Mobility for the Future:

Cambridge Municipal Vehicle Fleet Options

FINAL APPLICATION PORTFOLIO REPORT

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Executive Summary

The Public Works Department of the City of Cambridge is considering expanding its vehicle fleet by purchasing 300 additional Light Duty Vehicles (LDVs). Due to the uncertainty of future fuel costs, the Department wishes to investigate how its selection of fleet vehicles may affect the Net Present Value (NPV) cost of purchasing the vehicle fleet.

The Department is considering: (i) conventional vehicles; (ii) hybrid vehicles; and (iii) an experimental concept fuel cell vehicle, available as a subsidized case-study, offered by GM at competitive rates.

This report will use a two stage decision analysis to propose an optimal strategy for the selection of the municipal vehicle fleet. Following this, a binomial Lattice Model will be implemented to assess the value of placing a put option on top of the system in a trial of the prototype fuel cell vehicles.

The report concludes that the optimal two-stage approach is to: first lease a conventional vehicle fleet for four years, then lease a hybrid fleet for the next four years. The report also finds that the value of a flexible put option on the system is of negligible value, given the system inputs assumed in this model.

Finally, the report concludes that the Lattice Model provided the best method of decision analysis, given the path independent nature of the flexible put option on the system. While the two-stage decision tree analysis allows for path dependent system designs, it is more computationally intensive, particularly when expanded to multiple stages. For the purposes of the system in this study, the Lattice Model provides a simple, less computationally intensive method of decision analysis.

Table of Contents

Table of Figures

Table of Tables

1.0 Background

The Public Works Department of the City of Cambridge is considering expanding its vehicle fleet by purchasing 300 additional Light Duty Vehicles (LDVs). Due to the uncertainty of future fuel costs, the Department wishes to investigate how its selection of fleet vehicles may affect the NPV cost of purchasing the vehicle fleet.

The Department is considering: (i) conventional vehicles; (ii) hybrid vehicles; and (iii) an experimental fuel cell vehicle, available as a subsidized case-study, offered by GM at competitive rates.

Two approaches are used to determine recommended strategies for selecting an optimal system design. Section 2 of this report outlines the definition of the system, including the model inputs and boundaries. Section 3 employs a two-stage decision analysis framework to define an optimal strategy for the city's vehicle fleet over an eight year time period. In Section 4, a lattice model is used to provide a different approach to modeling uncertain fuel prices. Decision analysis is applied to the lattice order to determine the value of placing a flexible put option on the city's vehicle fleet. Following this, Section 5 provides a comparative analysis of the two decision methods. The report closes with conclusions provided in Section 6.

2.0 System Definition

The system studied in this report is an additional fleet of 300 vehicles that the City of Cambridge wishes to purchase to expand its municipal fleet. There are three different technologies considered: (i) conventional vehicles, (ii) hybrid vehicles, and (iii) experimental fuel cell vehicles. In addition, there are two available methods of obtaining the fleet; the vehicles may either be purchased by the City of Cambridge for a flat fee, or leased on a per year payment basis.

Table 1 below summarizes the salient inputs of each of the three technologies and system inputs. For this study, the City of Cambridge has communicated a desire to make a defensible business case for incorporating fuel efficient vehicles. Current literature suggests that consumers use discount rates from 25% to 33% in estimating the value of fuel economy (Schafer and Jacoby, 2006; Greene et al., 2005). To reflect this, a realistic and competitive discount rate of 30% is thus used in this study.

In order to select values for the capital cost of vehicles, the basic $18,000 USD Toyota Camry CE was used as a representative model for conventional vehicles, while the $22,000 USD Toyota Prius was selected as a representative hybrid model (Toyota, 2006). There are currently no competitive fuel cell vehicles on the market; for the purposes of this study it is assumed that GM is offering its fuel cell vehicle at a special subsidized cost of $30,000 USD. Annual operating costs were calculated based on a cost of 10 cents per mile traveled, with slightly higher costs assumed for the hybrid and fuel cell vehicle designs (VPTI, 2003). Fuel economy was based on representative values for the Toyota

Camry, the Prius (Toyota, 2006), and GM's Percept concept fuel cell vehicle (FuelCells.org, 2006). For the purposes of this study, it is assumed that the equivalent miles per gallon fuel economy assigned to the fuel cell vehicle can be multiplied by the cost of gasoline in order to calculate the fuel cell fleet's total equivalent fuel cost.

Finally, values were assigned for the overall fleet size, fleet lifetime, and vehicle miles traveled. In particular, the value of 50,000 vehicle miles traveled is well above the average of 11,000 miles per year in the Northeastern States (EIA, 2001); however it is assumed that the municipal fleet vehicles are driven more often—roughly five times further, for the purposes of this study —than residential vehicles.

Table 1: System model inputs for inflexible and flexible designs

	PURCHASE	LEASE	SOURCE
Discount rate	30%		Schafer and Jacoby, 2006; Greene et al. 2006
Fleet size	300 vehicles		Assigned value
Vehicle miles traveled	50,000 miles / year		Based on EIA, 2001
Fleet lifetime	8 years	4 years	Assigned value
capital costs			
Conventional vehicle	$18K USD	$2.5K USD / year	Toyota, 2006
Hybrid vehicle	$22K USD	$2.75K / year	Toyota, 2006
Fuel cell vehicle	$30K USD	$3.25K / year	Assigned value
operating costs			
Conventional vehicle	$5K / vehicle / year		VPTI, 2003
Hybrid vehicle	$5.25K / vehicle / year		Based of VPTI, 2003
Fuel cell vehicle	$5.5K / vehicle / year		Based on VPTI, 2003
fuel economy			
Conventional vehicle	30 mpg (city)		Based on Toyota, 2006
Hybrid vehicle	54 mpg (city)		Based on Toyota, 2006
Fuel cell vehicle	90 equivalent mpg (city)		Based on FuelCells.org, 2006

3.0 Two Stage Decision Tree Analysis

In order to study the effects of vehicle technology and ownership arrangement for the City, a two stage decision analysis will be used to define an optimal strategy for the City of Cambridge to pursue over an eight year period.

