Using Gaming Simulation to Explore Long Range Fuel and Vehicle Transitions




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# Using Gaming Simulation to Explore Long Range Fuel and Vehicle Transitions

By

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DISSERTATION

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# ABSTRACT


The world of 2050 will assuredly look different than that of 2012 in the fields of energy and transportation. The large deposits of easily accessible, conventional oil upon which the world has relied until now are in decline and will need to be supplemented with alternatives like electricity, hydrogen, biofuels, and non-conventional oils. The transition pathways are highly sensitive to economic, political, and environmental factors and are thus highly uncertain. Autopia is a simulation game designed to generate insights about the market dynamics of long-range fuel and vehicle transitions. Games have been shown to be valuable tools for generating robust, heuristic based approaches to problem domains that feature high degrees of uncertainty (i.e. uninsurable risk).

Autopia simulates a three-way market of consumers, vehicle producers, and fuel producers. Human players take on player roles in the market and attempt to optimize their outcomes, relative to their competitors, within a given energy price and regulatory scenario. Analysis of game play has revealed several emergent patterns: 1) High fuel prices lead to a bifurcated vehicle market with small, cheap, gas powered vehicles dominating the low end of the market and high trim electrified vehicles (HEV, PHEV, BEV) dominating in the top 30% income bracket, 2) It is difficult to sell an alternative fuel vehicle that is easily comparable to a similar conventional vehicle due to the price difference, and 3) Aggregate gasoline demand in a mature market will fall given an improving average fuel economy, but predicting the decline will tend to cause fuel producers to under-produce.

This research demonstrates a complete working prototype game, data analysis from actual games, and several insights into the system that I developed from observing multiple runs of the game.

## Acknowledgements

I would like to thank Joan Ogden for entrusting me with this fascinating and unique opportunity to develop a large scale model from first principles; Alan Meier for his input and feedback on game and model development; Cynthia Lin for her feedback and support on essential models; Jack Johnston for explaining the oil industry to me in great depth (wish you could have seen it Jack); Phillip Patterson for his enthusiasm and encouragement; unnamed source who added countless real-world details I could never have found in the literature, and finally to my beloved Bessie who stood by me while I struggled to bring this in -- your job was harder than mine!

In memory of Margaret Oakley (1929-2011).

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## ABBREVIATIONS

| | |
|---|---|
| **BEV** | Battery Electric Vehicle |
| **BPD** | Barrels of oil Per Day |
| **C** | Consumer (player) |
| **CD** | Charge Depleting mode –one of two PHEV drive modes. CD is the most efficient mode as the vehicle is essentially operating as a BEV, but it is limited to range of the battery. |
| **CS** | Charge Sustaining mode . PHEV drive mode after the CD operation is no longer possible. The PHEV acts as an HEV in this mode, running at substantially lower efficiency. |
| **CFV** | Conventionally Fueled Vehicle – vehicle powered solely by a gasoline or diesel engine (i.e. no electric motor). |
| **FP** | Fuel Producer (player) |
| **HEV** | Hybrid Electric Vehicle |
| **HFCV** | Hydrogen Fuel Cell Vehicle |
| **ITS** | Institute of Transportation Studies at UC Davis |
| **PHEV** | Plugin Hybrid Electric Vehicle |
| **VP** | Vehicle Producer (player) |

The Modelers' Hippocratic Oath

~ I will remember that I didn't make the world, and it doesn't satisfy my equations.

~ Though I will use models boldly to estimate value, I will not be overly impressed by mathematics.

~ I will never sacrifice reality for elegance without explaining why I have done so.

~ Nor will I give the people who use my model false comfort about its accuracy. Instead, I will make explicit its assumptions and oversights.

~ I understand that my work may have enormous effects on society and the economy, many of them beyond my comprehension.

Emanuel Derman and Paul Wilmott (2009)

*What you cannot comprehend, you are reluctant to believe; what you cannot evaluate, you do not trust; and what you do not believe or trust, you will not use. – Ferenc L. Toth (Toth 1986)*

# CHAPTER 1: INTRODUCTION

Effective policy planning requires a schema that can plausibly represent the future; a robpolicy approach to such an uncertain future must be founded on the principle of resilience within contingency; when we do not know what will happen, we must be ready to respond to a wide range of possibilities. There are many modeling tools available within the energy and transportation research communities for exploring particular pathways once a scenario has been specified, but there is no tool that can assist planners in exploring approaches to resilience within contingency (*contingency* defined as "*The absence of certainty in events")* (Jewell, Abate, & McKean, 2005). Given the critical issues and major investments that must be made in this domain, the lack of such a tool is a major omission.

The transition to alternative fuels and vehicles is a *complex problem* for which new ideas are required. A complex problem is a problem set within the context of a complex system. Given that a complex system is one in which the possible outcomes are effectively infinite, a complex problem must be approached with a wide perspective as it is not conventionally solvable in the way that, say, an optimization problem is solvable (Luhmann, 1985). A transition is complex because it has a large number of elements, that are richly interconnected, in non-linear relationships (Cilliers, 1998). For example, an alternative fuel cannot be successfully adopted unless the triad of consumers, fuel producers and vehicle producers are in proper synch with each other. The technology must be ready, available, and have buyers or it will be a market failure. Complex problems can be introspected for sensitivities, boundaries, properties, and contingency factors. These introspections, which can be revealed via serious games, have proven to be useful to decision-makers who must work in complex contexts.

The fossil fuel regime around which the world has developed for the last hundred years is in transition. Fossil fuels produce carbon emissions, which will need to be reduced if greenhouse gas reduction goals are to be met. This can be managed with multiple means including: efficiency regulation, carbon taxes, and carbon capture and sequestration. Conventional oil is not expected to meet demand in the future and will need to be supplemented with non-conventional crudes, natural gas liquids, coal liquids and oil sands (IEA, 2008). Many studies suggest that deep GHG emission cuts by 2050 will require that the LDV fleet contain a substantial fraction of electric vehicles. Unconventional oils have increased production and environmental costs (Charpentier, Bergerson, & MacLean, 2009; Méjean & Hope, 2008). Many countries, including the United States are not energy secure – they do not produce enough oil to cover their domestic needs. In the event of an oil supply disruption they could see much of their normal economic and societal functions come to a halt. (Guy, 1986; Kruyt, van Vuuren, de Vries, & Groenenberg, 2009; P. Leiby, 2007).

The gasoline engine established itself as the dominant prime mover for cars and trucks in the first quarter early years of the twentieth century. However, in the beginnings of the automobile industry (1885-1905) there was no dominant powertrain. Steam, electric and gasoline powertrains were all popular. Gasoline came to dominate, largely due to its high energy density, low cost, and high availability (Bryant 1976). Gasoline has an energy density of 13,000 Wh/kg, while batteries of that era managed no more than 25 Wh/kg,. The invention of the electric ignition for gasoline powered cars, making them easy to start, was the final straw for electric vehicles as battery manufacturers switched their focus from building large high capacity batteries to the small and inexpensive ones required for electric ignition(Cowan & Hulten, 1996).

A massive infrastructure has emerged to support gasoline (and diesel) powered vehicles (Melaina & Bremson, 2008). A vehicle technology transition, full or partial, would entail moving from CFVs (vehicles powered solely by fossil sourced gasoline and diesel) to a variety of drivetrain technologies (Birol, 2009; P., Rubin, J. Leiby, 2003). These include hybrid electric vehicles (HEV, e.g. Toyota Prius), plug-in HEVs (PHEV, e.g. GM's Volt), battery electric vehicles (BEV, e.g. Nissan Leaf), and hydrogen fuel cell vehicles (HFCV, not commercially available). Additionally, biofuels can be blended into gasoline and diesel or even completely replace them, offering another pathway to oil use reduction. Widespread adoption of these technologies will require significant changes in refueling infrastructure and consumer expectations.

In absolute terms, fossil fuel reserves are plentiful on the planet. Oil shale and tar sands can be economically viable when oil is as low as $30/bbl for an established site, i.e. capital costs are assumed to be "sunk", and only operating costs are counted (Welsch, 2011). New production is viable currently at somewhere between $70-$100/bbl. Synthetic gasoline and diesel can also be produced from coal and natural gas via the Fischer-Tropsch process (Schulz, 1999). However, we need to drastically reduce the rate at which we produce greenhouse gases if we are to avoid disastrous climate change impacts (M.L. Parry, 2007).

The use of fossil fuels for energy is a major source of the dangerously increasing level of atmospheric carbon that is driving climate change (Anderegg, Prall, Harold, & Schneider, 2010; Hansen et al., 2008; M.L. Parry, 2007; Oreskes, 2004, 2007). The number of extreme weather events has been escalating over recent years across the globe. In 2011 the US experienced a record number of events (12) that did more than a billion dollars of damage each (NOAA, 2011). It is vital that we cut carbon emissions from all energy consuming sectors of the economy, including transportation. Alternative fuel drivetrains offer the potential for improved vehicle efficiency and the usage of non-fossil derived fuels, such as renewable electricity, in our vehicles.

## USING MODELS TO UNDERSTAND TRANSITIONS

Models are tools used to help us envision the future. The transportation and energy community uses a variety of models to consider the environmental and cost implications of various transition pathways.

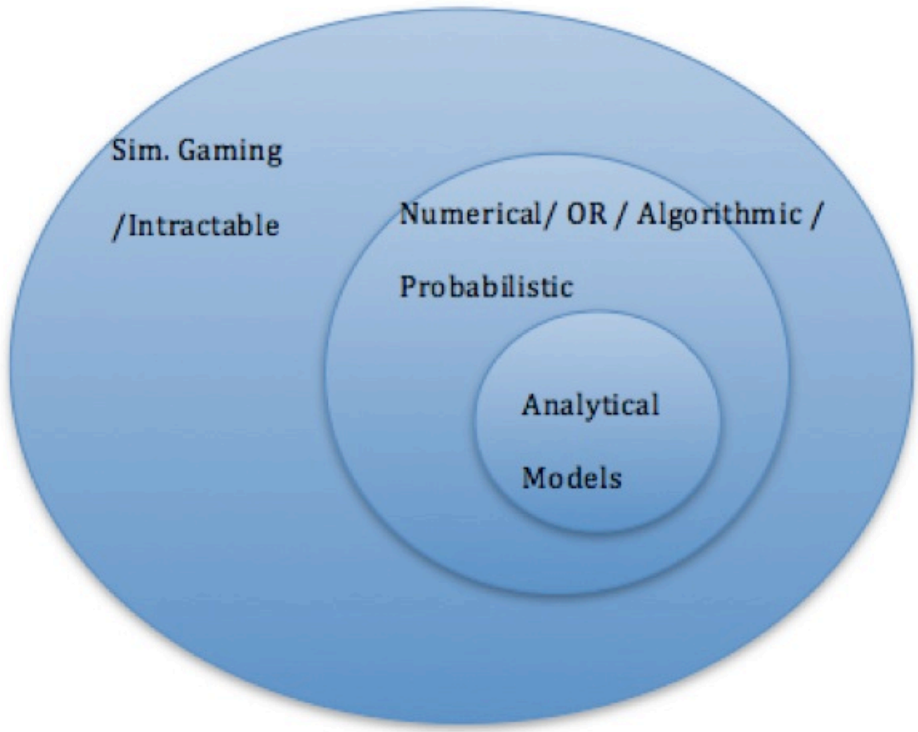


**Figure 1: Duke's Modeling Classification Diagram**

Richard Duke developed a graphic to classify modeling techniques that is useful when thinking about transition models, shown in Figure 1 (Duke, 1974). At the center of the system are analytical models. Analytical models can be solved by logic alone, within a human time frame. For example, when an integral can be calculated using the fundamental theorems of calculus alone it is said to have an analytical solution. If however, the rules cannot be applied (e.g. $\int \exp(-x^2)\,dx$) it is said that the problem has no analytical solution. Such problems must be solved with a numerical approach.

The next level is numerical / operations research / algorithmic and probabilistic models. These (typically computer-based) models use algorithmically controlled iterative logic to find an approximate solution. Tractable probabilistic problems are those that have probabilistic based variables that we can estimate. In the simulation gaming world we can look at intractable probabilistic variables -- ones we cannot assign a distribution to due to their overly complex nature.

The outermost grouping represents problem spaces that cannot be solved by pure mathematical or algorithmic methods. Initiatives such as starting or entering a war, or building an expensive new facility can have far reaching and drastic implications. Models of various sorts, like MARKAL, can help in making those sorts of decisions, but there are reasons we do not let computers make critical decisions on their own: no one would be comfortable, for instance, with letting a computer decide to launch nuclear weapons on its own. The scope of such a decision is too wide for a computer to comprehend. In contrast, we are perfectly content to let a computer map a travel route for us. The fact is that models are only representations of reality and should be treated accordingly (Brewer, G. and Shubik, M., 1979). Models that are highly accurate within a particular contextual range can fail spectacularly in other contexts. When the contextual parameter space is too wide and the cost of a failure is too high, we are in a space that is computationally intractable. Serious games are useful tools for problems that fall in this outer region.

EXAMPLES OF MODELS

There are many analytic and numerical energy models that try to address alternative fuel transitions. MARKAL and HyTrans are two important examples of these types of models. MARKAL ( short for MARKet ALlocation) is a popular energy/economic model, in use by over 50 countries. MARKAL is built on the General Algebraic Modeling System (GAMS), an optimization framework (Brook, Kendrick, & Meeraus, 1988). It uses optimization techniques to find the least cost combination of energy technologies to meet an energy and emissions related constraint set (Johnson, 2004; Seebregts, 2001) . MARKAL includes a simplifying assumption of perfect foresight about energy prices and technological progress. Perfect foresight is an extreme assumption (it is impossible to achieve), which limits the value of MARKAL results

The latest evolution of MARKAL, introduced in 1999, is called TIMES ("The Integrated MARKAL-EFOM System). TIMES, like MARKAL, is an optimization-based model. It is more powerful and flexible than MARKAL (Seebregts, 2001).

The ORNL and DOE developed the HyTrans hydrogen transition model from 2004-2007. It covers hydrogen generation, delivery, vehicle production, consumer choice and hydrogen usage relying on a number of other established models including GREET for GHG emissions, H2A for hydrogen production and delivery, and others. The model is a dynamic, non-linear optimizing market simulation that runs through 2050. It seeks to maximize producer profitability and consumer welfare. It outputs projections on hydrogen fuel costs, vehicle technology penetration and cumulative costs (Greene 2005; Greene 2007)

Leiby and Rubin developed the Transitional Alternative Fuels and Vehicles (TAFV) model in the mid-1990's (P. and J. R. Leiby, 1997; P., Rubin, J. Leiby, 2003; Sterman, 2001). TAFV develops estimates of alternative fuel and vehicle market penetration over a twenty-year period. Like Autopia, the modeled transition is dynamic, rather than long-run static equilibrated. Long-run static equilibrium models ignore the fact that the introduction of a new technology to a market is filled with uncertainties. Technologies may not evolve as assumed or may face unexpected barriers unrelated to their merit. Using a dynamic transition model allows model endogenous functions, like vehicle and fuel prices, to impact the outcome. The TAFV results suggest that AFVs will not achieve significant market penetration given low oil prices.

The Multi-Path Transportation Futures Study rigorously compares the progress potentials of alternative fuel and vehicle technologies in in the U.S. light duty vehicle market through 2050, in order to support fuel and GHG reduction policies (Plotkin, S. & Singh, M., 2009). The powertrains considered were: advanced technology gasoline, advanced technology diesel, hybrid electric vehicles, plug-in hybrid electric vehicles (10 and 40 mile range), hydrogen fuel cell vehicles (HFCV), plug-in HFCVs, and battery electric vehicles. Multi-Path uses PSAT (Powertrain Systems Analysis Toolkit) for fuel economy analysis and ORNL's Automotive System Cost Model (ASCM) along with literature reviews for cost modeling.

Scenario analysis is performed using NEMS – National Energy Modeling System (specific version for this NEMS-MP) .

System dynamic modeling is built on the concept of *stocks and flows*, *feedback loops* and *time delays.* System dynamic modeling is an alternative, more conceptual approach, to models like MARKAL and HyTrans. The goal of a system dynamic model is to understand a system as an operational whole. The relationships between functional objects in a complex system are often nonlinear: simple inputs can induce large changes in unexpected parts of the system –- "You can't just change one thing", as the saying goes (Sterman 2001). Stocks are a measure of some value, say money in an account at a particular moment--while flows measure the volume of transactions over a given period of time. System dynamic models would fit into the outer ring of Duke's modeling classification diagram. A bank account may have a stock of $1000 in it on a particular date, with a $10,000 flow over a year period, for example. Feedback loops modulate interactions amongst the stocks and flows. The components, stocks, flows and feedback loops of a system dynamic model are constructed as equations that are then run for a simulated time period. Struben and Sterman offer a system dynamic transition model They seek to identify important feedback structures that support or impede AFV penetration (Struben & Sterman, 2007) .

Andrew Ford reviews and analyzes the role of system dynamic modeling in the electrical power industry in "System Dynamics and the Electric Power Industry" (Ford, 1997). Electric power first became commercially available in the 1880's. As electric power became increasingly popular a technological debate over AC vs. DC transmission came to head. AC transmission implied a network of large power stations and long transmission line runs, while DC would mean small, local power stations and short transmission runs.

The AC based grid won out. This led to the Investor Owned Utilities (IOU) building increasingly larger power plants to harvest the profits that the efficiency gains meant in the regulated pricing scheme under which they operated. The large plants worked well until the energy crisis of the early of 1970’s when high energy prices reduced consumption and threatened the IOUs with substantial stranded assets. Ford explains the foundations of the crisis with system dynamics models. He argues that the identification of feedback loops can yield important insights and modeling.

These sorts of models are valuable tools to transportation and energy researchers however, they share an important limitation: they are restricted to outcomes within their initial assumption sets. A model like MARKAL can answer a question, but it does not inherently possess the ability to help its users create new ideas. The models are deterministic, an input set maps to a single outcome set. Monte Carlo methods can extend the range of possible insights to a degree, but even Monte Carlo methods are limited by their input parameterizations. Seekers of new ideas are consigned to their showers, gardens and wherever else they might seek ephemeral inspiration.

If our goal is not to analyze an existing idea, but to seek new and better ideas, purely analytical models are not the right tools, although they can be of assistance. The only practical approach to discovering good ideas is to start with a lot of ideas and evaluate the locally optimal. I now explore the possibilities for serious games to help in creating and evaluating ideas.

