VRM) to optimize decisions regarding vehicle purchases, scrapping, maintenance, and utilization. A formal optimization model, dealing with a similar but the more general

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[3] www.kbb.com, Kelly Blue Book new and used car prices, accessed July 15, 2010.

topic of equipment replacement models, was first introduced in the 1950's [2]. Another important development was the addition of *parallel replacement models* where management decisions are made for a set of machines or vehicles instead of one machine or vehicle at the time [3]. Although the machine or vehicle replacement literature is rich in models dealing with budget constraints [4], variable utilization [5], stochastic demands [6], and several vehicle types [7] these models are incomplete from an environmental or political standpoint.

Despite the modeling advances in VRMs since the 1950's, scant or null attention has been given in the fleet replacement literature to fleet costs associated with emissions and energy sources. Some researchers used averages and simpler economic models to evaluate the benefits of HVs over conventional vehicles. For example, researchers concluded that the hybrid Toyota Prius was not cost effective in improving fuel economy or lowering emissions against a conventional Toyota Corolla [8].

Other researchers have focused on the statistical analysis of fleet data and the relationships among age, utilization and costs [9-11]. Another line of research has focused on general life cycle optimization of vehicle replacement decisions [12, 13]; however, these approaches cannot be directly applied to a specific fleet because they were intended for policy planning purposes. Specifically, these life cycle models are not useful for a fleet manager because they do not provide requisite answers regarding *when*, *how*, and *what* to replace/scrap over time as a function of costs and utilization. Although this type of research can provide useful insights regarding the general timing of scrapping decisions or the probability of vehicle breakdown, it cannot be used to forecast or analyze the competitiveness of new technologies or vehicle types.

To the best of the authors' knowledge there is no published research that simultaneously incorporates into fleet management models the impacts of new engine technologies, GHG costs, fiscal policies, and market conditions.

3. Decision Model

The fleet replacement model described in this section aims to provide answers regarding *when*, *how*, and *what* to purchase/replace or salvage/scrap over time as a function of cost and utilization. The goal is to present a model that is parsimonious yet can evaluate the impacts of new engine technologies, GHG costs, fiscal policies, and market conditions. The VRM utilized in this paper is an extension of the work of Hartman [14] but also incorporates multiple vehicle types and GHG emissions costs associated to (a) vehicle utilization and (b) production costs.

For the sake of readability and easy interpretation of the model, decision variables or the cardinality of a set are denoted as capital letters; sets are denoted by bold capital letters; and parameters

are denoted using small letters, broken down in four categories (constraints, cost or revenue, emissions, and initial conditions).

Model Formulation

Indexes

Age of a vehicle type k in years: $i \in \mathbf{A}_k = \{0, 1, 2, \ldots, A_k\}$,

Time periods, decisions are taken at the end of each year: $j \in \mathbf{T} = \{0, 1, 2, \ldots, T\}$, and

Type of vehicle/engine: $k \in \mathbf{K} = \{1, 2, \ldots, K\}$.

Decision Variables

X_{ijk} = the number of i-year old, k-type vehicles in use from the end of year j to the end of year $j + 1$,

Y_{ijk} = the number of i-year old, k-type vehicle salvaged at the end of year j, and

P_{jk} = the number of k-type vehicles purchased at the end of year j.

Parameters

   (a) *Constraints*

$a_k = A_k$ = maximum age of vehicle type k (it must be salvaged when a vehicle reaches this age),

u_{ijk} = utilization (miles traveled by an i-year old, k-type vehicle during year j),

d_j = demand (miles traveled by all types of vehicle) from the end of year j to the end of year $j + 1$,

b_j = budget (available for purchasing new vehicles) constraint from the end of year j,

   (b) *Cost or revenue*

v_{jk} = cost of a k-type vehicle purchased at the end of year j,

om_{ik} = operation and maintenance cost per mile for an i-year old, k-type vehicle,

s_{ik} = salvage revenue (negative cost) from selling an i-old, k-type vehicle,

ec = emissions cost per ton of GHG,

dr_j = discount rate, value of money over time.