3.1 Scenario Development

Given the system definition outlined in Section 2.0 above, two system design scenarios are envisioned:

i) *Fuel is Cool (inflexible, conventional vehicles)*

In this fixed design, the new LDV fleet is entirely made up of conventional vehicles, purchased assuming an eight year lifetime. This scenario serves as a baseline for comparison with the second, flexible case.

ii) *Flexible Future (flexible, conventional vehicles)*

This design incorporates a flexible leasing option, where vehicles are leased at a higher annual capital cost, but can be exchanged for an entirely new fleet after four years. For simplicity, it is assumed that the fleet may only be composed of one vehicle type, and is completely exchanged for a new vehicle type after the four years.

In the first period, a conventional vehicle fleet is chosen. After four years, depending on the fuel costs the fleet may be exchanged for a hybrid or fuel cell fleet.

Figure 2 and Figure 3 show the initial decision trees for the inflexible and flexible analyses respectively. Each analysis initially assumes that the fleet is initially entirely comprised of conventional vehicles. In the *Fuel is Cool* scenario, the fleet is locked in for the entire 8 year lifecycle of the vehicles. However, in the *Flexible Future* scenario, at the end of the first 4 year lease period, it is possible to: (i) re-lease the conventional fleet; (ii) lease hybrid vehicles; or (iii) lease fuel cell vehicles.

3.2 Description of Uncertainty

The uncertainty in the decision analysis is introduced by the variable cost of fuel over the 8 year study period. In order to calculate the probabilities used in the analyses, the price of fuel was forecasted into the future using stochastic Geometric Brownian Motion (GBM).

Ex post values for the GBM forecast were provided by the historical data on annual U.S. gasoline prices from 1990 to 2005 (EIA, 2006). These values were used to calculate the average annual percent change of fuel prices and its corresponding volatility, which were used in the following formula to iteratively generate the forecasted fuel values from 2006 to 2014:

$$F = P * \{1 + [M + V(RND)]\}$$

Where F represents the forecasted fuel price for a consecutive year, P represents the previous fuel price, M is the mean, V is the volatility, and RND is a factor generated randomly from a inverse normal cumulative distribution with a mean of 0 and a standard deviation of 1. The values used to model the GBM forecast are shown in Table 2.

Table 2: Mean and volatility used in the GBM forecast (based on EIA, 2006)

INPUT	VALUE
Mean (M)	4.49%
Volatility (V)	13.40%

A sample forecast is shown below in Figure 1. From this method of producing stochastic forecasts of future gas prices, a Monte Carlo simulation of 500 randomized scenarios[1] was produced to calculate the probability of future fuel prices corresponding to two three different price ranges.

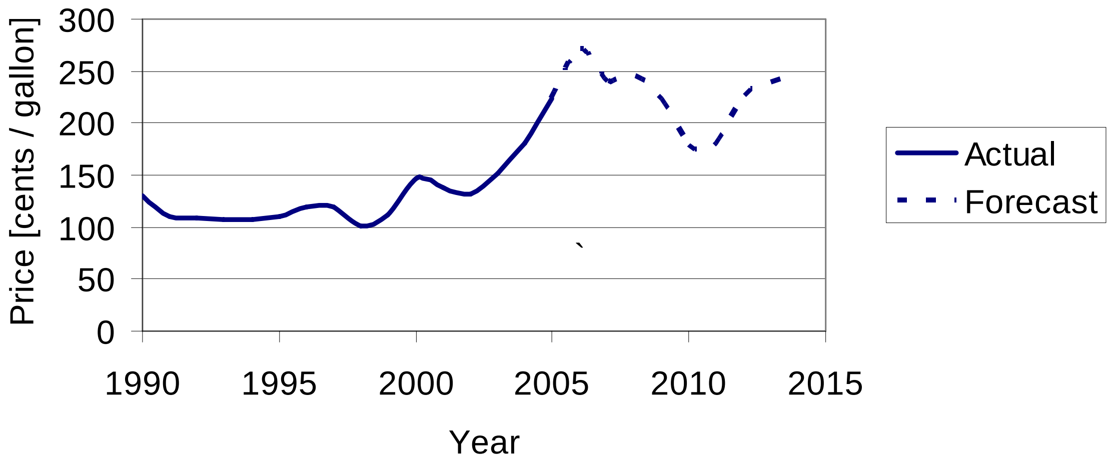

Figure 1: Sample of randomized forecast of fuel costs using Geometric Brownian Motion

[1] It should be noted that while 500 scenarios produced a representative result with minimum computational time, a larger range of 10,000 scenarios would be most appropriate in eliminating any variation in the outcome of the Monte Carlo analysis.

The three price ranges were defined as: (i) a “low” fuel cost range, where the cost of fuel remains below $3.00 / gallon; (ii) a “medium” fuel cost range, where the cost of fuel is in between $3.00 and $6.00 / gallon; and (iii) a “high” fuel cost range, where the cost of fuel exceeds $6.00 / gallon. The resulting probabilities of fuel costs corresponding to these three ranges are shown in Table 3.