## Serious Games and Other Models

A serious game is a complement, not a replacement, for more formal models like MARKAL. These games need to be as realistic as feasible within their specific contexts to be of use. Military games, the best known application of serious games, include extensive referee and control groups, composed of experts, to maximize game realism (Brewer, G. and Shubik, M., 1979). For a transportation energy themed game, the referee and control group would be made up of subject matter experts from the appropriate industries, NGOs and regulatory agencies. The serious game is a collection of models with a game interface. The game extends the models by allowing us to look at the possibilities presented by the union of the models within a narrative whole.

Serious games are most effective for modeling systems that contain substantial uncertainties. In games we can safely ask, "What is the worst thing that can possibly happen?" Games are weak as point estimators. Their strength is in the discovery of trends and feedback mechanisms.

## Research Objectives and Questions

Serious games have proven valuable in many fields for developing plans and insights. War games are the most well known, but serious games have been used in many fields (Abt, 1971; Mayer, 2009; Mayer, I. and Veeneman, W. (eds.), 2002). A game on long-range vehicle and fuel transitions that is configurable for a variety of scenarios has the potential to yield useful insights. The game format would allow researchers to explore complex multi-party dynamic interactions in order to seek emergent patterns on policy questions surrounding vehicle and fuel transitions.

RESEARCH QUESTIONS:

- Is it possible to design a serious game to model alternative fuel/vehicle transition?
- How can we model the behavior, decisions and interactions of different players in the market (consumers, vehicle manufacturers, fuel producers)?
- What sorts of insights can the system offer about the automotive vehicle and fuel market transitions ?
- What sorts of insights can the system offer about specific policies such as the 2025 CAFE standard or economic trends such as increasing oil prices?

OBJECTIVES:

- Design a system that models vehicle and fuel markets within configurable policy and energy scenarios.
- Implement it in browser-based software (i.e. participation does not require that players install software).
- Design a game interface that allows a streamlined access to the model

- Make the overall model “pluggable” -- configurable to support multiple assumptions about drivetrain technologies, fuel costs, regulatory policies and other system factors with minimal modifications.
- Run the game multiple times with human players.
- Analyze play results to see what can be learned from the system, and the types of data that it generates (what might it be possible to learn).

## DISSERTATION OVERVIEW

This dissertation is organized into six chapters. The first chapter is an introduction to the research. It provides an overview of the project and its results. The second chapter is a literature review. This chapter covers information on serious games, other models used for long-range vehicle and fuel trend forecasting, and the literature sources that helped define Autopia, the simulation game model I created to investigate the potential of a serious game approach . The third chapter describes the internals of Autopia in detail. The fourth chapter is a data analysis of several games: two discrete Autopia games, and a sequence of three related Autobahn games (Autobahn is an alternative version of Autopia). The fifth chapter is an analysis of overall trends that emerged over the span of played games. The final chapter discusses the implications of the research and recommendations for future work. Further details on the Autopia model and game results are contained in a set of appendices.

## CONCLUSION

The focus of this dissertation is the use of a serious game to serve as a laboratory for potential outcomes in long-range fuel and vehicle transitions under different policy, economic and technology assumptions. The game-based approach is a promising research subject because it is untried in the transportation domain but has delivered valuable insights in other domains of comparable complexity.

# Chapter 2: Literature Review

## Serious Games

*A serious game is a game that helps us improve our performance in the real-world – Paul Pivec (2011).*

Serious games, as a methodology, were first used to train for war.. Games similar to *Go* and *Chess* were used to teach tribal leaders the art of *down-board thinking*: understanding the consequences of one's actions and responding to your opponents counter-actions over the course of multiple, successive turns (Caffrey, 2000).Under wartime conditions it is expected that losses of soldiers, weapons, facilities, and territory can occur at any time; the ability to quickly mount viable responses to unexpected events is critical to success in war fighting.

Industrial planners seek efficiency in their operations in order to minimize costs. For example, strategies like *Just-in-Time Production* (JIT) minimize inventory overhead for manufacturers (Sugimori, Kusunoki, Cho, & Uchikawa, 1977). However, the minimization of excess stocks in the system also makes it vulnerable. A failure in one step of a production process can cascade into all processes that depend on it.

War planners, in contrast, seek resilience within contingency in their strategies. A single point of failure that causes a failure cascade within downstream processes is not tolerable within the military context. Military systems are designed with redundancies and built-in failure modes to maximize the strength of their weakest links. Strategic planning is critical for war fighting, but even more so is the ability to improvise effective responses to rapidly changing circumstances. Famed Prussian Field Marshall Helmuth von Moltke (1800-1891) put it succinctly: "No battle plan survives the first contact with the enemy." Von Moltke showed that the most effective army was one that understood its capabilities well enough to maintain effectiveness in rapidly changing, unpredictable scenarios.

To develop this self-knowledge von Moltke employed war games. In these games he would divide his army into two competing teams and have them engage in simulated battle over the actual terrain they expected to be fighting on in future wars. By playing these war games, which von Moltke pioneered as a universal practice for his armies, he was able to gain insights into how he would be attacked and how to defend against those attacks. Assuming his historic enemy, France, would come up with a plan no better than his army did, it was the equivalent of having the enemies' plans ahead of time. Not only did he gain a picture of his enemy's likely attack options, he also learned valuable lessons about moving and supplying his army. Von Moltke's training and planning work contributed to his highly successful military career (Caffrey 2000).

By practicing war-gaming von Moltke was able to generate a vast number of new ideas about how to use his forces and to test them. The games stoked the competitive nature of the officers in charge of the teams. The games were effective because they allowed new ideas to be developed and explored. Serious games are now used in a variety of situations including: military planning and training, infrastructure design and corporate strategy (Caffrey, 2000; Mayer, I. and Veeneman, W. (eds.), 2002; Senge, 1990).

Abt's book *Serious Gaming* (Abt, 1971) provides a full and practical treatment of serious gaming. He begins with a discussion of the power of games. In games, Abt argues, thought and action can be unified within a single activity, and that this combination produces the most illuminating possibilities for education and strategic insights. Multiple aspects of serious games are explored in the book, including: improving education, games for problem solving, game design, evaluating game cost effectiveness, and the potential future of the gaming methodology.

Published at the same time as Abt's *Serious Gaming* was Alfred Hausrath's *Venture Simulation in War Business and Politics* (Hausrath, 1971). Hausrath's work is complementary to Abt's, as they approach the material from different perspectives within the same historical context. Whereas Abt advocates for the power of games to improve decision-making and education in non-military domains, Hausrath takes a more historical, objective tack. Starting with the early history of the games, he follows them though their applications in the Viet Nam war, covering both the practice and theory of the games. This includes a section on the business simulations that developed out of OR logistics games in the 1950's.

*Games in a World of Infrastructure* (Mayer, I. and Veeneman, W. (eds.), 2002) is a modern take on the material covered in Abt's *Serious Gaming.* Abt's vision of extending war-gaming type methodologies to other disciplines is pursued within the specialized theme of infrastructure related games. Gaming is a well-suited methodology for infrastructure projects because they are large, have long lifetimes, expensive, and thus engender complex negotiations amongst the involved and affected parties: even parties that support the development of a facility can strongly disagree on elements of its design.

Mayer and Veeneman begin the book with several authoritative chapters that describe the methodology of "gaming-simulation" (i.e. serious gaming), distinguish it from game theory, and enumerate its strengths and weaknesses. Abt cites as the most important feature of gaming the ability to "unite thought and action." Mayer and Veeneman use the verb *integrate* to get at the same idea. Games juxtapose a tangible system of rules and objectives with the complexity and non-rationality of human motivations. To illustrate this non-rationality, take for example casino gambling games. People who gamble in casinos know that the odds are against them: the casino will always win in the long run, but they still play - -they are not rational profit maximizers. They seek to achieve the emotional experience that they associate with good fortune (Malaby, 2008).

The same sort of non-rational motivations apply in non-game contexts as well. People often act based on internal criteria that are partially or completely opaque to them. Games are a valuable methodology because they can allow these sorts of complex human behaviors to be observed. These behaviors are often relevant to the analysis of the simulated system, for instance the market gaming behavior seen in the electricity market deregulation simulations Infrastratego (Kuit, 2005) and UTILITIES21 (Backus, 2005) , was seen in the actual deregulated markets.

Abt and Mayer et al emphasize the idea that a simulation game should seek to glean insights into the working relationships of major entities within the modeled system. Data collection, both qualitative and quantitative, during and immediately after the game, is an important element of the process. However, one should not expect the games to be accurate point estimators. The power of the game is its ability to acquaint players and designers with the types and natures of the interconnections between the system levers.

## Noteworthy Games On Other Topics

There are many games that can be considered noteworthy in terms of the history of serious gaming. I have selected several to discuss here that I feel are pertinent. Sim City (ACMI, n.d.; Anon, 1999) was a highly popular, seminal, urban planning simulation game released by Maxis in 1989. It was the first of its kind. “Fold It!”(Cooper et al., 2010) is a game that has yielded highly useful scientific knowledge on the difficult problem of protein folding. Results generated from the game have been published in *Nature*. The Beer Distribution Game is a classic system dynamics game (Nienhaus, 2010; Xiao, 2009). Finally, the post-conflict resolution game SENSE will be discussed because it is an actively used large-scale policy game and shares similarities with the game I developed (USIP, 1995).

SimCity, released in 1989, is a classic, highly influential, personal computer game (ACMI, n.d.). In the game, players take the role of a mayor in charge of developing a city from scratch. The player has a budget with which he can designate zoning (industrial, residential and commercial), construct various types of power plants, develop transportation infrastructure, and make other decisions as well. The game is non-competitive in the sense that there is no winning or losing. Success in the game is derived from learning the sensitivities of the model so as to be able to accomplish one's own self-directed goals -- say, building a city with 500,000 citizens. Will Wright, the game's designer, was influenced by the system dynamics work of Jay Forrester (Anon, 1999). SimCity, in conjunction with its multiple sequels, is probably the most popular system dynamics model ever created.

The Strategic Economic Needs and Security Exercise (SENSE), developed by Richard H. White of the Institute for Defense Analyses (IDA) for the United States Institute of Peace, is a simulation of post-conflict decision-making in a mythical country called Akrona. The game itself takes three days to complete and is typically run with 40-66 players. A game master, along with three mentors, administers the game. There are additionally 12-19 "Tutor-Coaches" who assist the players with game operations. Players take on the roles of government agencies, NGOs and private sector officials. The objective of the exercise is to improve the players' skills in conflict analysis and resolution, improve their negotiating abilities, and to teach about how third parties can be used as mediators. SENSE has been used to train officials for post-conflict environments in many place, including Kosovo and Iraq (USIP, 1995).

One challenge with games is the translation of the game player experience into generally useful knowledge. Games like SENSE or SimCity provide experiences to players that, beneficial as they may be, are difficult to explain to non-players.

Even successful games -- those that engage players and meet their pedagogical objectives -- do not generally develop tangible results available to the outside world (Mayer, I. and Veeneman, W. (eds.), 2002). This makes "Foldit"[1] -- a protein folding game initiated by University of Washington protein scientist David Baker -- especially noteworthy (Bourzac, Katherine, 2008). Proteins are long strings of amino acids that occur in nature as complex, three-dimensional structures, i.e. folded. The protein's function is dependent on how it is folded.

Protein scientists are very interested in how proteins fold, but it was a difficult problem that could only be solved with computationally expensive search algorithms. Baker devised a screensaver program that would allow volunteers to donate spare computer cycles to this problem. like the SETI project (http://setiathome.berkeley.edu/) The screensaver program displayed the folding attempts as the computer worked to solve the folding problem.. Volunteers who watched the screensaver work told Baker they could often see promising folding strategies but had no mechanism to interact with the program. This led Baker to the idea of creating a protein folding game.

Foldit! is a graphical puzzle game. Players, alone or in teams, use a set of tools to fold a visual representation of a protein, seeking to find a minimum sized configuration. There are thousands of Foldit players around the world. No scientific knowledge is required to play

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[1] See http://fold.it.

[2] I participated in a Beer Distribution Game session in a marketing class at the UC Davis

the game. Players participate in a competitive community with online forums and public scoreboards. Foldit players have made actual, concrete scientific discoveries. Indeed, Foldit is the first serious game to have its results printed in the prestigious journal *Nature* (Cooper et al., 2010; Khatib, 2011). FoldIt demonstrates the fact that games can generate valuable knowledge. Policy games, like policy itself, are intrinsically more ephemeral than a pure science game like FoldIt, but Foldit does demonstrate that power that games have for generating new and useful insights into difficult problems.

### System Dynamics Models

System dynamics models describe the dynamic relationships between the parts of a system. Many games are system dynamic models designed for entertainment. SimCity is an excellent example as its designer, Will Wright, was highly influenced by the work of system dynamicist Jay Forrester. In these games the player seeks to discover the functions of the levers of the system so that he can manipulate them toward some objective. For instance, in SimCity low tax rates attract population to the city, which increases tax revenues to the city on a total basis, but decreases funds on a per capita basis. The player who decreases taxes too much will end up with a highly populated city with a poor quality of life, which will eventually drive population out of the city.

Developed at MIT in the 1960's, *The Beer Distribution Game* (BDG) (Nienhaus, 2010; Xiao, 2009) is still played regularly in graduate business school programs[2]. BDG's heritage can be traced through the military logistics games of the 1950's (Hausrath, 1971). The object of

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[2] I participated in a Beer Distribution Game session in a marketing class at the UC Davis Graduate School of Management in Spring 2011.

BDG is to efficiently manage a supply chain comprised of four links: a retailer, a distributor, a wholesaler and the factory. The action begins at the retailer. Customers buy cases of beer each week that the retailer sells from his available stock. The retailer then sends an order back to his distributor each week to restock his store. The beer brand experiences a sudden surge in popularity due to an unexpected product placement. This surge causes a shock to the supply chain. Each of the three levels beyond the retailer must compensate for it. This turns out to be difficult due to the delays in the order system. In a typical game the chain is emptied of inventory. Orders go unfulfilled while the factory works on a huge backlog that floods the chain with inventory some weeks later. It is feast or famine. This is called the *bullwhip effect* and is a famous problem in supply chain management. The game has been played thousands of times at companies and business schools around the world.

## Energy Related Games: Powerplay, Oil Schockware, Utilities21

In contrast to the relatively large number of games addressing complex military and logistic dilemmas, few games deal with energy or transportation. Energy games range from simple graphical games like SimCity's energy component to elaborate scenario games like Oil Shockwave (SAFE, NCEP, 2005) of which I found several relevant examples The same cannot be said for transportation, at least on the topic of light duty vehicles: I found no games on the subject.

Power Play (Ruth, 2007), a game about decision-making in energy efficiency markets, was the most influential on Autopia development. Power Play develops a game-based model of an energy market built around utilities, consumers, appliance manufacturers and generation technology firms. It is a large game, requiring at least eleven players and several hours of time. Power Play uses a turn-delimited game format. Players enter their game decisions into a computer. These decisions are an endogenous component of the overall model and affect subsequent turns.

Power Play, as of the writing of the article, only had one recorded play, which makes its results statistically insignificant. Players playing a game for the first time are prone to errors that they must struggle to correct for the rest of the game. The Power Play game provides a good example of this phenomenon, in that game the utility player mistakenly ordered 14,000 credits worth of new generation when he intended to order 1400. An experienced player would not have made that mistake. To generate good data, preventative measures should be taken to prevent this sort of *error-play.* Good pre-game instruction and multiple runs of the game, with the same players, can help accomplish this. However, this requirement can be difficult to meet, especially if you want high-level decision makers as players.

Another problem with the game session was the fact that their player group was composed of energy efficiency professionals. The homogeneity of the group skewed the game play towards a higher level of energy efficiency than was justified under the scenario. Diverse player groups are best for generating robust insights from games (Backus, 2005).

Despite the limitations of the play session, they did arrive at some interesting and useful observations. The most important is that energy efficiency policy can often have unintended equity implications. In the case of Power Play, low-income consumers ended up subsidizing high efficiency appliances that they could not afford to buy themselves. In effect, the poor subsidized the wealthy. If Power Play has a single message, it is that efficiency policies must be carefully examined for unintended consequences.

Oil Shockwave is a scenario game developed by the groups Securing America's Future Energy (SAFE) and the National Commission on Energy Policy (NCEP). The game in the report was played using former White House cabinet members and high ranking national security officials. It has been played in many prominent venues, including the World Economic Forum in Davos, and is packaged for university instruction (SAFE, n.d.).

Players are assigned roles in a fictional United States government cabinet that is faced with an oil supply disruption crisis. The scenario begins in late December of 2005 with civil unrest in Nigeria (the world's $5^{th}$ largest oil producer) leading to an 800,000 BPD production cut. This cut is compounded by an unusually cold Winter in the Northern Hemisphere that boosts oil demand by an additional 800,000 BPD. The cabinet, working from a list of suggested options, is tasked with coming up with a response to the crisis for the President.

The game then advances a few weeks (simulated time) into the future at which point terrorist attacks shut down major oil facilities in Alaska and Saudi Arabia. The cabinet is again tasked with developing a response for the President, and there are no easy answers. The simulation details are rich. U.S. military intervention in Saudi Arabia to stabilize the situation would inflame anti-American sentiment and thus be counter-productive. Furthermore, faith in Saudi Arabia's ability to stabilize the world oil market is faltering, and that is showing up in global and domestic economic instability.

Oil ShockWave's primary objective is didactic: it is meant to viscerally demonstrate the fragility of America's energy security. Indeed, importing about 49% of its oil, the US is vulnerable to political and environmental events in oil-producing regions (EIA, 2011a). The developers freely admit that Oil Shockwave is an editorial device intended to impart a particular message about the fragile state of US energy security (Kuit, 2005). In this way it is different from games like Power Play, which grant players a highly interactive scenario and more open-ended outcome possibilities.

Similar to Oil Shockwave in its narrative structure was "World Without Oil" (McGonigal, 2011). Instead of working with a selected group of subject matter experts like Oil Shockwave did, "World Without Oil" was an open format internet game. Anyone with internet access could participate for free. In the game players were given a blog on which they would respond to weekly narrative turns about a fictional massive oil crisis in the USA by writing game based blog entries describing how they would imagine their cities responding to the given scenario. The game, which was started in 2007, ran for 32 weeks. Archives of game and player developed content are available at www.worldwithoutoil.org.

Infrastratego(Kuit, 2005) was developed in the Netherlands in the mid-1990's to explore electricity deregulation. It is a large game, designed for 40-50 players. It was designed to reveal strategic patterns that might occur in the implementation of the *Electriceitswet* (Electricity Act) of 1998, which liberalized the electricity market in the Netherlands.