   (c) *Emissions*

ep_k = production emissions, in GHG equivalent tons, associated to a k-type vehicle,

es_k = scrapping emissions, in GHG equivalent tons, associated to a k-type vehicle,

em_{ik} = utilization emissions in GHG equivalent tons per mile for an i-year old, k-type vehicle, and

(d) Initial conditions

h_{ik} = the number of i-year old, k-type vehicles available at time zero.

Objective Function, minimize:

$$\sum_{j=0}^{T-1}\sum_{k=1}^{K}\left(v_{jk} + ep_k\, ec\right)P_{jk}\left(1 + dr_j\right)^{-j} + \sum_{i=0}^{N_k-1}\sum_{j=0}^{T-1}\sum_{k=1}^{K} om_{ik}u_{ijk}X_{ijk}\left(1 + dr_j\right)^{-j}$$

$$-\sum_{i=1}^{N_k}\sum_{j=0}^{T}\sum_{k=1}^{K}\left(s_{ik} - es_k\, ec\right)Y_{ijk}\left(1 + dr_j\right)^{-j} + \sum_{i=0}^{N_k-1}\sum_{j=0}^{T-1}\sum_{k=1}^{K} em_{ik}\, u_{ijk}\, ec\, X_{ijk}\left(1 + dr_j\right)^{-j} \quad (1)$$

Subject to:

$$\sum_{k=1}^{K} v_{jk} \cdot P_{jk} \leq b_j \qquad \forall j \in \{0,1,2,\dots,T-1\} \qquad (2)$$

$$\sum_{i=0}^{N_k-1}\sum_{k=1}^{K} X_{ijk} \cdot u_{ijk} \geq d_j \qquad \forall j \in \{0,1,2,\dots,T-1\} \quad (3)$$

$$P_{jk} = X_{0jk} \quad \forall j \in \{1,2,\dots,T-1\} \quad \forall k \in \mathbf{K} \qquad (4)$$

$$P_{0k} + h_{0k} = X_{00k} \quad \forall k \in \mathbf{K} \qquad (5)$$

$$X_{i0k} + Y_{i0k} = h_{ik} \qquad \forall i \in \{1,2,\dots,A_k\}, \forall k \in \mathbf{K} \qquad (6)$$

$$X_{(i-1)(j-1)k} = X_{ijk} + Y_{ijk} \qquad \forall i \in \{1,2,\dots,A_k\}, \forall j \in \{1,2,\dots,T\}, \forall k \in \mathbf{K} \qquad (7)$$

$$X_{iTk} = 0 \quad \forall i \in \{0,1,2,\dots,A_k-1\} \quad \forall k \in \mathbf{K} \qquad (8)$$

$$X_{A_k jk} = 0 \quad \forall j \in \{0,1,2,\dots,T\} \quad \forall k \in \mathbf{K} \qquad (9)$$

$$Y_{0jk} = 0 \quad \forall j \in \{0, 1, 2, \dots, T\} \quad \forall k \in \mathbf{K} \qquad (10)$$

$$P_{jk}, X_{ijk}, Y_{ijk} \in \mathbf{I} = \{0, 1, 2, \dots\} \qquad (11)$$

The objective function, expression (1), minimizes the sum of purchasing, maintenance, operation, salvage, and emissions costs over the period of analysis, i.e. from time zero (present) to the end of year T. Purchase costs cannot exceed the yearly budget, expression (2). The number of vehicles in the fleet at any time must equal or exceed the minimum needed to cover the demand in terms of annual miles traveled, expression (3). The number of vehicles purchased must equal the number of new vehicles for each vehicle type and year, except for the current time, expression (4); the number of new vehicles utilized during year zero must equal the sum of existing new vehicles plus purchased vehicles, expression (5). Similarly, expression (6) ensures the conservation of vehicles, i.e. the initial vehicles (not 0-age ones) must be either used or sold. The age of any vehicle in use will increase by 1 year after each time period (7). At the end of the last time period, there will be no vehicle in use for any age or type of vehicles, i.e. all vehicles will be sold at the corresponding salvage value, which is a function of vehicle type and age (8). When a vehicle reaches its allowable maximum age, a function of vehicle type, the vehicle must be sold at the corresponding salvage value (9). A newly purchased vehicle should not be sold before use (10). Finally, the decision variables associated to purchasing, utilization, and salvaging decisions must be integer positive numbers, expression (11).