Table 3: Probability of price of fuel corresponding to "high", "medium", or "low" cost ranges in years 2006 and 2010

YEAR	RANGE	2006	2010
Price of fuel below $3.00 / gallon	Low	99.60%	66.20%
Price of fuel between $3.00 and $6.00 / gallon	Medium	0.40%	33.60%
Price of fuel exceeds $6.00 / gallon	High	0.00%	0.20%

Therefore, the outcome of this characterization of the uncertainty in future fuel prices were three ranges of fuel prices (low, medium, and high), and their associated probabilities of occurring both in 2006 and 2010. This information enables the creation of decision trees for each of the two scenarios described in Section 3.1 above. Through analysis of these decision trees, it is possible to compare the NPV cost of each scenario and define a optimal strategy for the flexible scenario.

3.3 Decision Analysis Results

As mentioned above, given the cost range probabilities given in Table 3 above, the NPV costs of each scenario can be calculated for each fuel price range. From this, decision trees can be created for each of the two scenarios, *Fuel is Cool* and *Flexible Future*. The decision trees for the two scenarios analyses are shown in Figure 2 and Figure 3 respectively.

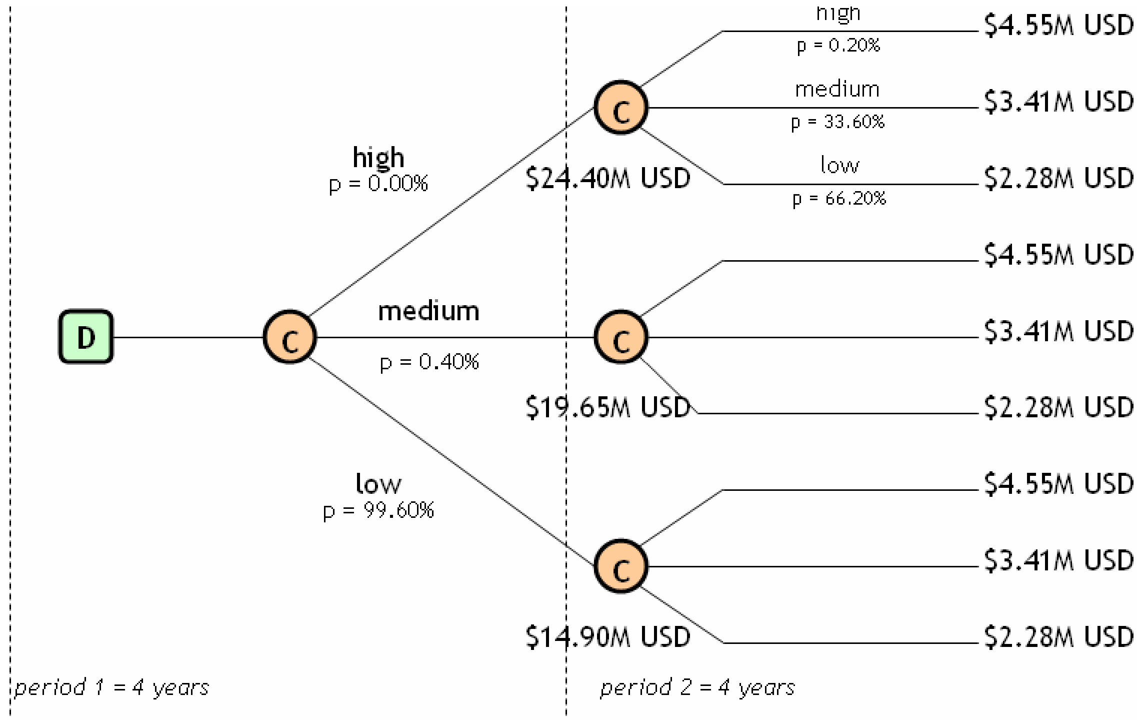