The conventional wisdom of the 1990's was that opening electricity markets to greater competition was the next evolutionary step for the industry (Ford, 1997). The Infrastratego analysis, which occurred before the actual transition, forecasted accurately many difficulties that would emerge in the actual transition. For example, the incumbent power companies (commissioned monopolies) still held great leverage over the system that they could exploit against new competitors entering the market. Managing the incumbents to level the playing field turned out to be a difficult problem in the game and in reality. The Infrastratego developers concluded that although liberalization offered the potential for many benefits that there were also dangerous vulnerabilities in the system that could easily be exploited. Infrastratego proved to be remarkably prescient in its findings.

UTILITIES 21 is almost identical to Infrastratego in theme (Backus, 2005). It is a large game, designed for 20-60 players and two-day play sessions. Players take on the roles of electricity retailers, generators and consumers within a dynamic electricity market. The macromodel for UTILITIES 21 was based on the FOSSIL 2 model (USDOE, 1980) used for the US national energy plans by the DOE from 1978-1996. Like Infrastrego play discovered, UTILITIES 21 found that the electricity market deregulation was ripe for exploitation.

The obvious question is: given the results of games like Infrastratego and UTILITIES 21, what was done about them? The answer is: not much. One of the well known problems with using serious games is that their results aren't especially convincing to non-players and those who are skeptical of the methodology (Abt, 1971; Caffrey, 2000; Mayer, I. and Veeneman, W. (eds.), 2002). Comically, the House of Representatives response to the results of UTILITIES 21 was to investigate if the game sessions were the cause of the market gaming! (House of Representatitives, 2003)

## CONCLUSION

The serious games methodology has proven itself over time as a potent tool for generating useful insights into complex problems in many fields. The games can take any number of formats, from the non-competitive, narrative approach of World Without Oil(Eklund, 2007), to strategic exercises like Utilities21(Backus, 2005), to computer based puzzle games like Fold It!(Cooper et al., 2010). Although there are games on many related subjects, there have been none on alternative fuel and vehicle transitions. The scope and complexity of such a transition make it a natural candidate for a game approach. In order to explore the potential for the application of a serious gaming approach to the transition problem I have developed, run, and analyzed a serious game called Autopia, which I will now describe.

# Chapter 3: Autopia Game Model

Autopia is meant to serve as a laboratory for understanding the impacts of policies, economic, and technology trends. It is a tool with which the design and implementation of policies can be safely explored. It is also the first serious game on the topic of long-range vehicle and fuel transitions. The topic of long-range transitions in transportation lends itself to the serious game methodology because the questions of interest are open-ended and the theme of resilience within contingency is of central concern within the policymaking process. I will here describe the game and its mechanics.

The scale of the Autopia game model is very large, covering two major industries and their customers. Given that my resources were limited to that of my own time as a graduate student and a small fund for incidentals, I had to be selective about where I applied my efforts. Not all of the component models are of equal quality. Some of them are quite minimal, written as working placeholders for later versions. However, that being said, I put extensive work into the game play calibration. All of the models and interfaces have been designed to work to support an engaging simulation. This is very important in a simulation game, and not easy to do, because players will not respond in the desired manner to a game that does not engage them.

## Game Overview

### Introduction

Autopia is a three-way market simulation game about alternative fuel and vehicle transitions scenarios. The game is designed to simulate the time period between 2010 and 2050. Players take on the roles of Vehicle Producers, Consumers and Fuel Producers. Energy and regulatory scenarios provide variation for the game. Producers seek to remain profitable in the face of a changing market. They compete against their fellow producers to be the most profitable. Consumer players represent large groups of drivers with similar incomes and vehicle preferences. Consumers are given a fixed amount of income to spend each turn ("allowance") that must be divided between mandatory fuel expenses for their existing fleet and new vehicles to replace those that they have lost to attrition. Consumer players seek to keep their drivers adequately stocked with vehicles, preferably with ones they find attractive.

A standard Autopia game has thirteen fixed player roles operated by teams of one to three players. The players are all to be located in the same room to allow for verbal communication during the game. Each player team must have access to their own computer with internet access and a modern web browser. No additional software is required. A full Autopia game can be played in four to eight hours, dependent on the objectives for the play session.

Five groups of consumers are represented.  I designed the consumer groups by looking at the car sales data that appears on a monthly basis in the online Wall Street Journal; it is one plausible classification scheme among many, and can be easily changed. The *young* consumer group represents entry-level vehicle buyers. They are a large, price sensitive group; fuel prices play an important role in how they enter and persist in the vehicle market.

*Family* consumers are a major niche who purchase larger mass market vehicles like mid-full size sedans, minivans, and crossover SUVs. The *enthusiast* represent drivers spending an average of about $25,000 for their vehicles who value performance in their vehicles and value less practical features than the *young* and *family* consumers[3]. Representing about 10% of the market is the *executive* group. They buy vehicles averaging $35,000 - $50,000, and sometimes more. The final group is the *green* group. They are a small group, up to 5% of the market, who are interested in efficiency technology and are willing and able to pay for it: these are the early adopters. The objective for all the consumer groups is first to possess enough vehicles to satisfy all of their drivers -- which is more of a challenge for some groups than others--and then to get the best possible vehicles. Consumer role players are rated with a performance score that describes success at meeting the vehicle needs and desires of their drivers.

Producers, unlike consumer players, are almost identical to each other. The FPs have almost no distinguishing features except for the fact that one of them is designated as the *utility*, and starts the game with only electric plants. I initially gave the VPs differing strengths and weaknesses, but I found through experience that it wasn't productive. In fact, diversifying the VPs too much actually led to less interesting outcomes as the VP who came out with the native advantage for a scenario would soon dominate the game. It is reasonable to assume there are at least four very large automakers in the world that are able to effectively compete against each other.

An Autopia game takes place within an economic, energy, and regulatory context. The game economy is an exogenous factor determined by the allowances given to the consumers each turn. Consumers spend their allowances solely on vehicles and fuel. Their allowances are the only source of income within the game; all producers must compete for it. The energy scenario is exogenously based but has an endogenous factor that acts according to how well fuel supply and demand are matched. The regulatory context is also pre-defined within the scenario. A CAFE scenario is included in the game. Other scenarios would require programming.

## Player Relationships

The standard Autopia game[4] is configured for five consumer roles, four vehicle producer roles and four fuel producer roles; however this can be changed as necessary for the scenario. Games can be played without covering all of the roles by using computer-operated players or by ignoring them.

[4] Other configurations are possible.

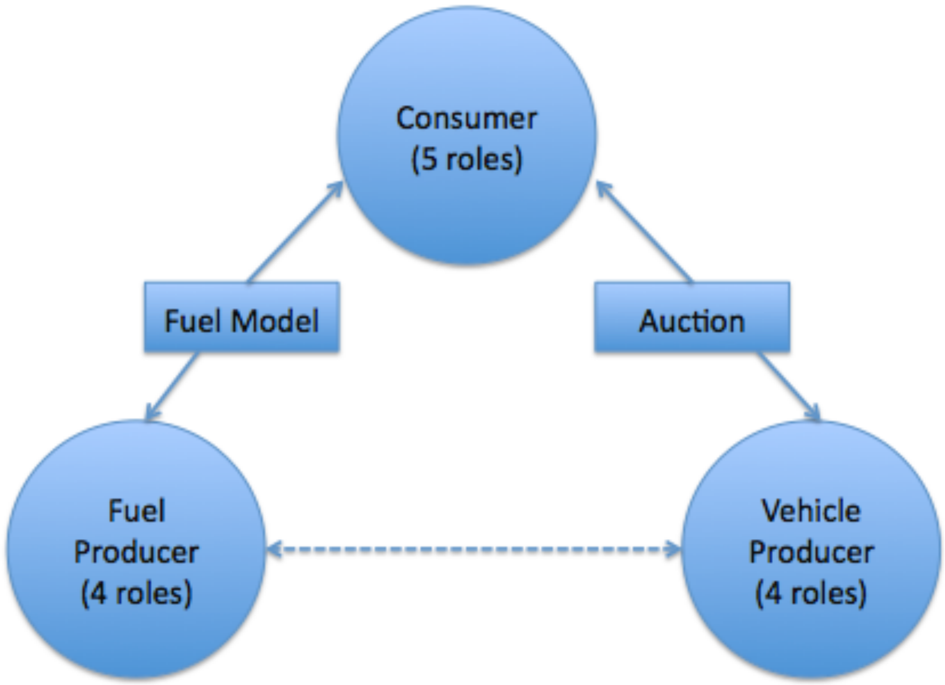


**Figure 2: Player Diagram**

The consumer buys vehicles and fuel with his transportation allocated income, which is called an *allowance* in the game. A consumer represents a group of buyers with similar vehicle preferences and income. Figure 3 shows the standard game consumer set. Consumers have a name, a target quantity of vehicles they're expected to buy per turn, an average vehicle price they seek to pay (at the start of the game), and a description. The game objective of the consumer is to keep his drivers in the sorts of cars they want to be driving. He is kept appraised on his performance via a score so as to encourage a faithful portrayal of his role[5].

| Name | # Veh./Turn | Ave. Veh. Cost | Description |
|---|---|---|---|
| young | 600 | 18000 | Young consumers are looking for inexpensive, efficient cars with style. |
| spec1_high | 23 | 112749 | High end consumer. Low purchase volume. |
| enthusiast | 400 | 24000 | Enthusiasts seek high performance vehicles first and foremost. They have tight vehicle purchase budgets but are not too concerned with efficiency. |
| family | 700 | 26500 | Family consumers buy midsize sedans and mini vans. They seek comfortable, practical cars and are budget conscious. |
| green | 47 | 35875 | Greens want high efficiency vehicles with good style. They are interested in new technologies and are willing to spend extra money for them, but not too much. |
| executive | 200 | 50000 | Executives buy prestige vehicles with high style and performance. |

**Figure 3: Consumer Player Descriptions (screenshot)**

Consumers interact with the VP in the *vehicle auction* segment of the turn. In the auction vehicles are released for purchase in timed increments such that all consumers have an opportunity to purchase vehicles of their choosing[6]. The auction runs at a pace that allows VPs to make live adjustments to their prices in response to their competitors' pricing and success. Since players are all located in the same physical space, negotiation can occur on

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[5] This feature was inspired by the fact that when Power Play was run at an energy efficiency conference the players biased the outcome of the game (Ruth, 2007). I expected I might have a similar problem with Autopia player groups.

[6] Early tests of Autopia did not have the auction. These games were biased towards players who made the quickest decisions, making quick vehicle purchase decisions the dominant play strategy.

vehicle prices. In practice this would often mean players calling out across the room to each other. An in-game email system is also available to players.[7]

Consumers have a direct, interactive relationship with the VPs in that they consult and negotiate with VPs about their purchase decisions. The relationship between the consumer(C) and fuel producer (FP) is passive in comparison. The consumer refueling assumption in Autopia is that consumers are indifferent about which brand of fuel they buy and that their VMTs are a function purely of the age of their vehicles.. New vehicles are driven 15000 miles a year during their first four years of service. This falls off by approximately 20% for each subsequent four year period that the vehicle survives. This simple VMT model / fuel consumption model is justified on the basis of the large size of the modeled market: there is no mechanism in the private vehicle fuel market that allows for millions of drivers to act in unison on fuel purchase decisions, so there should be none in the game.

Fuel producers in Autopia are strictly refiners; they do not produce any of the raw materials (e.g. oil, coal, natural gas) from which come their fuel products: gasoline, diesel, hydrogen and electricity. FP players do not set fuel prices. The assumption here is that they sell into a highly competitive market and all buy their materials at identical prices. FPs make their money by running their operations as efficiently as possible. The FP will maximize his

[7] This in-game email is a working experimental feature. It has been used in a few games, but was never fully explored as a game tool. The idea was to capture actual records of player negotiations for post-game analysis (players were told to not treat these messages as private conversations). In practice, the messages were not that interesting.

profit by always having the exact right amount of production capacity to meet consumer demand; if he has too much capacity online he will pay excessive fixed costs; too little and he will leave profits on the table. The FP game is slow and strategic—subtle it is a matter of properly discerning and reacting to the overall trend of the game with little immediate feedback. The VP and C games are much more active in comparison.

Fuel prices in Autopia are determined by the Fuel Model (FM). The FM takes as input for each fuel on each turn: an exogenously determined base price (set in the game scenario), aggregate fuel demand, and aggregate production capacity.  The model is built to reward players for finding the true market demand for a fuel by increasing the size of the revenue "pot" for doing so. Over or under-producing actual consumer demand causes sub-optimal aggregate returns to the FPs (although not necessary to each player).

### Money Flows

Money flows in the game are shown in Figure 4. All players begin the game with an initial stock of assets and funds. For consumers, the assets are their existing fleet and their funds are an allowance payment. Consumers are given an allowance each turn. The allowance funds are the only new money that enters the game once it has started. Fuel producers begin with a set of refineries and some initial funds. Vehicle producers begin the game with two car lines ready to sell in the auction and initial funds.

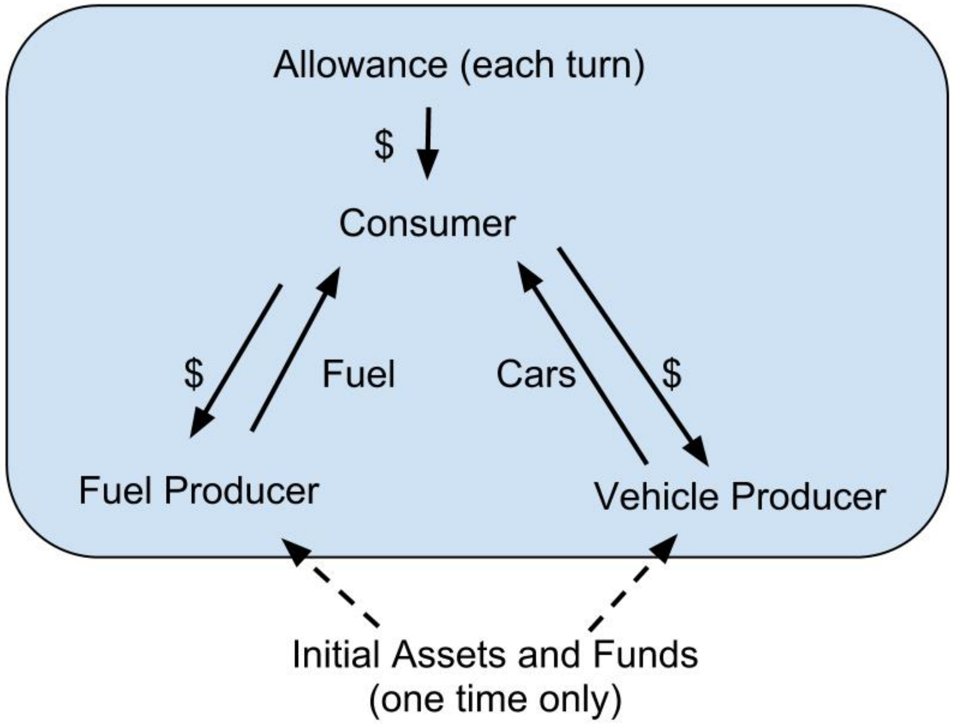


**Figure 4: Money Flows**

## MODEL DESCRIPTIONS

In this section I provide the details of the core models for Autopia.

### FUELS

There are four fuel types in Autopia: gasoline, diesel, hydrogen and electricity. Gasoline and diesel are petroleum-derived fuels that deliver 120 MJ and 132 MJ per gallon per gallon respectively. Hydrogen and electricity are sold in gallon of gas equivalent (GGE) units. A

GGE in Autopia is defined as 120 MJ. The feedstocks for hydrogen and electricity are not specifically defined. The base fuel prices in the scenario can be set to imply any feedstock(s) the experimenter is interested in.

Biofuels are not directly considered in Autopia for two main reasons: they are not directly considered in the Multi-Path study (Plotkin, S. & Singh, M., 2009) on which the Autopia vehicle models are based (i.e. there is no biofuel vehicle model), and the game development complications that arose from including an alternative liquid fuel with a variable energy density (dependent on blend) for gas and diesel powered vehicles were substantial relative to the benefits[8]. Biofuels can be assumed present in post-game analysis if desired.

### DRIVETRAINS CONSIDERED IN AUTOPIA

There are twelve drivetrains modeled in Autopia. These can be divided into two groups: conventional fuel vehicle (CFV) and alternate fuel vehicles (AFV). CFVs in Autopia are simply vehicles that do not contain an electric drive motor, i.e. non-hybrids. CFVs have either gasoline spark ignition or diesel compression ignition drivetrains; they constitute the vast majority of vehicles currently on the road (S. Davis, 2008). The other drivetrain types , including the HFCV, all have some level of electric drive and are thus considered AFVs.

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[8] For example, how does the fuel model account for flex fuel vehicles? When do those drivers buy biofuels and when do they choose petroleum fuels? There is the non-trivial implication of a biofuel / petroleum fuel equilibration process if biofuels are directly included in the current system. I preferred to use my time modeling more important system factors.

Basic hybrid electric vehicles (HEV) pair a gas or diesel engine with a small drive battery that are charged solely by the recapture of kinetic energy from the vehicle. These vehicles cannot be charged at outlets. Gas, diesel, and hydrogen fuel cell vehicles (HFCV) can be HEVs. All AFVs, including HFCVs and battery electric vehicles (BEV) are assumed to be at least minimal hybrids (i.e. small drive battery with regenerative braking), in line with the assumption made in Multi-Path.

Plug-in Hybrid Electric Vehicles (PHEV) are hybrid vehicles with increased battery sizes and plug-in charging capability, like a standard electric vehicle. Autopia includes models for PHEVs with 10 (PHEV10) and 40 (PHEV40) mile all electric ranges. PHEV10s and PHEV40s are available in the game on gas, diesel and hydrogen vehicles.

Battery Electric Vehicles (BEV) are full electric vehicles with a nominal 100 mile range.