4. Data Sources

The VRM model presented in the previous section allows for a complete accounting and optimization of purchasing, operations, maintenance, and emissions costs. The model is data intensive because it requires that the analyst prepares matrices with purchase cost, operations and maintenance, salvage values, and emissions costs as a function of vehicle type and age or time period ($v_{ik}, om_{ik}, s_{ik},$ and em_{ik} respectively). Herein, it is assumed that data sources, vehicle types, and results are applicable to the United States market (see Table 1). In particular, the model is applied to a homogenous segment of the market that comprises of the following competitors:

Table 1. Vehicles Analyzed

Model Brand	Engine Type	Purchase price	Efficiency
Ford Fiesta	Conventional	$13,320	34.5 mpg
Toyota Yaris	Conventional	$12,605	32.5 mpg
Honda Insight	Hybrid	$19,800	41.5 mpg
Nissan Leaf	Electric	$33,720	4 mi/Kwh
Average		$19,861	

Purchase prices in the United States were obtained from Kelly's Blue Book [15]. Similarly, depreciation or salvage values as a function of age and utilization by vehicle type were obtained from Kelly's Blue Book.   Purchase price includes manufacturer's suggested retail price (MSRP), registration, and delivery assuming that the destination is Portland, Oregon. In the case of electric vehicles there is no market or historical information regarding depreciation or salvage values. It is assumed that EVs have the same depreciation rate that hybrid vehicles have. Fuel efficiency is assumed to be the average of highway and city miles per gallon (mpg) values using US Environmental Protection Agency procedures[4]. In the case of the Nissan leaf a consumption of 0.25 Kilowatt hour per mile is assumed [16].

Maintenance and operating costs were obtained from historical cost fleet data provided by the Oregon Department of Transportation (ODOT) fleet management division. ODOT's fleet of sedans includes conventional and hybrid vehicles. ODOT's fleet management division has been collaborating with Oregon Universities and other studies have studied ODOT's replacement policies and cost functions [17, 18].   As vehicles age, in general, it is possible to observe a steady increase in O&M cost over time (see Figure 1). Due to the lack of EVs maintenance and operating cost records, EV maintenance and operating costs are assumed to be similar to hybrid vehicles costs.

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[4] www.fueleconomy.gov, accessed July 15, 2010.
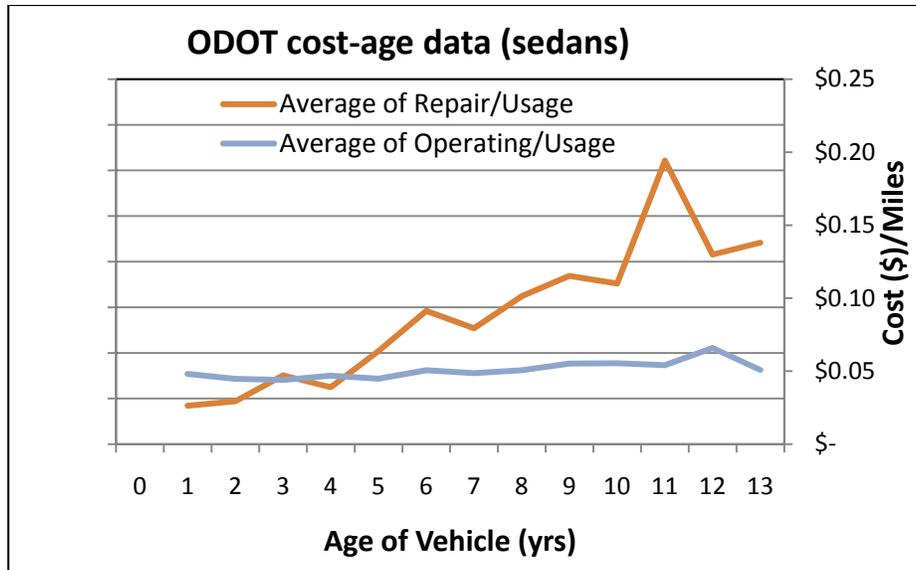
Figure 1- An example of a sedan's operation and repair costs ($/mile vs. age)

The typical period of ownership at ODOT is approximately 14 years. Hence, the period of analysis is assumed to be 14 years and all vehicles are sold at the beginning of year 15. In order to study the penetration of hybrids and EVs into conventional fleets, the initial fleet of vehicles is assumed to be 28 vehicles and the initial composition of the fleet is assumed to be comprised of Fords and Toyotas (50% for the Fiesta and Yaris, respectively). Purchasing budget constraints are set to $100,000 per year, which allows the purchase of up to five vehicles per year (utilizing an average purchase price across vehicle types, see Table 1). In terms of fleet size this translates into a maximum of 20% fleet turnover.