Figure 2: Two-stage decision analysis tree for *Fuel is Cool* design

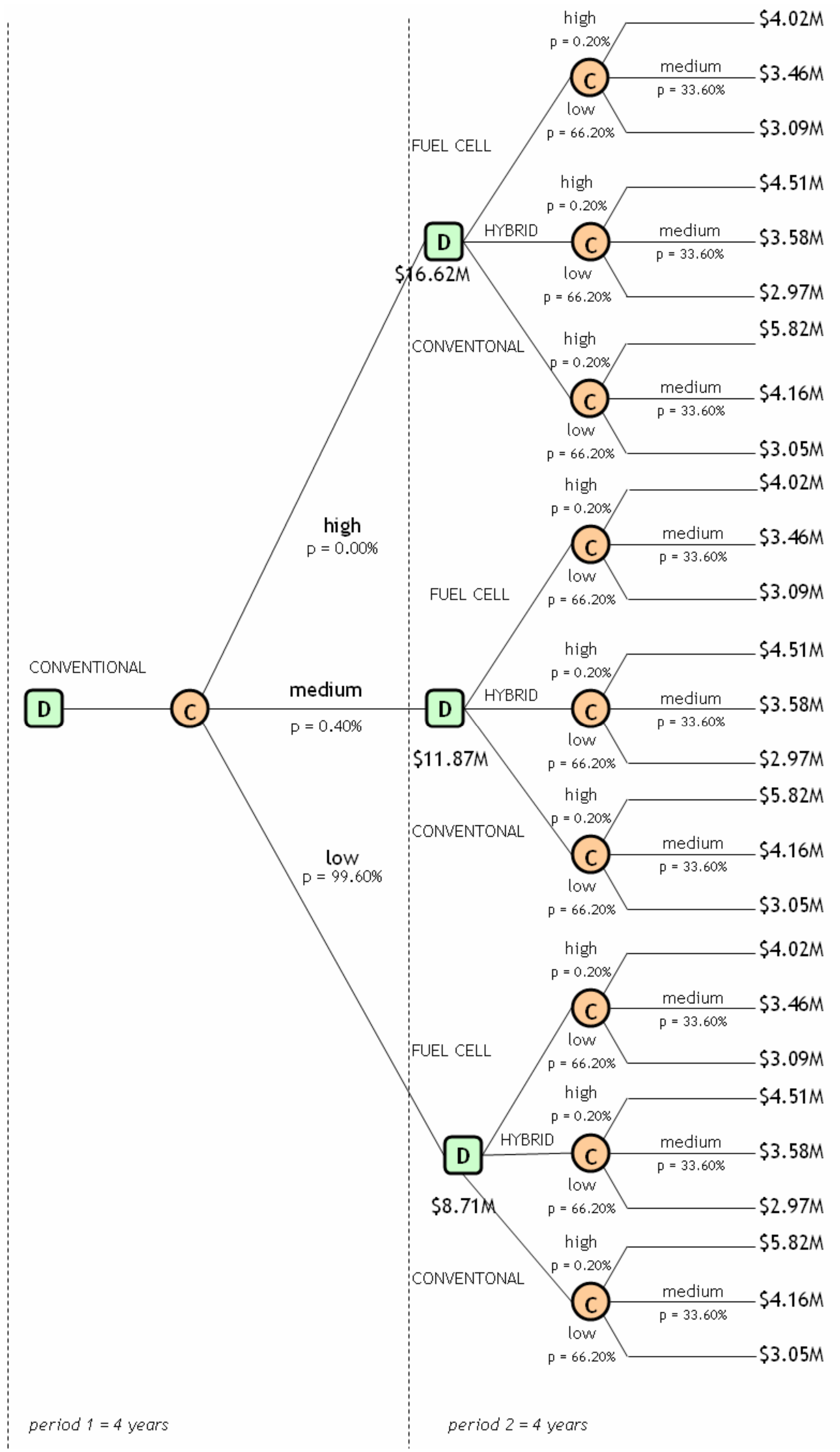

Figure 3: Two-stage decision analysis tree for *Flexible Future* design

The expected value of the *Fuel is Cool* design is calculated at **$17.58M**, as shown in Figure 4.

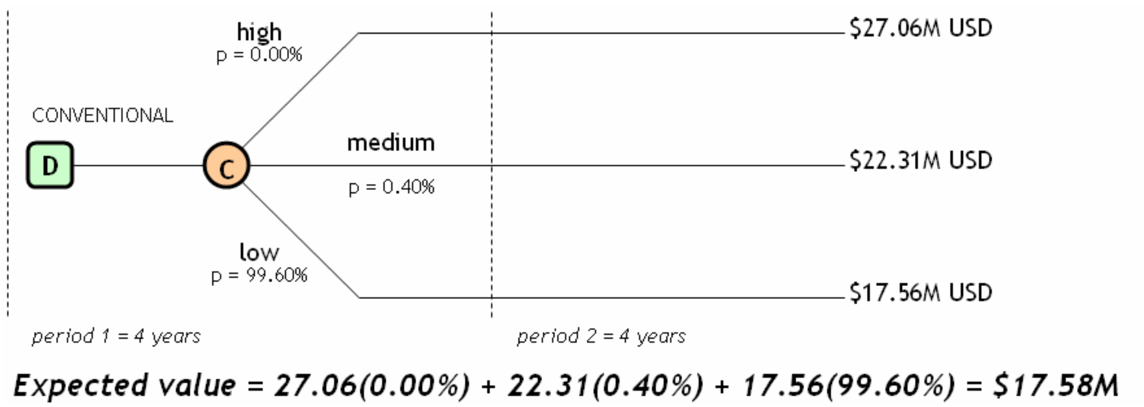

Figure 4: Second step of analysis for inflexible, conventional fleet design (*Fuel is Cool*)

The two-stage decision analysis for the *Flexible Future* design is somewhat more complicated. First, the expected value for each rightmost "chance" node was calculated; the results are shown by Table 4.

Table 4: Results of first step calculation of expected NPV in two-stage decision analysis

DECISION	EXPECTED NPV (USD, millions)
Conventional	3.22
Hybrids	3.18
Fuel Cell	3.43

From this calculation, the "conventional" and "fuel cell" decisions were rejected, as they involved higher expected NPV costs. The simplified decision tree is shown in Figure 5 below.

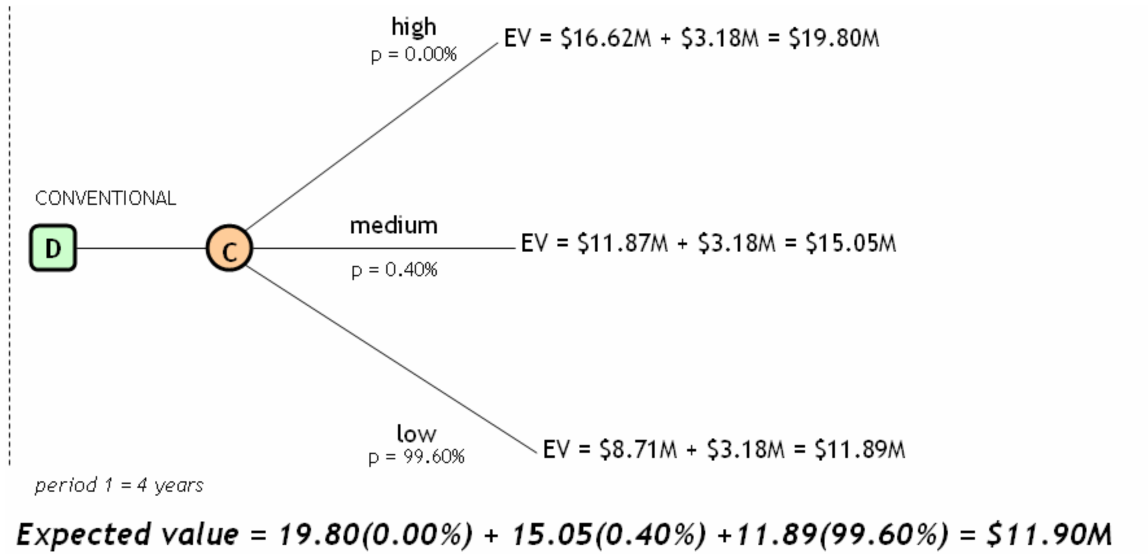

Figure 5: Second step of two-stage decision analysis for flexible design

From the simplified decision tree, the expected value for the *Flexible Future* design is calculated at **$11.90M**, which is **$5.68M lower** than the *Fuel is Cool* system design.