They are refueled solely by electric charging. Table 1 shows all of the vehicle drivetrains modeled in Autopia.

| **Type** | **Abbreviation** | **Fuel(s)** | **Hybrid** | **All Electric Range** | **Battery Size (kwh)** |
|---|---|---|---|---|---|
| Gasoline | gas | gas | | | |
| Diesel | gas | diesel | | | |
| Gasoline Hybrid | gas hev | gas | X | | 1 |
| Diesel Hybrid | diesel hev | diesel | X | | 1 |

| | | | | | |
|---|---|---|---|---|---|
| Gas PHEV 10 | gas phev10 | gas, electricity | X | 10 | 3 |
| Gas PHEV 40 | gas phev40 | gas, electricity | X | 40 | 12 |
| Diesel PHEV 10 | diesel phev10 | diesel, electricity | X | 10 | 3 |
| Diesel PHEV 40 | diesel phev40 | diesel, electricity | X | 40 | 12 |
| Hydrogen Fuel Cell | h2 | hydrogen | X | | 1 |
| Hydrogen Fuel Cell PHEV 10 | h2 phev10 | hydrogen, electricity | X | 10 | 3 |
| Hydrogen Fuel Cell PHEV 40 | h2 phev40 | hydrogen, electricity | X | 40 | 12 |
| Battery Electric Vehicle | bev | electricity | X | 100 | 45 |

**Table 1: Modeled Drivetrains (from Multi-Path)**

### VEHICLES

The VP's goal in Autopia is to make a profit by selling vehicles. In order to do this he must properly perceive the demands of the market – the right product, at the right price, in the right volume. A frequently used, and successful, VP strategy is to target a car at a consumer group. Their game experience will inform the VPs on the preferences of the various consumer groups. More advanced strategies seek to develop a vehicle that attracts two or more consumer classes, to increase demand. The VPs differentiate their product offerings by investing in R&D, which improves them in cost and efficiency (mpge).

The vehicle receives a highly detailed modeling treatment in Autopia. A *Vehicle* is an instance of a drivetrain (e.g. gas hybrid), manufactured to the technical capabilities of the VP, to which the VP has applied the customizing characteristics of *style* and *performance*, a production quantity, and a price. To create a vehicle product a VP sets a style, performance, and production scale on a drivetrain model base. This yields a production vehicle with a set of build cost and mpg, which the VP can see in his vehicle build screen (Figure 5).

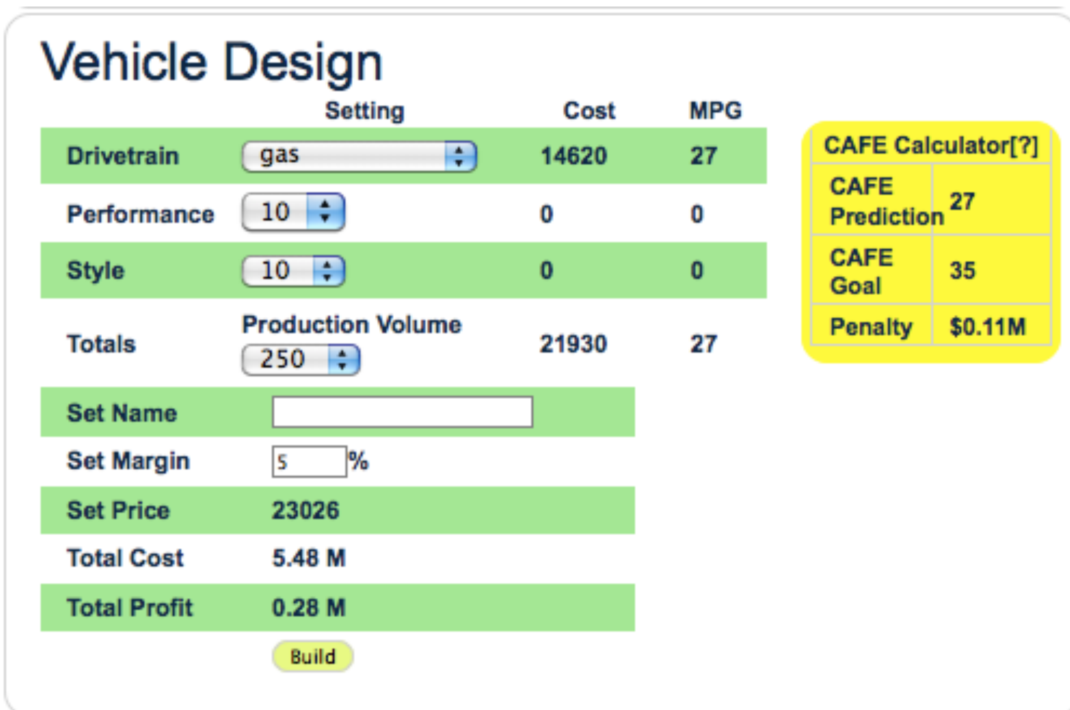


**Figure 5: Vehicle Build Screen**

*Style* and *performance* are the descriptive characteristics that a VP assigns to a vehicle., Cars are complex symbolic objects that people use to express themselves in addition to travel (Heffner, 2006; Ozaki & Sevastyanova, 2011; T. S. Turrentine & Kurani, 2007; Urry, 2004). Presenting vehicles in the way that buyers actually relate to them – in terms of aesthetics, utility, size, performance, comfort, reputation, technology, and prestige, is impossible to simulate effectively, especially when they are buying up to 700 vehicles in a fifteen minute turn (which are discussed in detail later).

I chose to use two descriptive variables: style and performance. Style represents the non-performance based elements of the vehicles e.g. appearance, size and amenities of the vehicle. Style can range from 0-40. Each level of style has a base cost of $500, which equates to an actual production cost of 1.5 – 4 times ($750-$2000) that amount, depending on the production volume of the vehicle. Style reduced from the base 10 points decreases the base production cost of the vehicle at that rate. Similarly, style costs 0.4 mpg, which is added when style score is reduced below ten. Performance describes the power (i.e. hp, kW) of the motor and its accompanying hardware (e.g. brakes, suspension). A point of performance costs $500 and 1 mpg. Dropping under the base level of ten decreases the cost of the vehicle and increases mpg. I chose to use two descriptive variables because it worked best in play testing.

The style and performance level costs were developed by taking the cost of an entry level Toyota Camry, of $22000 (Toyota, 2012), and then assuming that the lowest possible price a new car could ever be was around $10000 (Wood, C., 2011). Given the base vehicle was considered to have a style and performance of 10, I sought to determine the price of the minimum vehicle, one with style and performance ratings of zero by dividing the difference between the entry level Camry and the cheapest new car by twenty, the sum of the style and performance points for the base level Camry. This yields a level cost of about $500, pre-production. This is not an exact number, however, because it can be set to whatever the scenario designer would like, and indeed it has been different values in different games. I eventually standardized on the $500/level value because it made the games easier to compare against each other. The 1.0 mpg cost for performance and 0.4 mpg cost for style were chosen such that the performance cost was substantially more than the style cost, and so that fuel economy of the minimum vehicle (style: 0, performance: 0) would be about 40 mpg, this being about the maximum fuel economy a production gasoline vehicle can attain at the current time.  The mpg cost for style is assumed to be due to increased weight (style includes size) and power consumption. The mpg cost numbers can be easily changed for a scenario if desired.

Figure 5 shows the actual VP vehicle build screen. The VP sets a drivetrain in the first row, selecting amongst twelve possible options (see Table 1), each with its own cost and mpg. The base configuration of any vehicle is style:10, performance:10. This is meant to be the equivalent of a four-cylinder Toyota Camry on which the Multi-Path models that underlie the Autopia vehicle models are based (Plotkin, S. & Singh, M., 2009). As the VP alters the performance and style attributes, he can see immediately how the changes impact the vehicle build cost and mpg in the *Totals* row. The *Production Volume* determines the final cost of the vehicle. Very low production volumes increase the production cost, while high volumes minimize the unit costs. The lowest cost multiplier in Autopia is 1.5 times, which is achieved at a production level of over 250 units. This multiplier comes from the literature and would apply to the most popular types of vehicles like the Toyota Camry (Vyas, 2000). The highest multiplier is 4.0 times, for a production run of ten units. I chose this number because it worked well in the games. Actual multipliers between build cost (material and labor only) and production cost (build cost plus research, marketing, plan maintenance, non-wage labor costs like pensions) are considered to be trade secrets by manufacturers. I was not able to find a good source for calculating production-scaling costs so I coded a simple linear model for it.

To complete the vehicle, the VP player must set a name for the vehicle and also an initial margin. The margin decision is non-binding however as the VP can change his price in the interface whenever he wants.

Once the VP has designed a vehicle he likes he presses the *Build* button. Building a vehicle puts it in production for sale on the following turn. The total costs of the vehicle build are immediately deducted from the player's bank balance. A VP is limited to the production of vehicles for which he has immediate funding available. There is no mechanism for credit in the game. However, the VP is not bound to any vehicle production decision until the turn ends. A vehicle can be deleted at any time with a full refund of expenditures and no other penalties. This rule was included to prevent players from having to go to market with vehicles that are obvious mistakes in order to minimize error-play[9].

### R&D PROCESS

VPs develop their drivetrain technology by expending *RD Points* on research categories that improve the fuel efficiency and, usually, reduce the production cost of the available drivetrains. RD points are earned by selling vehicles profitably. Players are awarded one RD point for each $100,000 of profit they manage on their vehicle sales in a turn. In practice., turning a $100,000 profit in a turn is achievable but not easy. VPs are given an automatic

[9] Error-play is game play that occurs due to player mistakes and misunderstandings of the game.

four (4) RD points each turn and typically earn 0-5 more for their profitability. RD improvement is paid for with a point system rather than letting players use their bank balances to prevent unrealistic levels of investment. In practice, vehicle manufacturers have limited R&D budgets and cannot direct more than a small percentage of revenues to it (Bienenfeld, 2010).

The VP invests his points on the *RD Investment* screen (Figure 6). This screen offers six investment area options: gas, diesel, hydrogen, electric, hybrid, and efficiency (road load). The gas and diesel options accrue towards improvements in any vehicle (conventional, HEV, PHEV) that includes a gas or diesel engine. Hydrogen fuel cell performance is advanced with the *H2* area. *Electric* improves any vehicle with a battery drive component (HEV, PHEV, BEV, HFCV). The *Hybrid* area improves the cost and function of all hybrid class vehicles in the game. Finally, *Road Load* benefits the efficiency of the non-drivetrain portions of the vehicle. This can include things like low rolling resistance tires, improved aerodynamics and lightweight materials. An investment in *Road Load* benefits all vehicles. In practice much of a real VPs R&D budget goes to road load (Bienenfeld, 2010).

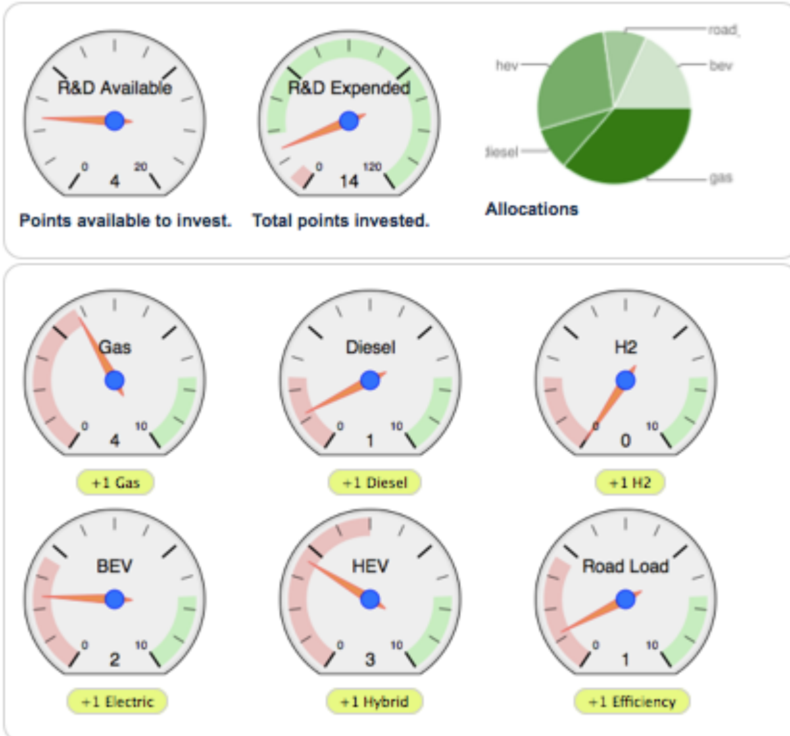


**Figure 6: RD Investment Screen**

When vehicle producers invest in RD areas they accumulate a balance in the area. These balances are then translated into scores for the various drivetrains by way of a linear equation:

$$\text{Drivetrain Score} = \sum_i w_i \, s_i \quad (where \sum_i w_i = 1)$$

where:

w is a coefficient for the RD area

s is the accumulated individual player score for the area

For example, the model for the *bev* vehicle is:

BEV score = 0.33 * Road Load (Eff.) + 0.04 * HEV + 0.63 * Electricity

This model says that almost 2/3 of the improvement in BEVs comes from investment in electricity related R&D, 1/3 from general efficiency research and a small amount from improvements in hybrid drive technology. Since the parameterization of these models is unknown, and thus debatable, I chose a plausible set of default values and made it a configurable feature of the system. The default values are shown in Table 2. A scenario designer can choose to set up these models as he likes without touching the main source code of the system.

**Table 2: Drivetrain RD Parameterization**

| Drivetrain | Gas | Diesel | H2 | Elec. | Hybrid | Eff. |
|---|---|---|---|---|---|---|
| gas | 0.667 | | | | | 0.333 |
| diesel | | 0.667 | | | | 0.333 |
| gas hev | 0.5 | | | 0.04 | 0.14 | 0.333 |
| diesel hev | | 0.5 | | 0.04 | 0.14 | 0.333 |
| gas phev10 | 0.334 | | | 0.165 | 0.165 | 0.333 |
| diesel phev10 | | 0.334 | | 0.165 | 0.165 | 0.333 |
| gas phev40 | 0.165 | | | 0.33 | 0.165 | 0.34 |
| diesel phev40 | | 0.165 | | 0.33 | 0.165 | 0.34 |
| h2 | | | 0.5 | 0.03 | 0.14 | 0.33 |
| h2 phev10 | | | 0.33 | 0.165 | 0.165 | 0.34 |
| h2 phev40 | | | 0.165 | 0.33 | 0.165 | 0.34 |
| bev | | | | 0.63 | 0.04 | 0.33 |

The drivetrain score is then fed into Multi-Path based models in order to calculate the base build cost and mpg for the drivetrain. These models were generated by fitting curves to the Multi-Path projections with either cost or mpg on the vertical (y) axis and year on the horizontal (x) axis (see Figure 7). The drivetrain score corresponds to the year; thus, the mpg is the interpolated value on the Multi-Path derived mpg curve, a best fit curve to the point estimates it makes, the drivetrain score being the independent (*x)* variable used to yield the dependent (*y)* mpg value. The same technique is used for the build cost calculations. Given an average accumulation of six (6) RD points per turn and a typical game of nine (9) turns, the expected total points for a VP will be 54. This configuration has proven sufficient to allow players to make decent progress on the curves without risk of getting too far past the 2045 end year of Multi-Path.

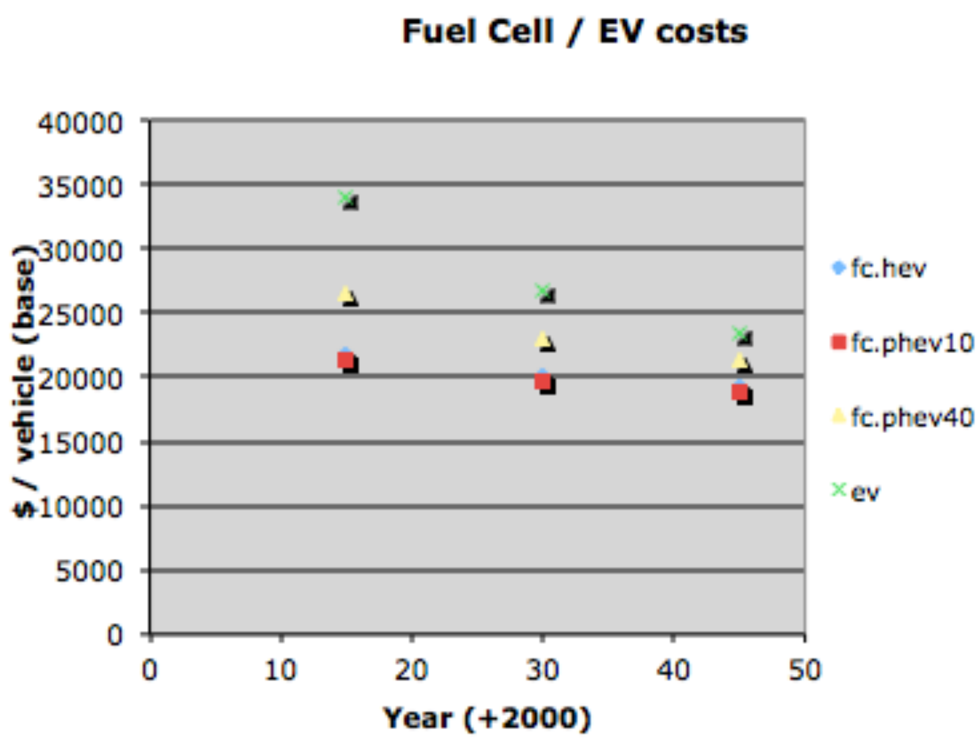


**Figure 7: Sample Cost Curves for Fuel Cells and BEV**

VEHICLE BUILD MODEL

At the end of each turn the drivetrain production characteristics (e.g. build cost, mpg) are calculated and stored using the procedure described in the R&D Process section. These are called the *Vehicle Models* in Autopia and there is one calculated for each VP for each drivetrain (i.e. 12 vehicle models per VP in the game). The process map for vehicle creation is shown in Figure 8.

When the VP creates a new vehicle he starts with the basic *Vehicle Model*[10]. The VPs vehicle models are a function of their RD investments in the various technology areas that are described earlier in the section. The vehicle model is a template vehicle based on a particular drivetrain. The VP instantiates a template by assigning it a *name, style, performance,* and *production volume*. The template itself is not an actual vehicle; if the VP produces a second vehicle with the same drivetrain in the turn, the template will be reused.

[10] *Vehicle Model* corresponds to the VehicleModel class in the Autopia source code.