In terms of emissions, the level of GHG emissions associated with conventional vehicle utilization is estimated as a function of fuel efficiency, fuel type and its carbon content[5]. For emissions associated with the EV we assume the most favorable scenario, i.e. zero tailpipe emissions and 100% renewable *green* energy sources. In reality, a precise estimate of electric energy sources ("clean" vs. "dirty") can vary greatly as a function of time of day and location of the charging station [19]. The cost of GHG was estimated using the current European cap and trade value, around 18.7 $/ton, although this value fluctuates wildly over time [17, 18]. The cost of electricity is assumed to be $0.12/kWh (an average for the US) although this cost can vary greatly by time of day, location, and energy source [20]. Energy equivalence in terms BTUs for fossil fuels and electricity was estimated using coefficients from the Transportation Energy Data Book [21].

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[5] http://www.epa.gov/oms/climate/420f05001.htm, **"**Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel", US EPA, accessed July 15, 2010.

Regarding the value of the coefficients ep_k and es_k (manufacturing and scrapping, respectively), research results have consistently indicated that the utilization based emissions ($em_{ik}\, u_{ijk}$) dominate. For example, for a generic USA family sedan driven 120,000 miles the utilization share is over 84% of the life cycle energy and 87% of the generated CO_2 [21]; similar conclusions were reached and employed by other researchers [8]. Unfortunately, emissions costs associated to the production/scrapping of vehicles are undoubtedly the most difficult parameter to estimate [21-23]. In addition, battery technology is advancing rapidly and it is difficult to forecast future GHG costs associated to manufacturing, mining, and vehicle mass [24]. Furthermore, GHG emissions are in direct proportion of vehicle mass [25] and EVs can be lighter/smaller due to their simpler mechanics and fewer components. Hence, due to the lack of current EV manufacturing and scrapping GHG data, the high degree of uncertainty associated to the available estimates and the high vehicle utilization (mileage) this research assumes a value of $ep_k + es_k =$ 8.5 GHG tons for conventional vehicles and a value of $ep_k + es_k =$ 9.5 GHG tons for HVs and EVs.

Finally, since purchase and operating costs take place over time, this research assumed a discount rate equal to the average 20-year treasury yield[6]. High discount rates tend to penalize EVs due to their higher upfront purchase costs. We adopted the average 20-year treasury yield for October, 2010, which is equal to 3.5%. This is an unusually low rate in part due to the current recession and US Federal Reserve policies. A zero percent discount rate may be acceptable for GHG emissions analysis since the effects of CO_2 on global warming can be felt for decades or even centuries. However, this approach is not appropriate for a private company and the goal of this research is to analyze the current economic feasibility of different engine technologies.

5. Scenarios

Three different types of propulsion systems for economy passenger vehicle sedans are considered: conventional gasoline engines, hybrid engines, and electric engines. Four different factors are analyzed: GHG emissions costs, electric vehicle tax credits, annual utilization, and gasoline prices (see Table 2). These values generate the 16 scenarios depicted in Table 3 and analyzed in section 6.

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[6] http://www.treas.gov/offices/domestic-finance/debt-management/interest-rate/yield.shtml, Daily Treasury Yield Curve Rates, US Treasury, accessed October 28, 2010

Table 2. Extreme values used for VRM scenarios

	EV Tax Credit ($)	GHG Costs ($/ton)	Gasoline Prices ($/gallon)	Vehicle Utilization (miles)
Base Case (scenario 0)	0	0	2.72	13,000
Extreme Case (scenario 15)	7,500	18.7	4.10	19,000