These results can be used to outline an optimal strategy in this situation: first, lease a conventional vehicle fleet for four years, and then lease a hybrid fleet for the next four years.

This strategy does not purport to be a master plan, or one narrow solution to the system design. It has attempted to account for the uncertainties of future fuel costs, and in doing so has found that the choice of hybrids yields the lowest NPV cost for every decision branch in the second period. In this case, the decision analysis recommends leasing a hybrid fleet in the second period in order to optimize expected value.

4.0 Lattice Model Analysis

4.1 Lattice Model Development

In addition to the decision tree analysis provided in Section 3.0, this study will also build a Lattice Model to forecast uncertainty with regard to future gasoline prices. This method is used to perform a closer examination of GM's experimental fuel cell vehicle.

As mentioned above, GM has offered to trial a small fleet of its new Precept fuel cell vehicles as a pilot-scale case study in the City of Cambridge. The City would like to assess the cost implications of introducing the fuel cell vehicles. In particular, Cambridge would like to be able to use the fuel cells if gas prices warrant their use; however, if prices fall to a point where hybrids may be more viable, GM has agreed that the City may switch the fuel cell fleet at any point in the eight year study for a new fleet of hybrids.

By developing a binomial lattice model, the price of fuel will be forecasted over eight periods. This model assumes that the rate of change in gas prices, and their associated probability of occurring, are path independent and remain constant over the eight period analysis. Through the specification of an average rate of increase per year, and an average fuel price variance, the lattice model can be generated to yield a probability distribution of gasoline prices.

Table 5 summarizes the input parameters used to develop the lattice model.

Table 5: Input parameters for lattice model

INPUT	VALUE
fuel price inputs	
Fuel price in 2006 (S)	\$2.50 / gallon
Average annual fuel price increase	\$0.11 / gallon
Standard deviation in fuel price	\$0.63 / gallon
Percent average fuel price increase (v)	4.60%
Percent standard deviation (σ)	6%
Time step (Δt)	1 (annual)
lattice parameters	
"Up" path modifier (u)	1.23
"Down" path modifier (d)	0.81
Probability of the up path outcome (p)	0.60

The starting fuel price determined by averaging fuel prices over the last four months from EIA weekly retail gasoline prices for all formulations and grades (EIA, 2006a). The average annual fuel price increase was calculated from the Monte Carlo analysis of the GBM forecasts by finding the average price increase each year, and averaging this value over the 8 period study. This value of 4.60% shows good agreement with the historical value of 4.49%, based on data provided by the EIA (see Table 2).

By contrast, the historic deviation provided by the EIA data is 13.40% (see Table 2). This historical estimate is illustrative, however there is good reason to suspect that gasoline prices may be experience a lower level of volatility over the next 8 years as new supply becomes available from Canadian tar sands and potential reserves in Alaska and the Outer Continental Shelf. In order to balance this information against the historic volatility in gasoline prices, a value of 6% was chosen for this study[2].

Finally, the u, d, and p modifiers were calculated from the v, σ, and Δt terms using the following three equations (de Neufville, 2006a):

$$u = e^{\sigma\sqrt{\Delta t}}$$

[2] See "National Energy Board says Canada's oil sands production could be three million barrels per day by 2015", June 2006, at http://www.neb-one.gc.ca/newsroom/releases/nr2006/nr0615_e.htm.

$$d = \frac{1}{u}$$

$$p = 0.5 + 0.5\left(\frac{v}{\sigma}\right)\sqrt{\Delta t}$$

These terms where used to construct the lattice model explained in the following sections.

4.2 Lattice Model Results

The input parameters shown by Table 5 were fed into a binomial lattice model (de Neufville, 2006) in order to generate both an outcome matrix and its associated probability matrix.

FUEL PRICE [USD / gallon]								
2006	2007	2008	2009	2010	2011	2012	2013	2014
2.50	2.65	2.82	2.99	3.18	3.37	3.58	3.80	4.04
	2.35	2.50	2.65	2.82	2.99	3.18	3.37	3.58
		2.22	2.35	2.50	2.65	2.82	2.99	3.18
			2.09	2.22	2.35	2.50	2.65	2.82
				1.97	2.09	2.22	2.35	2.50
					1.85	1.97	2.09	2.22
						1.74	1.85	1.97
							1.64	1.74
								1.55

Figure 6: Lattice of fuel price outcomes ($'s / gallon)

The lattice shown in Figure 6 summarizes the fuel price outcomes over eight periods following the starting year of 2006. Each of these outcomes is associated with a probability of occurrence; these probabilities are shown below in Figure 7.

PROBABILITY LATTICE								
2006	2007	2008	2009	2010	2011	2012	2013	2014
1.00	0.88	0.78	0.69	0.61	0.54	0.48	0.42	0.37
	0.12	0.21	0.27	0.32	0.36	0.38	0.39	0.39
		0.01	0.04	0.06	0.09	0.12	0.15	0.18
			0.00	0.01	0.01	0.02	0.03	0.05
				0.00	0.00	0.00	0.00	0.01
					0.00	0.00	0.00	0.00
						0.00	0.00	0.00
							0.00	0.00
								0.00

Figure 7: Lattice of associated probabilities

By multiplying the fuel price outcomes in 2014 by their associated probabilities, the expected value of each future state can be determined. Figure 8 below shows the Probability Distribution Function of fuel prices in 2014. Note that the average expected value is also shown in the graph corresponding with $3.63 / gallon. The Cumulative Distribution Function is shown in Figure 9.