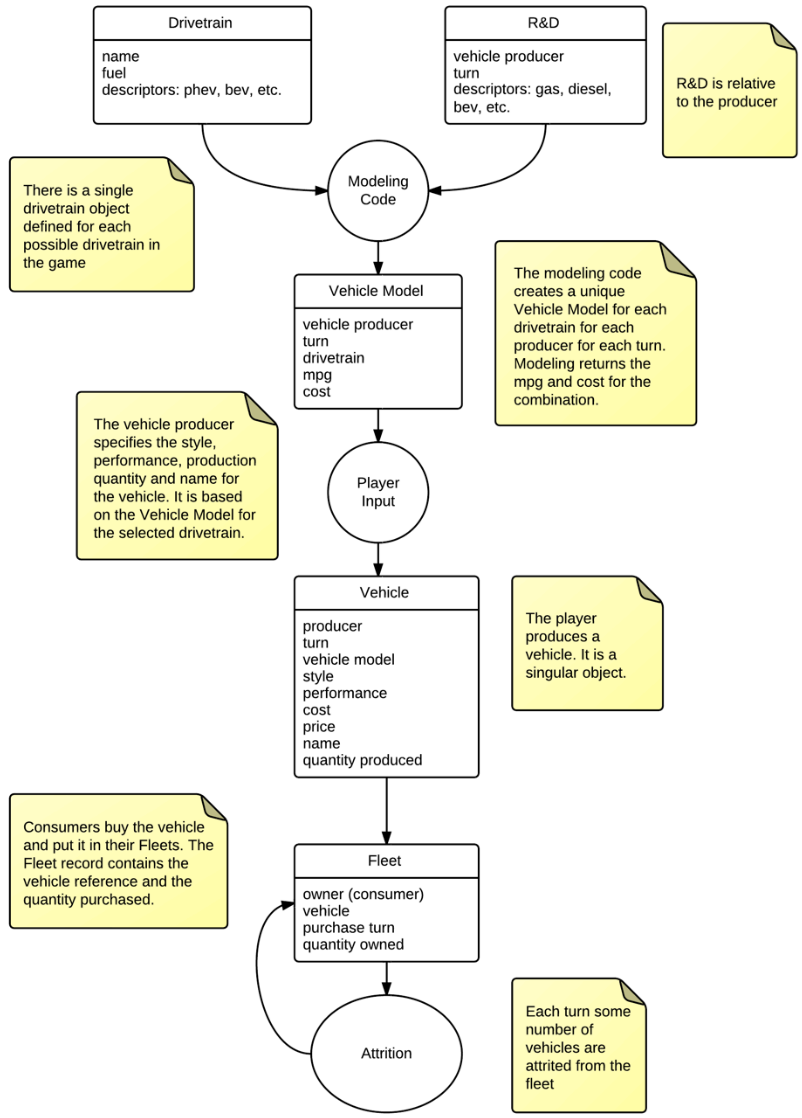


**Figure 8:Game Vehicle Life Cycle**

When the VP commits to building a particular vehicle, it is stored for release into the next vehicle auction, after the turn update. It is fixed in all characteristics with the exception of price, which the VP can change at any time, before or during sales. After the turn update the vehicle is entered into the vehicle auction. Consumers who buy the vehicle have it added to their fleets. At the end of each turn the C will lose a fraction of his vehicles to attrition (see *Turn Update* section for further details).

Any vehicles that are left in the VP's inventory at the end of the turn are considered *distress sales.* The VP recovers 75% (a settable game parameter) of each vehicle's build cost as a penalty for misgauging the market demand for the vehicle. The distress sale process in the game is a loose metaphor for what happens when a vehicle is unpopular. In the real world a car manufacturer would not blindly keep building a planned production run if his unsold inventory was too high; instead, he would shut production down until the excess inventory was cleared. The distress sale penalty in Autopia represents the costs of a bad or unfortunate decision to the VP; more complex representations were not possible within the game construction.

### THE FUEL MARKET MODEL

Consumers make automated purchases of fuel each turn immediately after they receive their turn allowance (see *Turn Update* section). The purchase of the fuel lowers their available budgets for vehicle purchases. This reflects that a vehicle purchaser doesn't know exactly how much a new vehicle's fuel expenses will be until he actually begins to drive the vehicle, at which point he has a commitment to the vehicle that cannot be easily undone (i.e. buying and selling entails a significant time and possibly money cost to the consumer and so is not undertaken lightly).

Fuel producers in Autopia seek to optimize their resource set for the existing market. This means that there is a set consumer market size for each fuel type in the game at the time when the fuel purchases are calculated, and the price of the fuel does not affect it. The abstraction assumes that the fuel producers in the game are the dominant suppliers for consumers within the game boundary, but that in the event that the fuel producers do not meet the required market demand, the price is driven high enough that other suppliers are able to enter the market to cover for the excess demand.

The game is designed to avoid the scenario where the fuel producers as players destabilize the market. This is predicated on the modeling assumption that real fuel producers prefer an orderly chain of operations in terms of incoming resources and outgoing products. Fuel producers cannot sit on excessive inventory, nor can they operate their refineries profitably at less than 85% capacity (Johnston, 2009). Akin to driving a train, an FP wants to avoid rapid changes in speed.  Their profit optimization strategy is based on finding a price and demand point that works with their resources and remaining within it. Their logistics chain is complex to the point that they must manage it for stability, not for short-term profit extraction (Johnston, 2009)[11].

A destabilization can occur for two reasons: 1) producers attempt to meet the market but fail due to inadequate information or poor decisions, and 2) producers attempt to exploit the market by withholding supply in order to drive prices higher. This can happen alone or in combination. Using a weak coupling model for the market prevents destabilization; the fuel producers aren't really producing the fuel for the market, they are trying to collectively guess the size of the market. If they guess well they will maximize their returns. The goal is for the fuel producer to focus his game efforts on understanding the market and getting his production levels right. That is how profits are maximized in the game.

### SCENARIOS

There are three scenarios to consider for fuel market clearing: 1) fuel producers, as a group, match production to demand , 2) fuel producers under-produce, and 3) fuel producers over-produce. As stated above, the game goal for the fuel producer is to allocate the right amount of resources to the market so scenario one is achieved. The other two scenarios will be sub-optimal for producers as a whole in that they will fail to maximize the size of the available revenue pool.

---

[11] The fuel producers' preference for an orderly, predictable market does not exclusively determine the price of fuel. There are many other factors at work in this system. See the *Elasticity Testing* section for further discussion.

## DEFINING VARIABLES

There are several variables that will be used to describe the model. They are described here:

$C_d$ is the quantity of consumer fuel demand in gallon of gas equivalents (gge)

P is the fixed exogenous price of the fuel for the turn in the scenario.

R is the aggregate quantity of fuel resources put on the market by the fuel producers.

ε is a price sensitivity constant[12].

P* is the actual price of the fuel. It depends on the ratio between supply and demand.

The market price setting equation is:

$$\$P^{*} = \$P[1 + \varepsilon\left(\frac{C_d(gge)}{R(gge)} - 1\right)]$$

**Equation 1: Price Setting Equation**

The derivation of the formula is shown here, starting from the definition of ε:

---

[12] The *price sensitivity* constant was originally called the *elasticity* constant, but I changed it because it was confusing.

$$\frac{\Delta P\%}{\Delta Q\%} = \varepsilon$$
with:
$$P^* = P(1+\Delta P\%)$$
$$P^* = P(1+\varepsilon\Delta Q\%)$$
$$\text{given } \Delta Q\% = (\tfrac{C_d}{R} - 1),$$
$$\therefore P^* = P[1+\varepsilon(\tfrac{C_d}{R} - 1)]$$

**Equation 2: Finding the Price Change (%) Given Quantity Change and Fixed ε**

The elasticity of the fuel market is a well studied subject in the transportation field (Dahl, 1996, 2004) . It is commonly taken to be a description of the demand response of consumers to changes in the price of fuels if no other context is given. This is why it is important to clarify that the price sensitivity constant in Autopia has nothing to do with the consumer response to fuel prices. Consumers in Autopia are completely inelastic with regards to fuel consumption. They will spend every cent they have to fill their vehicles and they will drive them to their target VMT without regard to the expense. They can only respond to fuel prices by buying more efficient cars and by reducing their levels of vehicle ownership *The price sensitivity constant (ε) in Autopia defines the price response to the gap between fuel supply and demand (ΔQ%); ΔQ% and ε are the known values in the first line of* Equation 2 – *they are used to calculate ΔP%, the unknown.* Given a low price sensitivity constant, P* responds weakly to changes in $C_d$ and R. Alternatively, a high price sensitivity prompts strong responses in P*.

SIDEBAR: DEFINING ΔQ

The definition of ΔQ (see Equation 2) here is the marginal percentage difference between consumer demand ($C_d$) and resources supplied (R). One is subtracted from the ratio to center the value around zero.

## PRICING EXAMPLES

### SCENARIO 1: MARKET EQUILIBRIUM ($C_D$ =R)

In the case where supply perfectly meets demand P*=P as,

$$
\begin{aligned}
&\tfrac{C_d}{R} = 1 \\
&P^* = P[1 + \varepsilon(1-1)] \\
&P^* = P[1+0] \quad . \\
&\therefore P^* = P
\end{aligned}
$$

**Equation 3: Equilibrium Market**

### SCENARIO 2: MARKET UNDER SUPPLIED ($C_D$ > R)

Applying Equation 2 , it can be seen that that $C_d$ > R implies that P* > P; prices increase if game fuel producers do not meet the demand of the consumers. However, the producers are assumed to lose the excess market share to other producers (market loss of $C_d$ –R) outside of the game.

### SCENARIO 3: MARKET OVER SUPPLIED ($C_D$ < R)

In this case, P* < P, as it is the reverse of Scenario 2. Revenue falls, and since fuel producers profit is a margin on the actual price of the fuel profits are lost.

This model is demonstrated with sample data in Figure 9. When consumer demand is equal to the fuel producers' supplied volume (note: in this case log(demand/supply) = log 1=0), percentage of the available consumer funds for the fuel are maximized to the game fuel producer group. It also maximizes the profits available to the game FPs. This holds provided that the fuel model price sensitivity constant (ε) is between zero and 0.5 (i.e. $0 < \varepsilon < 0.5$), although individual FP results will vary depending on their decisions[13]. In the event the game FPs under-supply the market the shortfall is made up by other fuel producers outside of the game. This represents a real revenue loss to the FPs, as those sales could have been theirs. For reference, fuel prices generated by the model can be seen in Figure 10 at several price sensitivity levels. Note that the price of fuel goes up much more steeply than it falls. The function was selected for that behavior in order to reflect the fact that there is an underlying floor price on the resources used to make fuels.

[13] The curve is most symmetric at $\varepsilon$=0.25. When $\varepsilon = 0$ the left side of the curve is equal to the max at log(D/S)=0, while the right side falls steeply. As ε approaches 0.5, the right side flattens out at the max (log (D/S)=0) while the left side ascends steeply. Game settings of $0.2 < \varepsilon < 0.3$ are recommended.

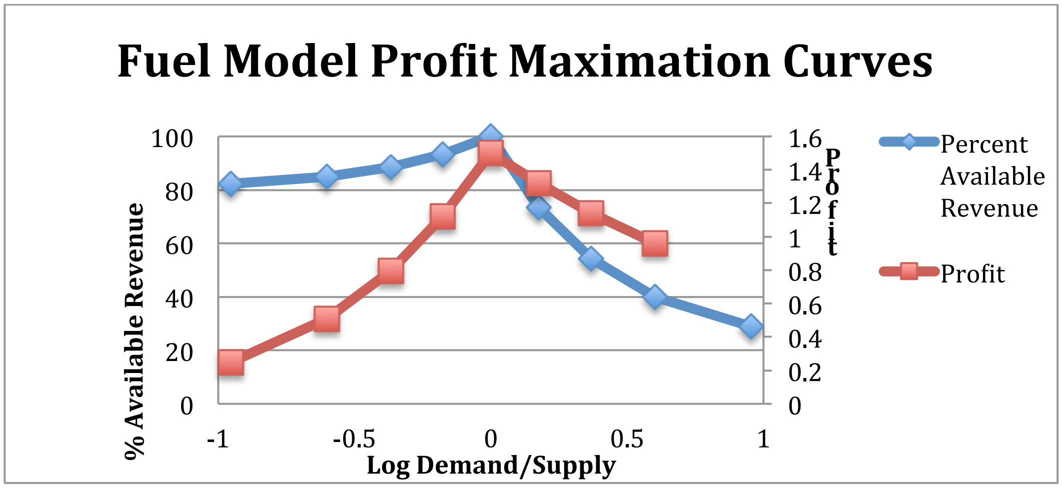


**Figure 9: Fuel Model Optimization (ε – 0.30)**

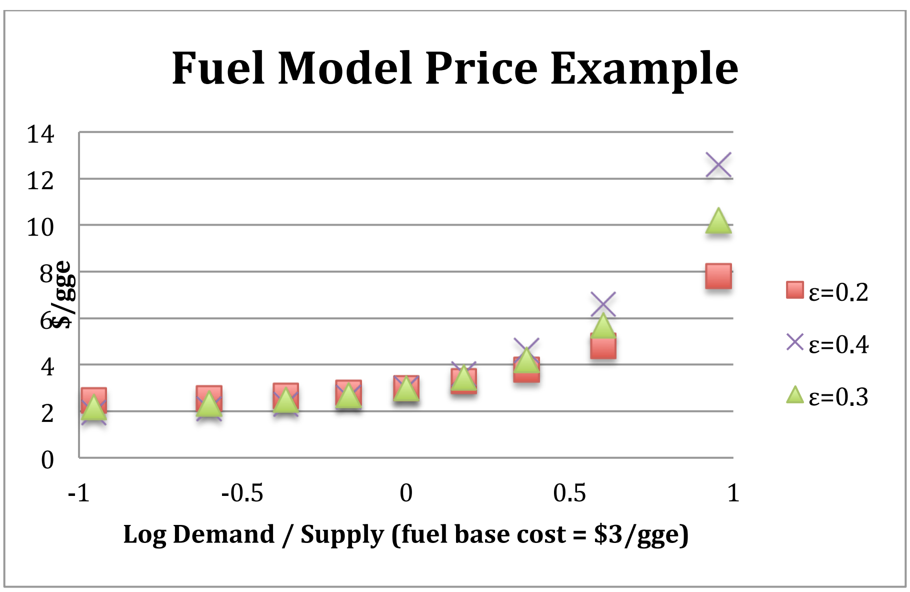


**Figure 10: Fuel Model Price Example**

## Fuel Model in Action: Examples

To illustrate the workings of the *Fuel Model* I will provide several examples. For all examples assume the following:

- 4 Fuel Producers
- Each Fuel Producer can produce up to 1000 units of fuel and is identical in every way.
- Price of fuel is $1/gge.
- Price sensitivity constant ε = 0.20

### Example 1: Producers Match Demand with Supply (Optimal)

- Demand = 2000 units
- Producers each supply 500 units (4 x 500 = 2000)

$$P^* = \$1 * \left[1 + 0.20\left(\frac{2000}{2000} - 1\right)\right]$$

$P^* = \$1$

Net Aggregate Revenue = $1 * 2000 = $2000

Net Revenue per Producer = $500.

### Example 2: Producers Under-Supply Market

- Demand = 2000 units
- Producers each supply 250 units (4 x 250 = 1000)

$$P^* = \$1 * \left[1 + 0.20\left(\frac{2000}{1000} - 1\right)\right]$$

$P^*$ = \$1.20

Net Aggregate Revenue = \$1.20 * 1000 = \$1200

Net Revenue per Producer = \$300.

In this case the producers have driven up the price of the fuel but lose out on revenue because of missed demand. The unsupported demand is assumed to be handled by non-player FPs who will enter the market when prices get high enough.

EXAMPLE 3: PRODUCERS OVER-SUPPLY MARKET

- Demand = 2000 units
- Producers each supply 750 units (4 x 750 = 3000)

$$P^* = \$1 * \left[1 + 0.20\left(\frac{2000}{3000} - 1\right)\right]$$

$P^*$ = \$0.93

Net Aggregate Revenue = \$0.93 * 2000 = \$1867

Net Revenue per Producer = \$467.

In this case they plan their operations such that the market is over-supplied, which drives the price of the fuel down. It is important to note that FP isn't actually over-producing the fuel but rather is running excess inventories that force him to clear his stocks out at a discount. The actual overage of 1000 units may not have been produced in full. The excess would be disposed of in alternate markets as distress sales.

## HOW FUEL PRODUCERS MAKE A PROFIT

Fuel producer profits are a function of their market share, fuel price, demand quantity, and their operating margin. Market share is calculated based on the ratio producer's online capacity (i.e. refineries producing the given fuel for the turn) to the total online capacity. For example, if a producer puts 4,000 gges of fuel online in a turn in which there are 20,000 gges of total online capacity his market share will be 20%. The market share is multiplied by the price of fuel, *P**, as calculated in Equation 1. The unit of *P** is $/gge. The market demand, labeled *Q (gge)*, is the lesser of either: 1) The total online capacity of producers, or 2) Actual consumer market demand. Consumers will try to buy all of their fuel from in-game providers, but if there is excess demand they will buy from non-player providers, who are willing to enter the market due to increased prices. The final value in the function is the FP's margin (*M)* for the turn. The margin is a value from 0-10% that is determined by the efficiency of their online refineries -- large refineries are more efficient than small ones and thus increase margins. However, since refineries must be fully committed if they are online and cost more to operate, larger refineries are riskier. The profit function is shown here:

$$\$\pi_i = \frac{R_i\,(gge)}{\sum_j R_k(gge)} * \$P^*/gge * Q(gge) * M_i.$$

**Equation 4: Profit Formula**

where:

π is the profit to fuel producer *i*

$R_i$ is the resource commitment of fuel producer *i*

$\Sigma R_k$ is the sum of all fuel resources made available by all fuel producers

$P^*$ is the market price per gge of the fuel (from Equation 1)

Q is the total consumer demand (gge) *met by game FPs (a min function)*

$M_i$ is the margin for producer *i* ($0.0 < M < 0.10$)

EXAMPLE 4: THE CHEATING PRODUCER

In this example a cartel is formed by the FPs in order to manage the market price, but one producer cheats on his quota. In this case the cheater exploits the discipline (or gullibility) shown by the other producers.

- Demand = 2000 units
- Honest producers produce 250 units (3 x 250=750)
- Cheating producer produces 1000 units

$$P^* = \$1 * \left[1 + 0.20\left(\frac{2000}{1750} - 1\right)\right]$$

$P^*$ = \$1.004

Net Aggregate Revenue = \$1.004 * 1750 = \$1757

Net Revenue per Honest Producer = \$251.

Net Revenue to Cheating Producer= \$1004

This case represents a game theory type scenario in which the players must decide whether to stick to an agreement for mutual benefit or break the agreement for personal gain. In this example the cheater makes an excess profit by producing at his maximum level, but that is only possible profitably because the other producers under-produced.