Table 3. Scenarios

Scenario	Combination	EV TaxCredit	GHG Costs	High Gasoline Prices	High Vehicle Utilization
Scenario 0	BASELINE				
Scenario 1	1 Combination				High Vehicle Utilization
Scenario 2				High Gasoline Prices	
Scenario 3			GHG Costs		
Scenario 4		EV TaxCredit			
Scenario 5	2 Combination			High Gasoline Prices	High Vehicle Utilization
Scenario 6			GHG Costs		High Vehicle Utilization
Scenario 7		EV TaxCredit			High Vehicle Utilization
Scenario 8			GHG Costs	High Gasoline Prices	
Scenario 9		EV TaxCredit		High Gasoline Prices	
Scenario 10		EV TaxCredit	GHG Costs		
Scenario 11	3 Combination		GHG Costs	High Gasoline Prices	High Vehicle Utilization
Scenario 12		EV TaxCredit		High Gasoline Prices	High Vehicle Utilization
Scenario 13		EV TaxCredit	GHG Costs		High Vehicle Utilization
Scenario 14		EV TaxCredit	GHG Costs	High Gasoline Prices	
Scenario 15	Extreme Case	EV TaxCredit	GHG Costs	High Gasoline Prices	High Vehicle Utilization

For example, scenario one (S1) is the baseline case but with high vehicle utilization (19,000 miles instead of 13,000 miles). Scenario nine (S9) is the baseline case but with a tax credit of $7,500 for EVs and a gasoline price of $4.10 per gallon. If GHG costs are applied, i.e scenario S3, then $ec = \$18.7$ and zero dollars otherwise.

The values shown in the four columns of Table 2 were established based on: (a) the US federal government tax credit [19], (b) a median European value for GHG in \$/ton [26], (c) the current level of gasoline prices in the USA during July 2010 and the highest value of US gasoline prices reached in the summer of 2008 [27], and (d) the average vehicle utilization in the US and ODOT fleet and a high utilization that is the 90% percentile of the utilization distribution for ODOT's fleet of sedans [28].

6. Results and Discussion

For each scenario it is possible to minimize total costs over the planning horizon, expression (1); for each scenario the optimal evolution of the fleet is indicated by the decision variables X_{ijk} (vehicles in use), Y_{ijk} (vehicles salvaged), and P_{jk} (purchases). For example, Figure 2 shows the number of vehicles in use over time for the baseline scenario (scenario 0). In the base case the number Toyota Yaris are purchased steadily toward throughout the simulation due to their higher resale value (the Fiesta has the highest rate of depreciation). It is clear that conventional vehicles dominate purchasing decisions in the near future if we assume an average vehicle utilization rate, low fuel prices, no GHG costs, and no tax incentives for EVs. In this baseline scenario, the fuel efficiency of the fleet tends to decrease over time because the model can save the most money by purchasing the Yaris. In the baseline scenario the EV (Nissan Leaf) is not selected or purchased anytime during the 14-year planning horizon.
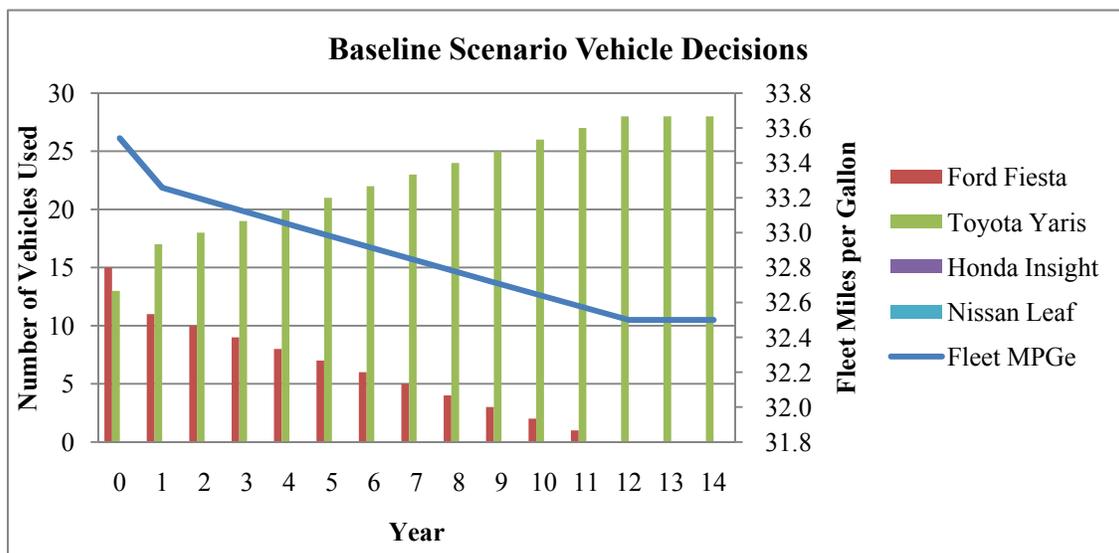
Figure 2. Baseline scenario vehicle decision progression.