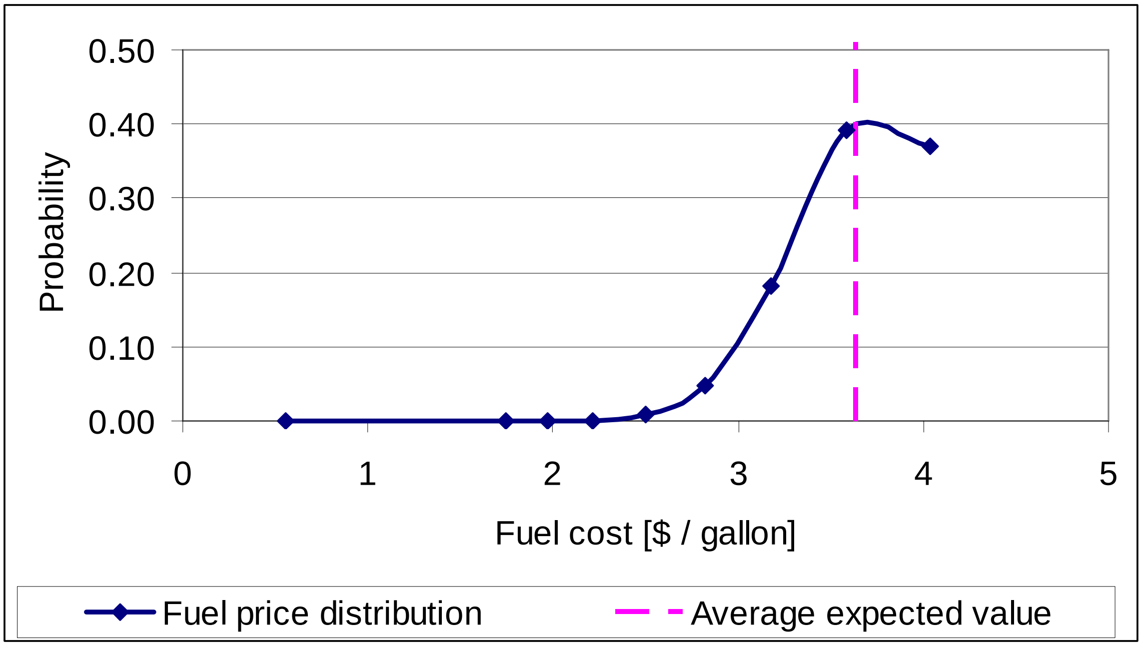

Figure 8: Probability distribution of fuel price in 2014

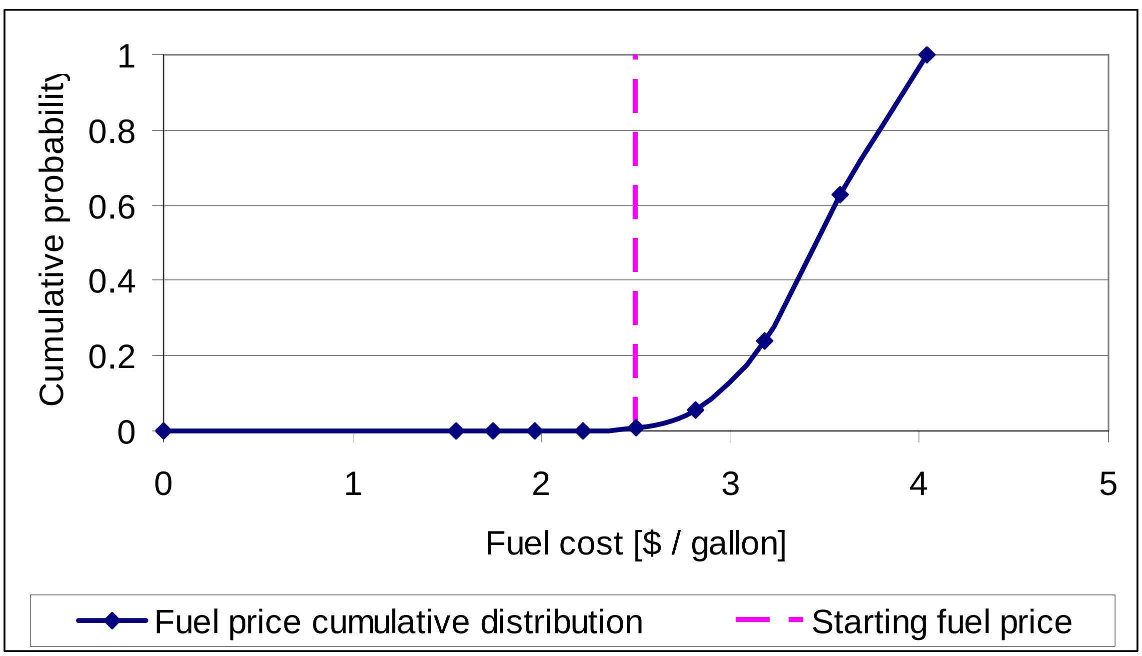

Figure 9: Cumulative distribution of fuel price in 2012

The lattice model shows that fuel prices have a high probability of remaining between $2.00 / gallon and $4.00 / gallon until 2014. The cumulative distribution function in

Figure 9 shows that the original fuel price of $2.50 corresponds to a very low probability, suggesting it is highly likely—if not certain—that fuel prices will increase from the original value by 2014.