## CALCULATING PHEV FUEL USAGE

Calculating PHEV fuel allocation is complex because Autopia must account for vehicle's non-electric fuel (i.e. gas, diesel or hydrogen) and the electricity usage.. When a PHEV has sufficient battery power available it will operate as a pure electric vehicle, running down the battery in the process. This is called Charge Depleting (CD) mode. When the battery has been drawn down to a threshold point, it operates as an HEV in what is called Charge Sustaining (CS) mode.

The CD and CS values can vary depending on how far the car is driven between recharges, the terrain it is driven over, and the driving style. Autopia, as a macro model, does not consider any of these things directly. Mean values are used for VMT for the consumer classes and the nominal mpg is taken as the actual mpg for the vehicle (nominal mpg is usually an optimistic prediction).

The  fuel consumption allocation between  of a PHEV is calculated as follows:

$$\mathrm{GGE}_{CD} = \frac{u \times \mathrm{vmt}}{\mathrm{mpg}_{CD}}$$

$$GGE_{CS} = \frac{(1-u) \times \mathrm{vmt}}{\mathrm{mpg}_{CS}}$$

**Equation 5: GGE Calculations for PHEVs**

where:

vmt = VMT (per year) (known)

u = CD utility factor ( 0 ≤ u ≤ 1 ) (known)

$mpg_{CD}$ = mpg in CD mode (unknown)

$mpg_{CS}$ = mpg in CS mode (known)

The VMT is calculated based on the age of the vehicle. The utility factor is based on the all electric range of the PHEV(Kromer, 2007). The CD MPG of the vehicle is unknown and must be estimated. The CS MPG is assumed to be the MPG of an equivalent HEV (fuel, style, performance) (note: given that the HEV version of the vehicle will have a substantially lighter battery using the HEV MPG estimator will have a slight positive bias.

To estimate the CD MPG I use this identity:

$$u \times \mathrm{mpg}_{CD} + (1-u)\mathrm{mpg}_{CS} = \mathrm{mpg}_{nom}$$

rearranging to:

$$\mathrm{mpg}_{CD} = \frac{\mathrm{mpg}_{nom} - (1-u)\times\mathrm{mpg}_{CS}}{u}$$

where:

$mpg_{nom}$ is the nominal mpg of the vehicle as given by Multi-Path based models.

## Consumer Modeling

*If you go into a person's house and look at his surroundings, you'll see exactly who he is. If you look at the same person in his car, you'll see who he wants to be.*

*J Mays, Chief Designer, Ford*

### Consumer

The consumer represents a large class of vehicle and fuel consumers with similar vehicle preference characteristics. Players in this role receive an allowance at the beginning of each turn as their sole source of income. The allowance represents all income to the group that is available for fuel and vehicle purchases. It includes income from selling used cars[14]. The allowance must cover their fuel expenses and vehicle purchase expenses, which are the only things they buy in the game.

The consumer player is evaluated based on how he meets the profile based needs and preferences of his group using a point system. The first goal of the consumer is to have enough vehicles to meet the group's quantity of vehicles owned desires. The players lose about 25% of their vehicles per four-year turn to attrition, which they will seek to replace in

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[14] Used car income is assumed within the allowance, but it is not explicitly modeled. It would be interesting to allow consumers to enter used vehicles into the vehicle auction to represent the flow of used cars between different consumer classes. It is technically feasible, but it would make the auction much more complex and would probably require two-player consumer teams to manage vehicle sales and purchasing in the auctions.

the vehicle market (S. Davis, 2008). Consumers want a certain number of cars to meet their driver demands. If the consumer does not have enough money to meet his drivers' demand for cars some of those drivers will shift to alternative modes; his driver count will drop and he will receive a smaller allowance, although it will increase on a per capita basis as the poorest drivers are assumed to leave the driver pool first. The number of cars varies from 200 for the small *green* player to about 3000 for the larger consumers. The second goal is to buy vehicles that are as attractive as possible to this group.

### VEHICLE CHOICE

How then does a player in the consumer role choose appropriate vehicles for his drivers? This is done by means of a consumer profile, which the player can see on the consumer home page. The profile is divided into three aspects: *mpg, style* and *performance.*

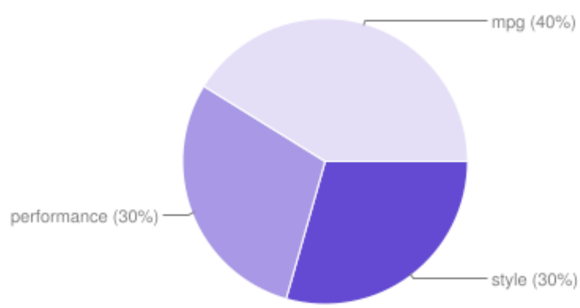



Figure 11: Consumer Profile

Each consumer has a different profile and different levels of income. These differences help to spread the vehicle market out so that not every consumer wants the same thing at the same price point, i.e. consumer players will be attracted to different vehicles in the market even if they are at the same price point.

### THE CONSUMER VEHICLE SCORE MODEL – S*

The consumer vehicle score model was originally developed to help deal with the amount of information consumer players had to process in order to select their vehicles. Players found linking the profile model (preferences for style, performance, mpg) to a choice in the vehicle market was too hard and didn't make sense. This led to the introduction of the S* score. The S* score helps consumers purchase cars that rate well in their utility models.

In Figure 12 we can see the set of four vehicles as perceived by the *Executive* and *Family* players. They are exactly the same except for the S* score, so only the S* score is shown for the Executive. The S* score is calculated based on the player profiles, which are shown in the lower half of the table. The S* value can be thought of as an overall attractiveness measure of the vehicle for the consumer. In the given example we see that the Executive is uninterested in the low style and performance vehicles with high mpg (asian x2, gt 1) and is most enthusiastic about the vehicle with the lowest mpg but highest style and performance. In contrast, the Family buyer is much more attracted to the high mpg vehicles. This consumer still likes the higher style and performance vehicles better, but there is not as much of a difference between the top and bottom S* scores as with the Executive. Note also that the S* score is independent of finances: consumers can like cars that they are not able to afford.

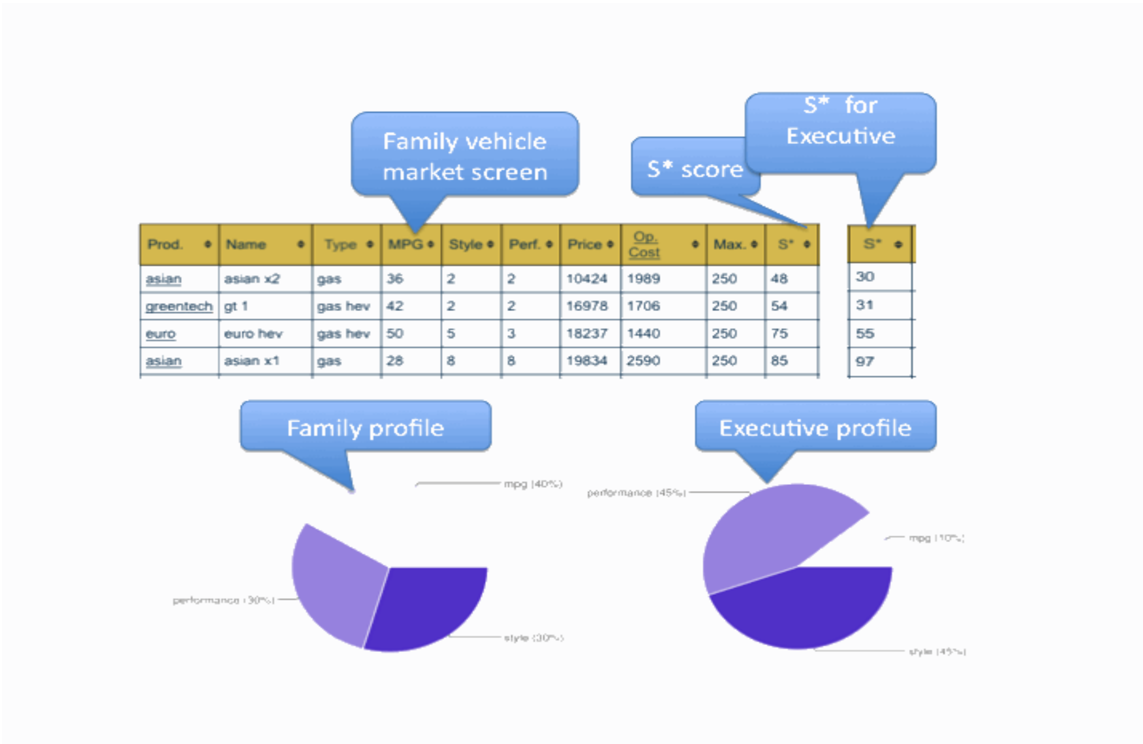



**Figure 12: Vehicle Choice**

The score is calculated like this:

$$s_x = 10 \times \lambda \times \sum_i p_i \frac{(x_i - \mu_\iota\ )}{\sigma_\iota}$$

where:

s is the score (S*) for vehicle *x*

$p_i$ is the percent coefficient for attribute *i* (i.e. $\Sigma p_i = 1$ )

i is the subscript for the profile attributes (style, performance, mpg) of the consumer

$x_i$ is the value of attribute *i* for vehicle *x*

$\mu_i$ is the mean value for attribute *i* for the consumer over the last 3 turns

$\sigma_i$ is the standard deviation for attribute *i* for the consumer over the last 3 turns

λ is a style-to-performance ratio modifier calculated with:

$$\lambda = \min\left(0.1, 1 - c * \left(\frac{x_{performance}}{x_{style}} - \frac{p_{performance}}{p_{style}}\right)^2\right)$$

where:

c is a calibration constant (set to 0.125 in practice)

x is the vehicle attribute

p is the consumer percentage weight for the attribute

The purpose of the λ value is to penalize extreme vehicles (e.g. performance:10 style:0). The assumption in Autopia is that consumers want parity between style and performance characteristics that is similar to the ratio of the performance and style characteristics in their profiles. The λ function is maximized at the point where the ratios are equal. The λ function was added to Autopia in response to a bug players discovered in the vehicle scoring system: namely that if a consumer had a preference of one over the other in the profile, then vehicles that were lopsided towards the preferred characteristics had much higher S* scores than those that attempted to balance them more realistically.

### CONSUMER PLAY EXPERIENCE

The consumer player begins each turn with an update of his position in the game and his objectives for the turn. The headlining information of the consumer home screen (Figure 13) is a short message about the satisfaction the consumer player's drivers feel about their vehicle ownership situation. Messages range from "Your drivers are very happy with their vehicle options" if things are going well, to "Your drivers are unsatisfied. You have lost 10% of them to alternative modes[15]." They are also apprised of their bank balance, how much they spent last turn on fuel and vehicles, their fleet average mpg, and a score that describes how well their meeting their driver needs. The overall consumer score is used to encourage players to stay true to their roles. High scores are achieved by buying vehicles with high S* scores and keeping a sufficient number of cars in the fleet. The consumer players compete against each on score. This provides another incentive to stay in character.

The consumer player is also informed of how many vehicles he needs to purchase the next turn, ideally (to maximize his score), his total fleet size, and a target average vehicle price, which he can use as a guideline value when participating in the auction. Finally there are charts on his total fuel consumption and fuel expenditures, broken out by fuel type .

[15] The actual alternative modes are unspecified. This just means that some drivers have stopped using private vehicles as their dominant mode.

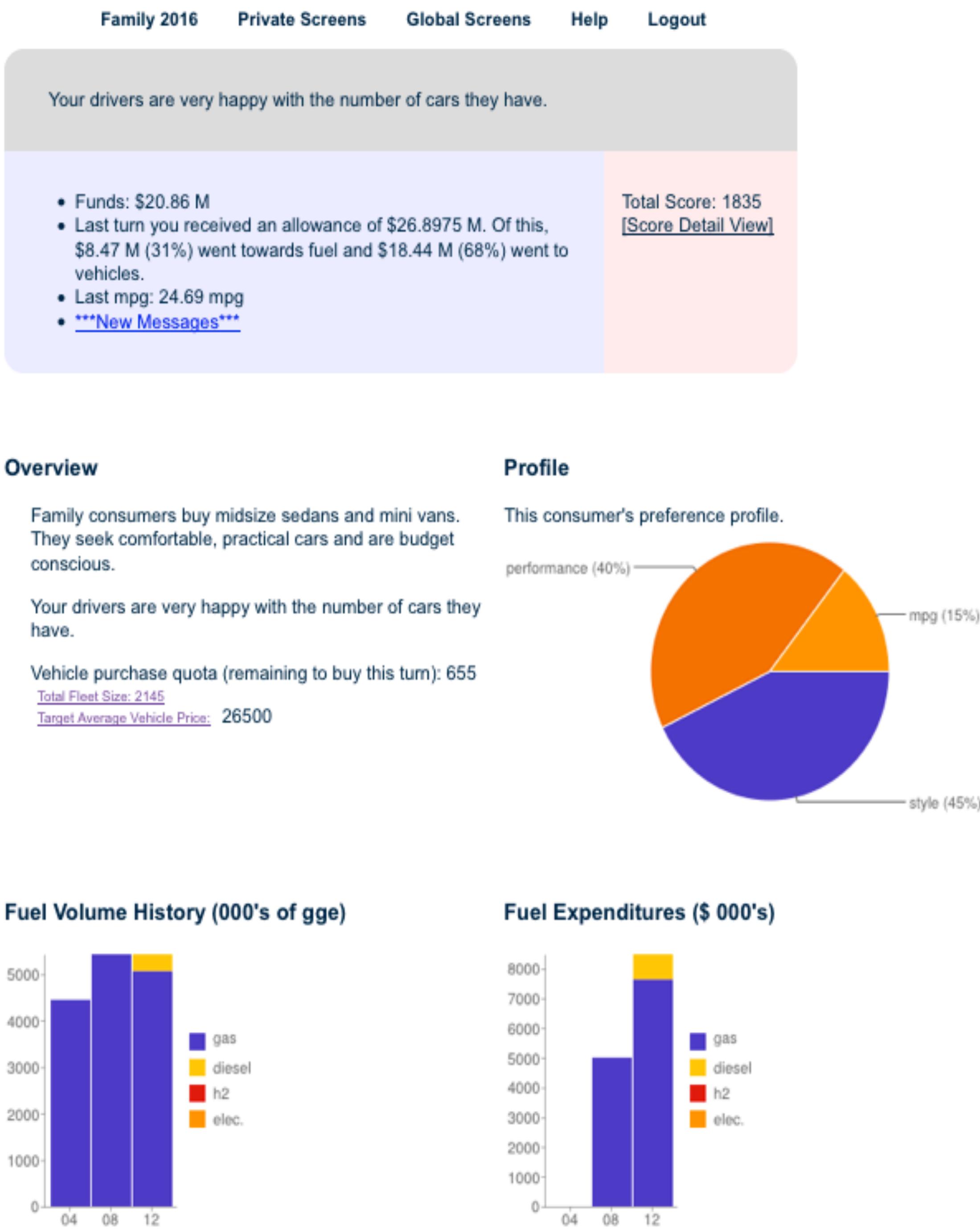



**Figure 13: Consumer Home Screen**

On the consumer's fleet screen, shown in Figure 14, he can see the current status of his fleet in terms of drivetrain, age, quantity of vehicles, fuel consumption, and other characteristics of the vehicles.

| Vehicle | Producer | Age | Drivetrain | Fuel | MPG | Style | Performance | Quantity | Vehicle Annual Fuel Usage (gge) |
|---|---|---|---|---|---|---|---|---|---|
| green gas hev 45 | asian | 8 | gas hev | gas | 41 | 7 | 7 | 46 | 300 |
| family gas hev 56 | asian | 12 | gas hev | gas | 29 | **12** | 11 | 75 | 349 |
| green gas hev 25 | euro | 8 | gas hev | gas | 50 | 6 | 6 | 28 | 249 |

**Figure 14: Consumer Fleet Data Screen (partial)**

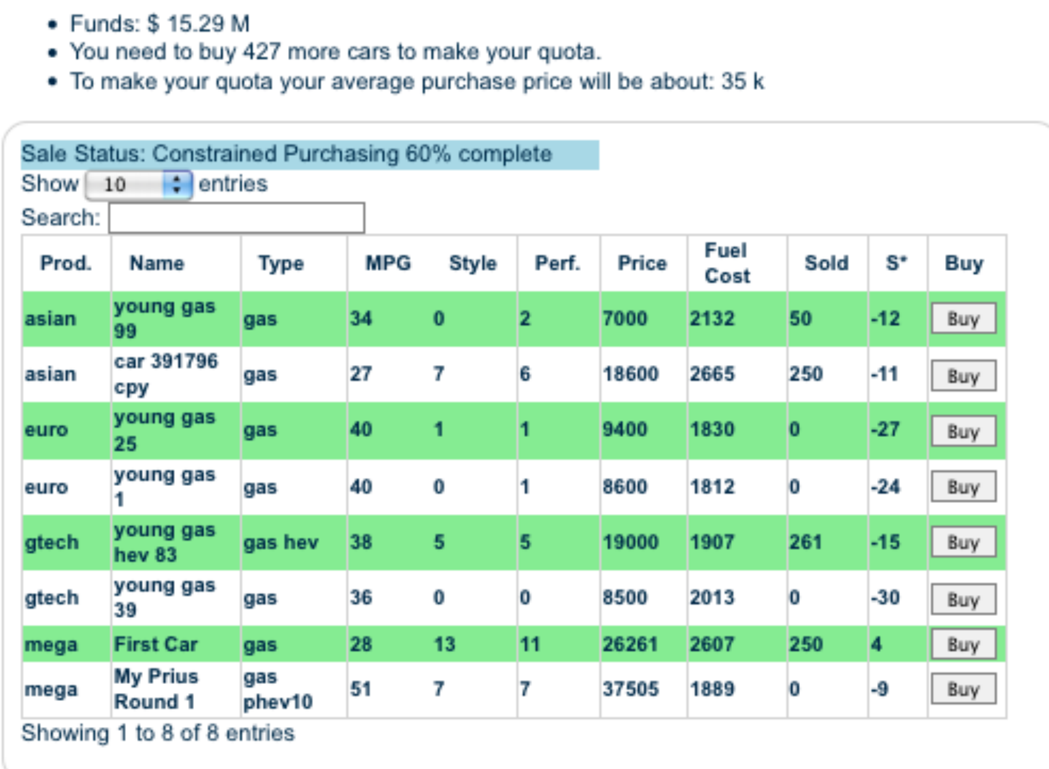
## The Vehicle Auction

The *Vehicle Auction* is where the consumers purchase new vehicles to replace those they have lost to attrition. The Consumer and VP players participate directly in the auction; the VP putting his vehicles developed on the last turn up for sale, and the consumer selecting from amongst them. The auction runs across the entire length of the turn in three separate phases. It begins with a short segment of about one minute in which no vehicle purchases are permitted. This gives participants a chance to survey the market before making any decisions. This is followed by a *constrained purchase* phase that runs through minute seven of the turn. Purchases in this turn are *throttled* such that the percentage of vehicles released to the market is equal to the percentage of time that has passed in the phase, e.g. if this phase is five (5) minutes long then 20% of the vehicles of each type will be available for purchase at the end of the first minute. Furthermore, the consumer player is limited to buying the same fraction of his target purchases in that time. This scheme allows for fair access to first choice vehicles for all consumers, regardless of size. The end of the turn is an *open purchase* phase. Any consumer can buy as many vehicles as he can afford. Note that the auction runs for the entirety of the turn. The VP players typically do their RD allocation in the *open purchase* phase; at that point the auction action is mostly done.