Table 4 compares the baseline scenario (S0) to the various single combination scenarios (S1 to S4) and highlights the percentage changes in some key efficiency performance measures. For example, a 2.8% increase in row 1-column 1 indicates that higher vehicle utilization (19,000 miles per year per

vehicle instead of 13,000 miles per year per vehicle) results in higher fleet fuel efficiency over the 14 year analysis horizon. This result agrees with statistical analysis of the impact of fuel prices on automotive fleet composition which have shown that higher fuel prices shift new auto purchases towards more fuel-efficient vehicles and accelerates the scrappage of older, less fuel-efficient used vehicles [29]. Econometric estimates suggest that a 10 percent increase in gasoline prices from 2005 levels would generate a 0.22 percent increase in fleet fuel economy in the short run and a 2.04 percent increase in the long run.

Table 4. Baseline vs. Individual Factors

	Fleet MPG	Final HEV & EV Fleet (% difference)	Total CO2 / miles	Costs per Mile ($/mi)	Energy (BTU/mi)
S1/S0	2.8%	0.0%	-6.6%	-13.3%	-2.7%
S2/S0	2.8%	0.0%	-2.3%	19.9%	-2.7%
S3/S0	1.6%	0.0%	-1.3%	3.1%	-1.5%
S4/S0	0.0%	0.0%	0.0%	0.0%	0.0%

It is somewhat ironic that the EV tax credit does not alter the optimal policy on its own (see row S4/S0). On the other hand, high vehicle utilization leads to some of the most efficient outcomes on a per mile basis. Higher fuel costs or a "carbon tax" would also lead to a more efficient fleet and an overall reduction in energy consumption (in British Thermal Units per mile or BTU/mile) and GHG emission levels (in tons per mile).

Table 5. Baseline vs. Combined Factors (2 Combined)

	Fleet MPG	Final HEV & EV Fleet (% difference)	Total CO2 / miles	Costs per Mile ($/mi)	Energy (BTU/mi)
S5/S0	3.9%	0.0%	-7.5%	6.4%	-3.7%
S6/S0	2.8%	0.0%	-6.6%	-10.4%	-2.7%
S7/S0	2.8%	0.0%	-6.6%	-13.3%	-2.7%
S8/S0	2.8%	0.0%	-2.3%	23.0%	-2.7%
S9/S0	5.3%	3.57%	-5.0%	19.9%	-5.1%
S10/S0	1.6%	0.0%	-1.3%	3.1%	-1.5%

Table 5 compares the baseline scenario (S0) to the various double combination scenarios (S5 to S10). Unlike Table 4, an EV tax credit combined with high fuel prices leads to a highly efficient outcome in terms of fleet efficiency, GHG emissions, and energy consumption (see S9/S0 row). The combination

of high gas prices and utilization also leads to efficient fleets (see S5/S0 row). Table 6 compares the baseline scenario (S0) to the various triple combination scenarios (S11 to S14). In this case, the combination of high fuel prices, high utilization, and tax credit combined (row S12/S0). leads to the most efficient outcome in terms of fleet efficiency and emissions/energy consumption per mile. As expected, the most efficient fleet and the lowest level of energy consumption and emissions per mile is obtained when all four factors are combined (row S15/S0).