4.3 Lattice Model Decision Analysis

In addition to the results of analysis above, the City of Cambridge wishes to explore the possibility of investing in the experimental fuel cell fleet offered by GM as a unique proto-type test case. Rather than commit to the test over an eight year period, the city would like to assess the value of implementing an arrangement where the fuel cell fleet may be exchanged once for a hybrid fleet at any point over the eight year prototype study.

Drawing from the lattice model developed in the last section, a decision analysis approach will be applied in order to determine the value of incorporating such an option on top of the existing system. First, the cost of an inflexible base case will be assessed over six periods. Next, a flexible option scenario will be analyzed. Based on these scenarios, the value of a the option to switch the vehicle fleet will be calculated over a range of different starting gasoline prices.

The inputs for this analysis are the same as shown by Table 5 above. Additionally, the system inputs for fuel cell and hybrid vehicles outlined in Table 1 were used to calculate the NPV costs of the two systems.

Using the gasoline prices calculated by the binomial lattice (see Figure 6 and Figure 7 above), a base case scenario was created. In this scenario, the City of Cambridge leases a fleet of fuel cell for the entire six year period. There is no option for the City to switch to a hybrid vehicle fleet. The outcome lattice for this option is shown in Figure 10, with a total NPV cost of $12.1M USD.

BASE CASE OUTCOME - ALL FUEL CELLS [USD]									
	2006	2007	2008	2009	2010	2011	2012	2013	2014
	3041666.667	2709564.8	2414796.1	2153092.6	1920678.9	1714214.9	1530745.5	1367655.7	1222631.5
		352030.22	626921.3	837707.13	995432.63	1109440.8	1187619.8	1236615.6	1262014.6
			40759.155	108836.01	193823.17	287767.91	384693.24	480202.96	571157.16
				4721.0603	16801.83	37387.185	66581.847	103796.29	148007.16
					547.03554	2432.6575	6493.207	13485.35	24015.702
						63.40826	338.25031	1052.9352	2498.2013
							7.3523022	45.742014	162.67334
								0.8527883	6.0615647
									0.0989448
EV =	$3,041,667	$3,061,595	$3,082,477	$3,104,357	$3,127,284	$3,151,307	$3,176,479	$3,202,855	$3,230,493
NPV =	-$12,141,919	< - base case cost of fleet over 6 years							

Figure 10: Probability-weighted fleet cost outcome for base case scenario of inflexible fleet of fuel cell vehicles

Alongside the above base case model, a second scenario was created where the City of Cambridge has a one-time option to switch from leasing a fleet of fuel cell vehicles to a fleet of hybrid vehicles. Given the uncertainty in fuel prices, it is possible that future gasoline costs will drop below a point where it is more economical to lease the cheaper, yet less fuel efficient hybrid vehicles. The decision framework based upon the system model inputs is shown in Figure 11.

DECISION FRAMEWORK								
2006	2007	2008	2009	2010	2011	2012	2013	2014
FC	FC	FC	FC	FC	FC	FC	FC	FC
	FC	FC	FC	FC	FC	FC	FC	FC
		FC	FC	FC	FC	FC	FC	FC
			FC	FC	FC	FC	FC	FC
				FC	FC	FC	FC	FC
					HYB	HYB	FC	FC
						HYB	HYB	HYB
							HYB	HYB
								HYB

Figure 11: Flexible option decision framework (FC = fuel cell vehicle fleet; HYB = hybrid vehicle fleet)

The outcome lattice for the flexible option scenario is shown below in Figure 12. The total NPV cost is calculated at $12.1M USD.

FLEXIBLE CASE OUTCOME [USD]									
	2006	2007	2008	2009	2010	2011	2012		
	3041666.667	2709564.8	2414796.1	2153092.6	1920678.9	1714214.9	1530745.5	1367655.7	1222631.5
		352030.22	626921.3	837707.13	995432.63	1109440.8	1187619.8	1236615.6	1262014.6
			40759.155	108836.01	193823.17	287767.91	384693.24	480202.96	571157.16
				4721.0603	16801.83	37387.185	66581.847	103796.29	148007.16
					547.03554	2432.6575	6493.207	13485.35	24015.702
						62.992902	337.5066	1052.9352	2498.2013
							7.2736248	45.442379	162.31567
								0.840289	5.9966996
									0.0971217
EV =	$3,041,667	$3,061,595	$3,082,477	$3,104,357	$3,127,284	$3,151,306	$3,176,478	$3,202,855	$3,230,493
NPV =	-$12,141,918	**<- cost of flexible fleet**							

Figure 12: Probability-weighted fleet cost outcome for flexible option scenario

The NPV costs of the base case and flexible scenarios are nearly equivalent, therefore the value of the flexible option is negligible. However, this result is sensitive to the initial starting price of fuel used in the analysis. As a result, a follow-up analysis was conducted to determine the sensitivity of option value with respect to the starting price of fuel.

The result of this analysis is shown in Figure 13. Here, the value of the option is large at low gasoline prices, but its value decreases as gas prices increase. This is due to the fuel-saving benefits of the fuel cell vehicles, which are favored at high gas prices. Therefore, as the starting fuel prices increase, the option of switching to less fuel efficient hybrid vehicles becomes less attractive, and the option itself is worth less.

Compare this result to Figure 9 above suggests that this option is likely of negligible value in this case. The option is only worth significant value below a starting fuel price of $2 / gallon, but the Lattice model predicts that fuel prices will almost certainly increase above $3 / gallon by 2014. As a result, the option of switching the fuel cell fleet to hybrid vehicles offers negligible value.