**Figure 15: Vehicle Auction Turn Diagram (15 minute turn)**

Shown in Figure 16 is a typical consumer view of the vehicle auction screen. At the top of the screen are simple bullet points of useful information. The first is the funds available to the player to spend the vehicles at this time. If the player does not use all of his funds, they are held over for subsequent turns. Next we see a line about his quota goal: the number of vehicles he needs to replace this turn if he is to maintain his vehicle fleet count. The final bullet point is a dynamically calculated running average price of vehicles he can afford while staying within his budget. This set of data for the consumer was developed through play testing to offer the basic financial data that the consumer player needs so that she he may focus his attention on the auction, and finding the right vehicles, rather than calculating numbers while simultaneously trying to negotiate the auction.

One of the overall design goals of the Autopia interface was to minimize the need for calculations by presenting the most commonly requested statistics where players wanted to see them. I wanted players to focus on essential decisions and not on tedious calculations unrelated to the research objectives. This also helps to equalize players across various levels of analytical sophistication. Given the heterogeneous nature of the player groups, that was an important consideration.



- Funds: $ 15.29 M
- You need to buy 427 more cars to make your quota.
- To make your quota your average purchase price will be about: 35 k

Sale Status: Constrained Purchasing 60% complete

Show 10 entries

Search:

| Prod. | Name | Type | MPG | Style | Perf. | Price | Fuel Cost | Sold | S* | Buy |
|---|---|---|---|---|---|---|---|---|---|---|
| asian | young gas 99 | gas | 34 | 0 | 2 | 7000 | 2132 | 50 | -12 | Buy |
| asian | car 391796 cpy | gas | 27 | 7 | 6 | 18600 | 2665 | 250 | -11 | Buy |
| euro | young gas 25 | gas | 40 | 1 | 1 | 9400 | 1830 | 0 | -27 | Buy |
| euro | young gas 1 | gas | 40 | 0 | 1 | 8600 | 1812 | 0 | -24 | Buy |
| gtech | young gas hev 83 | gas hev | 38 | 5 | 5 | 19000 | 1907 | 261 | -15 | Buy |
| gtech | young gas 39 | gas | 36 | 0 | 0 | 8500 | 2013 | 0 | -30 | Buy |
| mega | First Car | gas | 28 | 13 | 11 | 26261 | 2607 | 250 | 4 | Buy |
| mega | My Prius Round 1 | gas phev10 | 51 | 7 | 7 | 37505 | 1889 | 0 | -9 | Buy |

Showing 1 to 8 of 8 entries

**Figure 16: Vehicle Auction - Consumer View**

Next can be seen a line that says "Sales Status." The status shows "constrained purchasing 60% complete." This is the second phase of the auction. In this specific case it means that the consumer is allowed to have purchased up to 60% of his fleet acquisition quota and, that 60% of each vehicle type is available on the market. For example, if 300 vehicles of a certain type had been created then 180 of them would be available for sale at this point, and a consumer with a 600 vehicle quota would have been allowed to purchase only 360 total vehicles (of all types) at the same point. This means that he has to choose other vehicles to buy if he does not want to get left selecting from the dregs in the "Open Purchase" phase of the turn as choosing earlier offers better selections consumer players. The system works well for forcing players to make diverse purchase decisions, which reflects the diverse market choices of real consumer classes.

The auction table shows the vehicles for sale. It is sortable by clicking on the column headers. The first column of the table provides the game VP name for the vehicle. Next come the vehicle name, drivetrain type, MPG, style, and performance values: the fixed characteristics of the vehicle. The price column, a dynamically updated field, follows. The VP can change this value at any time during the auction in order to match market demand. The fuel cost tells the projected cost to run the vehicle for one turn given current fuel prices. The sold column provides an indication of the popularity of the vehicle within the market; all players can see how many of the vehicles have been sold at that point in the auction. If a consumer notices that a car he wants to buy is selling quickly, he will need to be more aggressive in buying them so he get some before they sell out. Alternatively, for a poorly selling vehicle the consumer might wait to see if the VP reduces prices in order to move them out.

The S* score indicates the relative attractiveness of the vehicle to that consumer. The S* score is individual to each consumer. Family consumers, for instance, will have different S*scores than executives for the same vehicle. Purchasing vehicles on the higher-end of the S*score range will yield higher turned scores for the consumer, given that he achieves his quota of replacement vehicles. The consumer executes a purchase by clicking the buy button in the row for the selected vehicle. Upon clicking the buy button he is presented with a dialog box that tells him, the maximum number of vehicles of this type he could purchase under throttling (i.e. current maximum) and without throttling (i.e. absolute maximum, given available funds)..He enters the number of cars he wants in the dialog box and confirms the purchase. The cars are added to his fleet, given that the purchase is legal. This is an irreversible transaction.

### THE VEHICLE AUCTION – VEHICLE PRODUCER PERSPECTIVE

The constrained purchase phase of the turn is the most active and exciting portion of the game turn. Consumers and VPs often call out to each other across the room negotiating prices. VPs with weak products will cut prices in order to compete with more popular vehicles. VPs who find themselves with a popular vehicle that lacks competitors will usually increase their prices to take advantage of the high demand This would correspond to the real-world as a high demand, limited availability vehicle, such as the Toyota Prius in 2008(Mitchell, J., 2008).

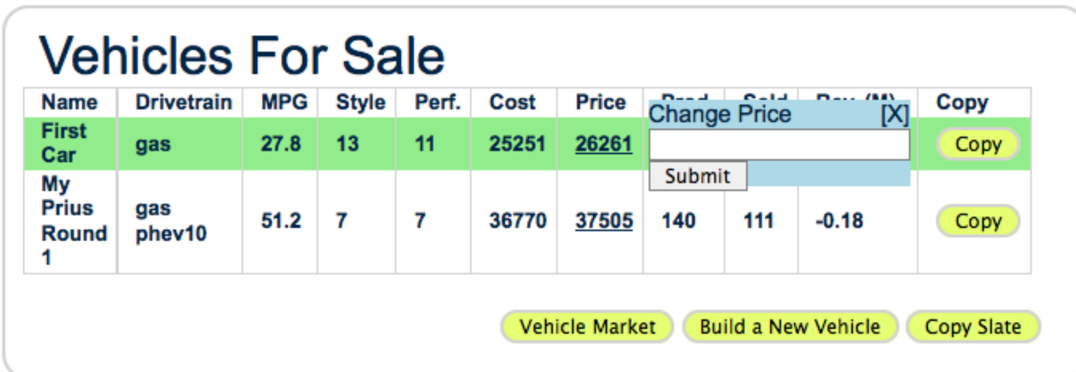



**Figure 17: Vehicle Producer Home Screen - Price Change**

The VP can monitor the state of the auction on his home screen

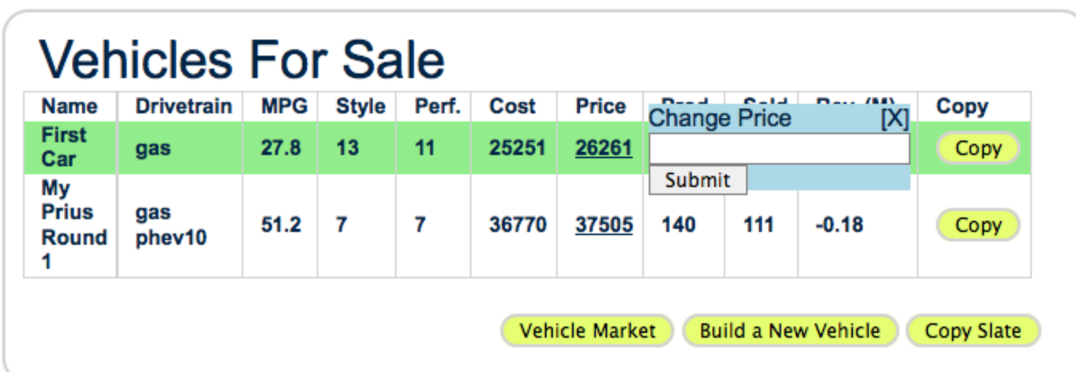



Figure 17). He can change his prices in the auction by clicking on the price link. This will pop-up a *Change Price* box. The VP can enter a number in the box and it will change the vehicle price in the auction immediately.

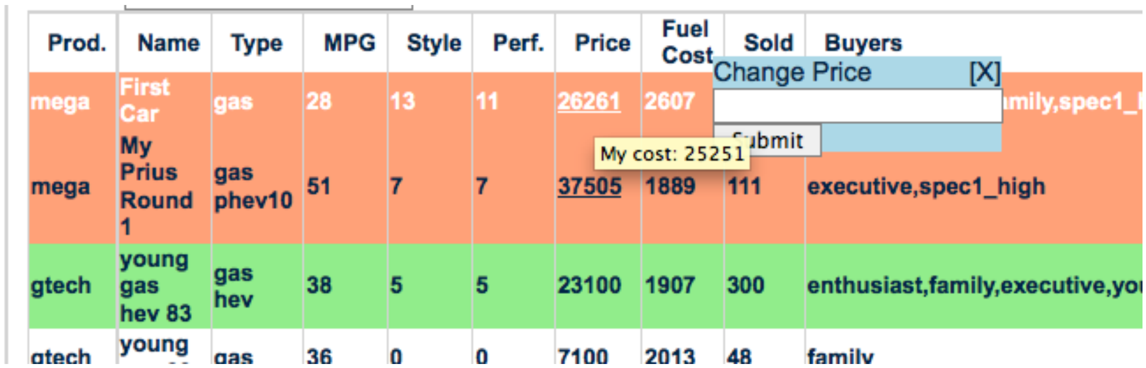



**Figure 18: Vehicle Producer Auction - Change Price**

The VP also has the ability to change vehicle price on the *Vehicle Market* screen (aka *Vehicle Auction* - Figure 18*).* Hovering the cursor over the underlined prices (only available for his vehicles – he can't see the costs of his competitors) the VP can see his vehicle cost. Clicking on the price link will produce a *Change Price* box as on the home screen. Players suggested this particular interface. By providing the critical features and information on the auction screen itself it allows VP players to stay focused on the auction action.

## Regulation and Policy Simulation - CAFE

The Corporate Average Fuel Economy (CAFE) regulations are a set of federal law that seeks to improve the overall fuel economy of vehicles sold in the U.S. by penalizing manufacturers who do not meet the published standards(Rubin, 1998; US EPA, 2004). Manufacturers can balance out low mpg vehicles with high mpg vehicles to meet the standards. The CAFE standards are currently scheduled to go to 54.5 mpg in 2025 (NHTSA, 2012).

The particulars of the CAFE standard are too complicated to be fully implemented in Autopia. A simplified version is used instead. CAFE sets a fuel economy standard for a given year in the *mpg* unit. At the end of each turn, each VP's average fuel economy for vehicle's sold (distress sales do not apply) using the harmonic mean, the method used in the CAFE standard itself(D. L. Greene, 1998). This statistic is inverted from *miles per gallon* to *gallons per mile (gpm)* and is then compared against the standard, also in gpm. For each gpm deficit the VP is penalized $550 per vehicle. For example, if the deficit was 2 gpm and the VP sold 500 vehicles, his penalty would be: *$550/gpm * 2 gpm * 500 = $550,000.* The VP is provided a projection of his CAFE penalty prospects on the vehicle build screen as shown in Figure 19. The projection assumes that the VP sells all the cars that he produces.

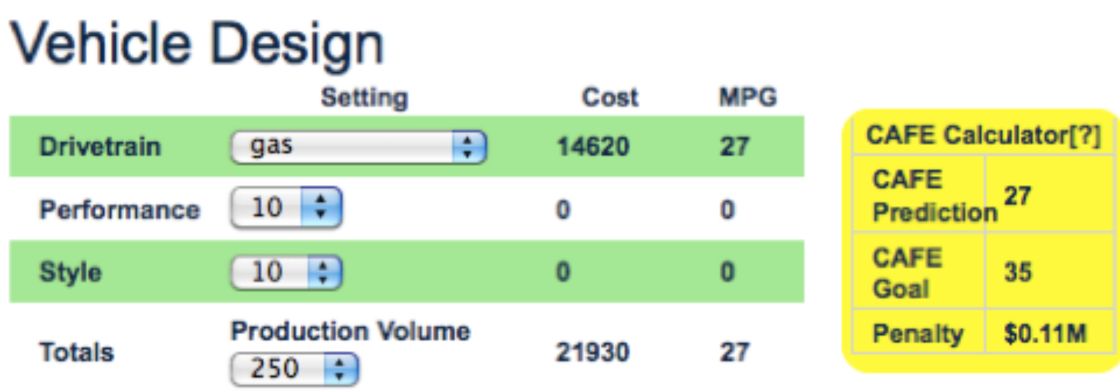



**Figure 19:CAFE Calculator (on Vehicle Design Screen)**

## GLOBAL FUEL DATA SCREEN

All players have access to global fuel data as shown in Figure 20. Shown to players are charts of detailing the fuel price history ($/gge), fuel volume history (how much fuel was sold, per fuel type), the gross fuel revenues, and electricity usage data. Additionally, all players can see charts on the supply, demand, and production capacity for all game fuels (not shown).

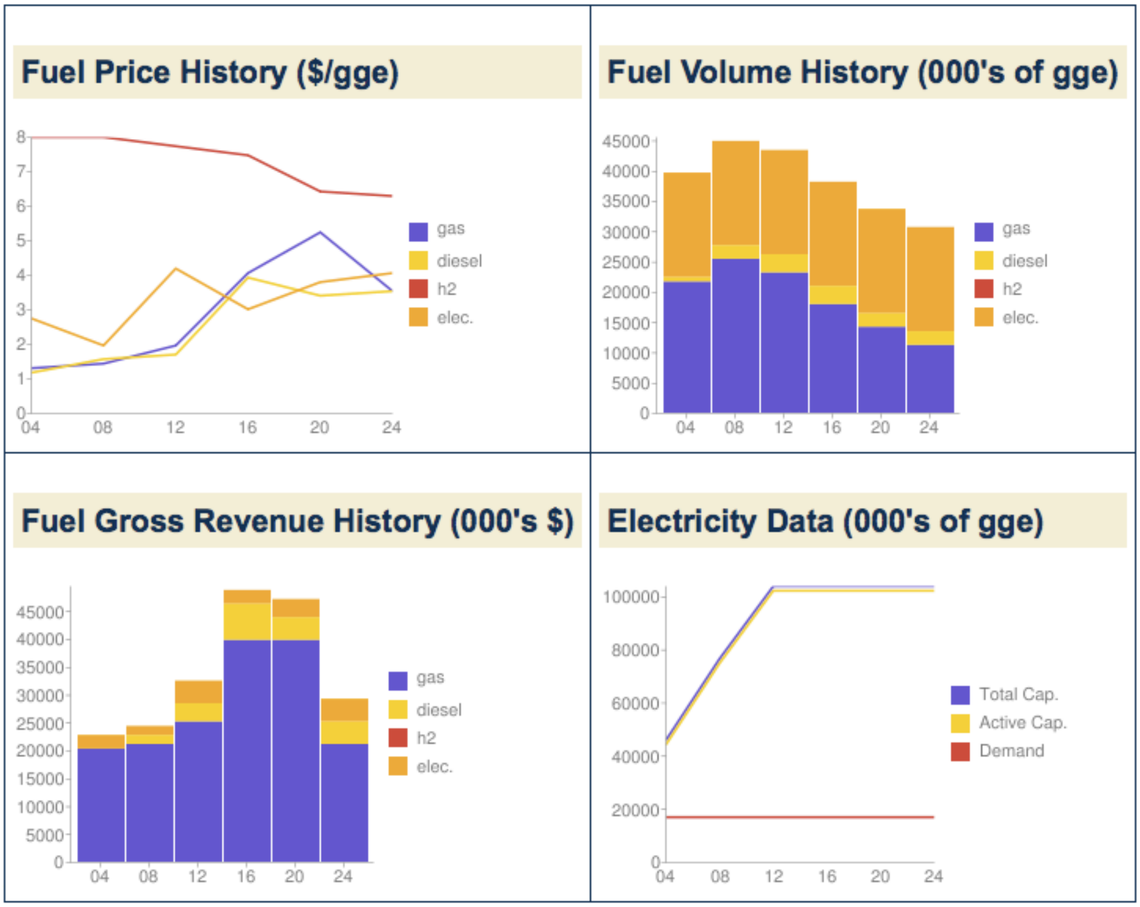



**Figure 20: Global Fuel Data**

## AUTOPIA FUEL PRODUCER

In Autopia the fuel producer (FP) manages a set of refineries. Each turn the FP must decide which plants to operate, which plants he should retire, and where to expand capacity. The objective of the FP is to maximize profits by properly predicting the market directions for the fuels. The FP makes his decisions by reviewing the game generated data and consulting with the other players.