Table 6. Baseline vs. Combined Factors (3 and 4 Combined)

	Fleet MPG	Final HEV & EV Fleet (% difference)	Total CO_2 / miles	Costs per Mile ($/mi)	Energy (BTU/mi)
S11/S0	4.0%	0.0%	-7.6%	9.3%	-3.8%
S12/S0	71.8%	64.3%	-47.3%	2.4%	-38.6%
S13/S0	2.8%	0.0%	-6.6%	-10.4%	-2.7%
S14/S0	10.5%	10.7%	-10.0%	22.9%	-9.5%
S15/S0	72.8%	64.3%	-47.6%	4.2%	-38.9%

DISCUSSION

The results presented in the previous three tables highlight the variability in terms of outcomes. The recent volatility of fossil fuel prices produces uncertainty in the market. This uncertainty is compounded by the concerns regarding GHG levels, climate, and further government regulation to push for more competitive fuel efficiency standards. Higher fuel efficiency standards will have a significant impact on overall transportation emissions and energy levels [30]. On the other hand, the high levels of US government public debt lead to uncertainties regarding the feasibility of long-term tax incentives for EVs.

It is clear that the current European market cap and trade price of GHG emissions alone is not significant for fleet management decisions in the current market. On the other hand, technological changes are likely to have a significant impact on the competitiveness of EVs. For example, battery costs are expected to drop from $400 per kilowatt/hour ($400/kwh) to $200/kwh in four years; this would drop the price of the Nissan Leaf by $4,800. There is also great uncertainty in terms of EVs depreciation, maintenance, and operation costs. Car manufacturers seem optimistic since they are offering battery guarantees for eight years or 100,000 miles[7].

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[7] http://www.economist.com, "A sparky new motor", The Economist, October 9th, 2010, online and printed edition

Some factors that can affect the economic feasibility of EVs were not included in this research. For example, the issue of "range anxiety"; it was assumed that EVs have the same utilization as conventional and hybrid vehicles. Government subsidies and regulation will be necessary to provide fast charging stations. In Oregon, the state and federal government are subsidizing the construction of Level 3 charging stations that can provide an 80% recharge in 20 to 30 minutes and a network of 1,100 Level 2 charging stations across the state[8]. Other countries, like Israel, are experimenting with stations to swap batteries in a few minutes[9]. This study assumed that there are no costs associated to the charging infrastructure needed for EVs. However, a report prepared for the US Department of Energy indicates that the costs associated with providing charging infrastructure for EV or PHEV vehicles will be one of the key factors determining the success of this new "clean" technology[10]. Costs associated to home recharging stations are approximately $2,000 or more if the house has an outdated electrical installation; at the moment, the federal government and some cities are providing subsidies[11].

7. Conclusions

The VRM presented in this paper integrates traditional fleet management costs with environmental elements such as GHG equivalent Life Cycle Costs in terms of vehicle production and utilization. Employing real-world fleet and cost data, it was shown that VRMs can illuminate policy decisions and guide the usage of public and private resources to reduce monetary and environmental costs. Sophisticated decision tools and models are needed to manage the complex tradeoffs surrounding fleet management decisions.

For EVs to be competitive, it is clear that tax incentives are needed in the current environment with relative moderate fuel prices, higher initial purchase costs for EVs, and no carbon taxes. Gasoline prices have a great influence on vehicle replacement decisions and any increases will undoubtedly encourage the rate of high MPG vehicle purchases. With increased utilization, the same trend will be observed however GHG emission levels will not be significantly reduced. The current price of carbon from European cap and trade markets does not affect replacement decisions as much as gasoline price does. The results and discussion clearly indicate that more research is needed to follow the evolution of market prices and technologies. Fluctuations in terms of batteries, fuel prices or carbon taxes, and tax incentives or government subsidies can lead to dramatic changes in competitiveness.

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[8] http://www.oregonlive.com/business/index.ssf/2010/10/more_charging_stations_on_the.html , "More charging stations on the way for electric vehicles in Oregon" The Oregonian, accessed October 16, 2010

[9] http://www.abc.net.au/news/stories/2010/10/26/3047994.htm?section=justin , "Electric car fleet to hit the road in Israel", ABC news, accessed October 16, 2010

[10] http://avt.inel.gov/pdf/phev/phevInfrastructureReport08.pdf

[11] http://www.nytimes.com/pages/automobiles/autospecial2/index.html, "Bringing Home Baby, Your Electric Car", New York Times, accessed October 16, 2010

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