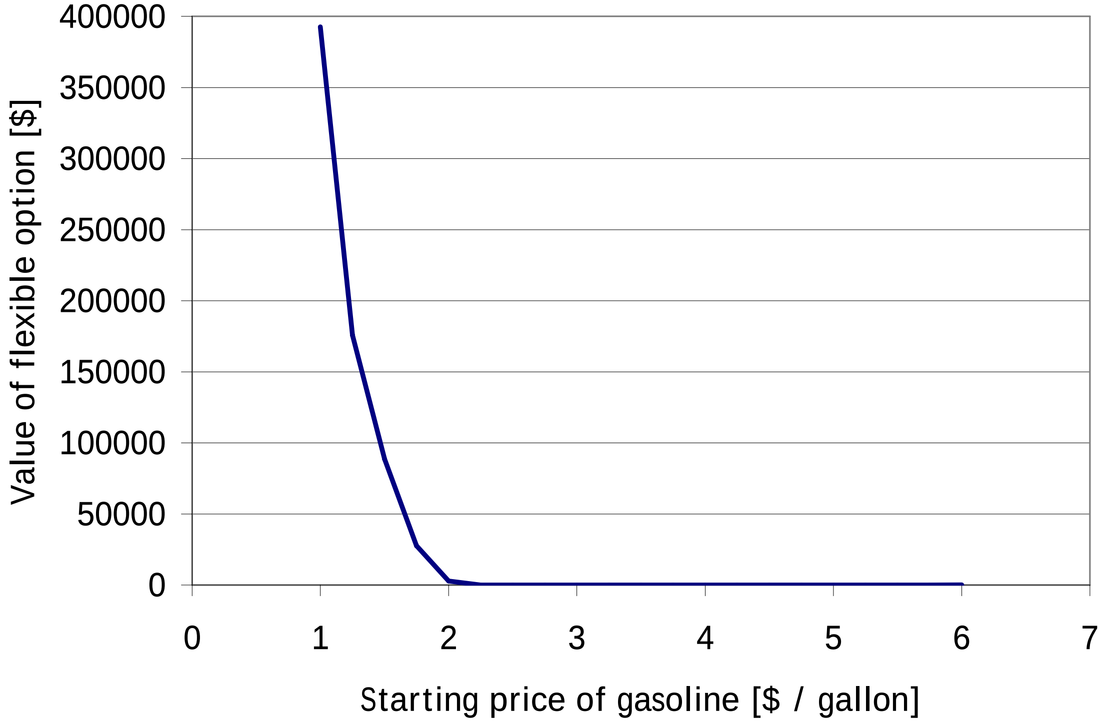

Figure 13: Effect of starting gasoline price on the value of having the flexible option

This study has demonstrated how a binomial lattice model can be used with decision analysis to determine the value of flexibility within a system. It was found that the benefit of a flexible option to switch from leasing fuel cell to hybrid vehicles was negligible at the initial starting price of $2.50 USD / gallon. It also determined that, while the value of the option increases as gasoline prices decrease (Figure 13), it is almost certain that gasoline prices will rise to 2014 (Figure 9).

As a result, our Lattice Decision Analysis concludes that the flexible option to switch the experimental fuel cell fleet to a hybrid fleet during the eight year study would not provide significant value to the City of Cambridge.

5.0 Comparative Analysis

This study performed two different methods of decision analyses to determine the value of flexible options on a 300 vehicle fleet for the City of Cambridge. This section provides some brief comments on the relative strengths and weaknesses of each approach within the context of this study.

While both of these methods have certain advantages and disadvantages in analyzing uncertainty into the future, the Lattice Decision Analysis model in Section 4.0 appears to be the most appropriate. This is primarily due to path independence of the system that was modeled. Having the ability to switch the entire fleet from fuel cell vehicles to hybrids at any point in the study period represents a flexible *put* option *on* the system.

The option is a *put* since it protects against a loss if fuel prices drop too low. It is also an option *on* the system in the sense that it does not require a changes to the technical design of the system in order to exercise. In this way, the option is essentially a "black box"; by looking at the system across the entire study period, the option can be exercised at any point where the capital costs of the fuel cell vehicles outweigh their fuel savings benefits.

Due to the path independent nature of the system, the Lattice Model provides a simple, less computationally involved way of performing the fleet decision analysis. By contrast, the decision tree approach used in Section 3.0 does not require a path independent system, but it is considerably more computational intensive and time consuming. This complexity is compounded by adding multiple stages, whereas the Lattice Model is able to scale up and down more easily. This is evidenced by the fact that our decision tree analysis was only two stages, while the Lattice Model allowed eight stages of decision analysis.

6.0 Key Lessons and Conclusions

This study has attempted to outline two different approaches to the vehicle options available for the City of Cambridge's municipal fleet. First the study examined uncertainty in future fuel prices using a GBM forecast with a Monte Carlo analysis. This information was used in a two-stage decision tree analysis to determine the value of a flexible leasing option, and to define an optimal strategy for selecting the fleet composition over two four year periods. Next, a Lattice Model was developed to determine the value of a option allowing the City of Cambridge to switch its fleet from fuel cell vehicles to hybrids at any point in the eight year study.

This Application Portfolio report has helped the authors explore the concept of flexibility within a system subject to uncertainty. Contrasting two different types of decision analysis in this exercise has helped illuminate different strengths and applications for both decision analysis trees and the Lattice Model of decision analysis. Fundamentally, this report stressed the role of flexibility as an important factor in dealing with uncertain circumstances. By considering uncertainty in gasoline prices on the system, this report is able to make several key conclusions on fleet purchase decisions.

First, the decision tree analysis concluded that an optimal strategy for the fleet composition was to lease a conventional fleet for four years, then lease a hybrid fleet for the following four years. In terms of the experimental fuel cell proposition provided by GM, the Lattice Model decision analysis concluded that a the flexible option to switch the fleet at any point in the eight year study provided negligible value.

Finally, it was argued that the Lattice Model provided the best method of analysis for this study. Given the path independence of the flexible *put* option *on* the fleet system, the Lattice Model provided a simple, less computationally intensive method of decision analysis.

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