### BUILDING AND OPERATING REFINERIES

FPs manage a set of refinery assets. The refinery has a fuel type (gas, diesel, electricity or hydrogen), a size, an operating cost, a dormancy cost (i.e. refinery is left dormant for a turn) , a life span, a build time and cost and a margin. *The fuel producers sell all electricity used in the game by consumers, stationary (i.e. residential) and mobile (transportation).*

- Fuel type – A refinery can produce gas, diesel, hydrogen or electricity. A gas refinery can be converted to diesel and vice versa at no cost. Hydrogen and electricity refineries cannot be altered for fuel type.
- Size – A refinery has a nominal size (large, medium, small, micro) and a physical size. The size describes the volume of fuel produced per turn in thousands of GGEs. Gas, diesel and hydrogen are sized at 400, 200, 100 and 50 thousand GGEs per turn. Electric "refineries" are sized at 4000, 2000, 1000 and 500 GGEs per turn.
- Operating cost / Dormancy cost – Each turn the FP will choose whether or not to operate a refinery.

| Name | Size (,000's GGE) | Operating Cost ('000's) | Inactive Cost ('000's) | Build Cost ('000's) | Build Time (Turns) | Margin |
|---|---|---|---|---|---|---|
| Micro | 50 | 2 | 1 | 34 | 1 | 0.04 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Small | 100 | 3 | 1 | 70 | 1 | 0.06 |
| Medium | 200 | 5 | 3 | 105 | 2 | 0.08 |
| Large | 400 | 10 | 5 | 157 | 3 | 0.10 |

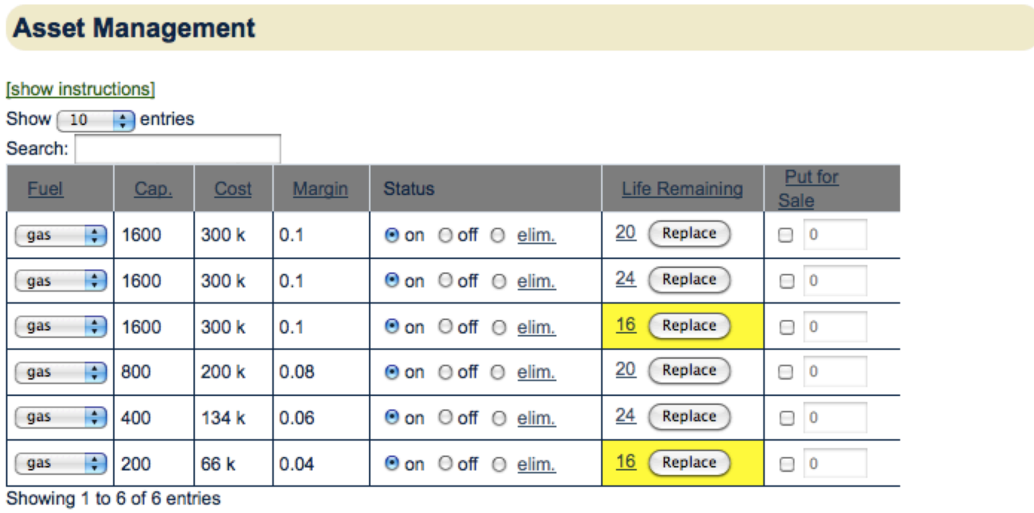
**Table 3: Gas, Diesel and Hydrogen Refineries Characteristics**

| Name | Size (,000's GGE) | Operating Cost ('000's) | Inactive Cost ('000's) | Build Cost ('000's) | Build Time (Turns) | Margin |
|---|---|---|---|---|---|---|
| Micro | 500 | 13 | 6 | 354 | 1 | 0.04 |
| Small | 1000 | 25 | 13 | 710 | 2 | 0.05 |
| Medium | 2000 | 50 | 25 | 1052 | 3 | 0.06 |
| Large | 4000 | 100 | 50 | 1578 | 4 | 0.07 |

**Table 4: Electric Refineries Characteristics**

## MANAGING REFINERIES

The most important interface for the FP is the Asset Management screen on the FP's home page (Figure 21). This interface is where the players manage all of their refineries. Gas and diesel refineries can be converted to one or the other. Hydrogen and electricity refineries can only produce their stated fuel type and cannot be altered. In the *Status* column the FP player decides whether he wants the refinery on, off or eliminated for the turn. The decisions



Asset Management

[show instructions]

Show 10 entries

Search:

| Fuel | Cap. | Cost | Margin | Status | Life Remaining | Put for Sale |
|---|---|---|---|---|---|---|
| gas | 1600 | 300 k | 0.1 | on off elim. | 20 Replace | 0 |
| gas | 1600 | 300 k | 0.1 | on off elim. | 24 Replace | 0 |
| gas | 1600 | 300 k | 0.1 | on off elim. | 16 Replace | 0 |
| gas | 800 | 200 k | 0.08 | on off elim. | 20 Replace | 0 |
| gas | 400 | 134 k | 0.06 | on off elim. | 24 Replace | 0 |
| gas | 200 | 66 k | 0.04 | on off elim. | 16 Replace | 0 |

Showing 1 to 6 of 6 entries

**Figure 21: Fuel Producer Asset Management**

are not recorded until the end of the turn in the fuel allocation section of the simulation. The FP is unlike the VP who must make their decisions about vehicle production in the prior turn. I debated whether the FP should have to make his decisions about refinery status on the prior turn. The issue was resolved in play testing in that it was too hard for the FP to make this decisions for the following turn.

The *Life Remaining* column tells how many years (4 years to a turn) the plant has left before it is automatically decommissioned. Color codes are used to draw the player's eye towards plants requiring an imminent decision if they are to be replaced without a loss of capacity. Yellow is the warning color. If the table cell is red that means the plant cannot be replaced in time to maintain a level service capacity.  The last column, *Put for Sale,* allows players to put the refinery on the market to sell to other players. No player has ever used it in testing or in an actual game.

### THE REFINERY COST MODEL

The concept behind the refinery cost model is that the cost of building a refinery of a given size and type will converge on a fully learned out cost. The modeling function is:

$$C = b\left(1 + \frac{1}{n}\right) \qquad n \geq 1$$

where,

C= cost of the refinery

b = base cost of the refinery type

n = the number of refineries of this type and size the player has built.

With each refinery built, the cost goes down a diminishing amount. Since the players will not build that many refineries in the game of any given size and type (less than 10 probably), they will never get too close to the theoretical base cost. This model is built very simply but is easily replaceable. In practice very few refineries are built in a game, so the *learn-out* factor doesn't really come into play too much. The modeling for the FP segment of the game is less detailed than that for the VP and the C due to development constraints and the difficulty of obtaining information on the subject. Fuel refining is an esoteric subject compared to consumer behavior and vehicle manufacturing. The literature is not as available on this subject. I mostly relied on my interviews with Jack Johnston, a retired planning executive for Exxon and subject matter expert on energy and fuels,.

### FUEL PROVIDER DECISION DATA

The FP has a number of data sources to assist him in his decision-making. Central to his decisions should be gauging the mood and sentiments of the consumer and vehicle producer players by interacting with them and listening to their conversations. For instance, if consumer players are overheard to be begging VPs for more inexpensive cars, that should be taken as a cue that future fuel consumption will probably decline in the future.

The other sources of data are charts, available to the FPs only, that provide a more detailed view of the market than is available to the other players. Figure 23 shows a summary statistics plot of the FPs own production. This data is immediately updated as the FP manipulates his refinery assets (Figure 23), in both table and chart form. Again, these are the statistics that I learned players wanted to see from actual games and play testing. In addition the FP player can see an overview chart of the long-range status of refinery capacity in Figure 22. This chart shows the aggregate production capacity of all operating refineries in the game across time. It takes into account the refinery retirement, which is why it dips at the end. FP players can use this chart to help them decide on when to build build new refineries.

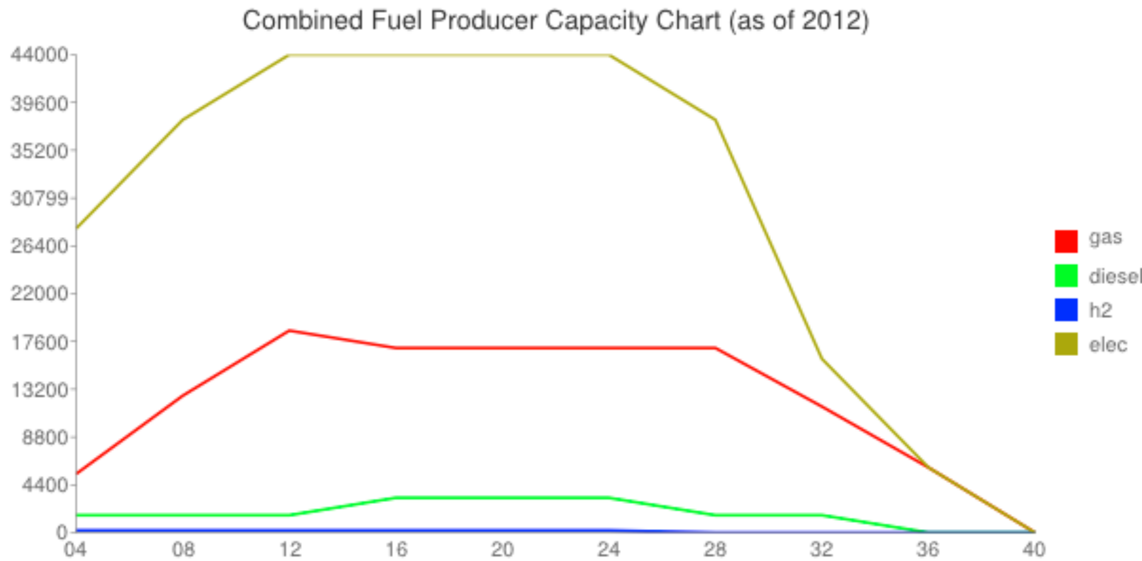



**Figure 22: Refinery Market Status (y: capacity (gge) x: year (from 2000)**

Figure 23 shows a private data summary chart for the FP. The top table gives the player's total capacity (gges) per fuel, active capacity (online refineries), the operating cost for that level operations and the effective margin. The charts below it show the same data in bar chart form.

| Fuel | Total Cap. | Active Cap. | Op. (k) | Margin |
|---|---|---|---|---|
| Gas | 4.6 M | 4.6 M | 29 | 0.09 |
| Diesel | 1.6 M | 1.6 M | 10 | 0.1 |
| H2 | 0 M | 0 M | 0 | 0 |
| Elec. | 0 M | 0 M | 0 | 0 |

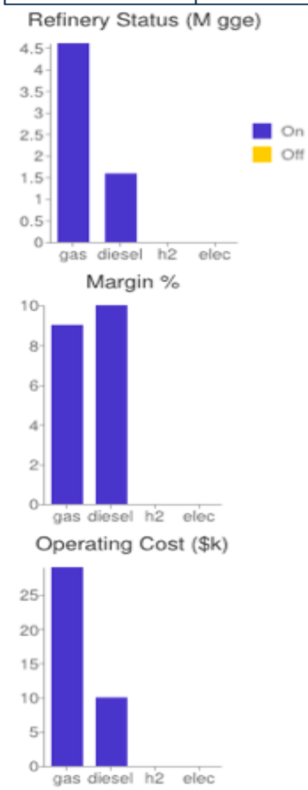



**Figure 23: Summary Statistics**

## GAME MODEL UPDATE SYSTEM

At the core of Autopia is the system model update framework, which is run at the end of each turn. The update is based on the players' game decisions, exogenous factors from the scenario, and the internal models. Figure 24 shows the sequence, in order, of Autopia/Autobahn from the model update perspective per each player type.

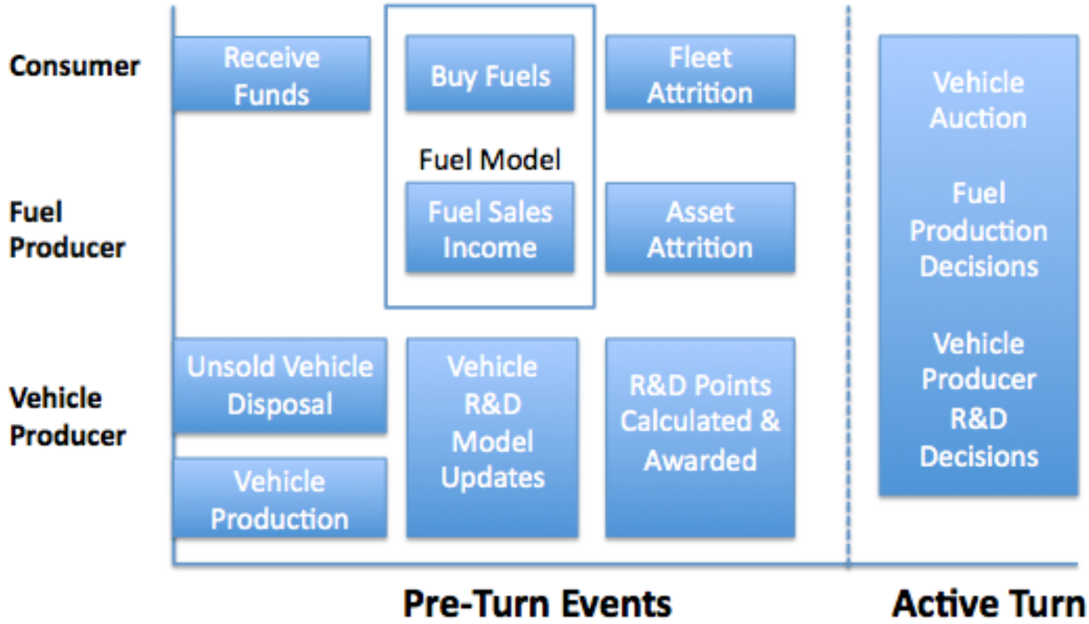



**Figure 24: Turn Event Diagram**

The consumer update sequence starts with the receipt of a fuel and vehicle allowance. This allowance is added to whatever bank balance the player currently has. The consumer allowance is the only source of revenue in the game. All profits to the VPs and FPs come from these funds. Next the consumer buys his fuels. This is done automatically with payment taken from his bank. Fuel consumption is calculated across the player's fleet based on the vehicle vintages. Plug-in hybrid vehicles are assessed for electricity as well as the gasoline, diesel or hydrogen they consume. Finally, a vehicle attrition model is applied to the player's fleet. The fleet is reduced based on vehicle age: older vehicles are increasingly retired from service. The maximum game lifespan of a vehicle is 32 years (8 turns), at which point they constitute a small percentage of the total fleet. The fleet attrition drives the need for replacement vehicles, which the consumer will purchase in the vehicle auction of the next turn.

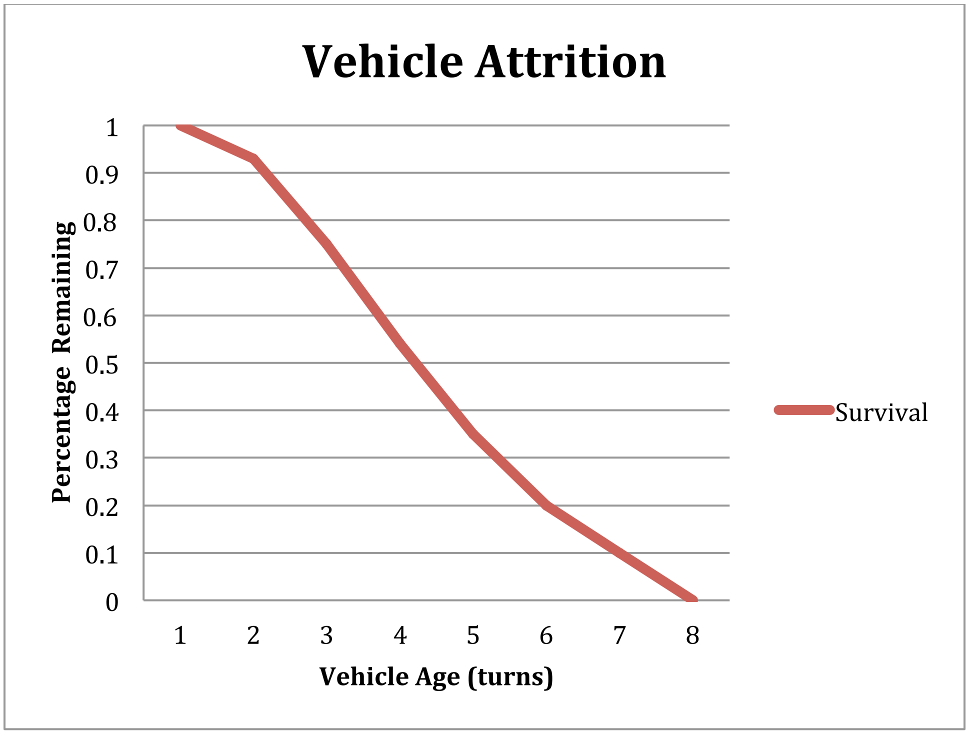



**Figure 25: Standard Attrition Curve (1 turn = 4 years) (S. Davis, 2008)**

The FP's turn update starts with fuel sales and income accrual from the consumers. FP income is based on the margin they have attained via the management of their refinery resources. Larger, more efficient, refineries pay a better margin on produced fuel than small refineries, but they also cost a lot more to operate than smaller refineries, on an absolute scale. Large refineries only make economic sense if they are run at near full capacity. If that is not the case the FP is better off running a smaller refinery that more closely matches the demand he is expecting. The actual prices he receives for fuels are determined by the fuel model and depend on how closely FPs as a group match the aggregate consumer demand. After the fuel has been priced and sold, refineries that are at the end of their operating lives are removed from the game in the *asset attrition* phase. Asset attrition occurs on a standard time table and players are made aware of the ages of their assets in the game.

The VP turn update begins with the disposal of vehicles he has failed to sell in the turn. These unsold vehicles are considered to be vehicles that were planned but never actually produced. In reality this would be the equivalent of shutting down an assembly line earlier than planned. VPs are paid a credit of 75% of the cost of the unsold vehicle; in theory the worst a VP should ever do on a vehicle is a 25% loss, but a VP can choose to sell below that loss point in the vehicle auction if he wants to. Vehicle production is also handled during this segment. Vehicles are produced at the technology level the player had attained prior to his R&D allocations for the turn; R&D effects on vehicle capabilities always trail by a turn.

Next comes the R&D technology update sequence for the VP. This applies his R&D investments from the last turn into new production technology for his next round of new vehicles. R&D expenditures, which are made using points rather than money, improve the efficiency of the powertrains (i.e. mpge) and, typically, but not always, lower production costs. The powertrain models are based on the *Multi-Path Transportation Futures Study* (Plotkin, S., 2009). Applying R&D points to a technology, such as batteries or hydrogen, has effects across all powertrains that use them. For example, investing in battery research will improve non-plug-in hybrids (e.g. Toyota Prius), PHEVs, and BEVs to differing extents, based on their battery utilization. R&D points are awarded at the end of the update sequence based on the player's profitability.

## SIDEBAR: AUTOBAHN

Autobahn is a lightweight implementation of Autopia. Autopia is designed for at least 13 players and to take about 4 hours. Autobahn, in contrast, is for 1-4 players and can be completed in as little as 45 minutes with experienced players. Autopia consists of three player roles: VP, FP and Consumer. Autobahn automates the Consumer role and replaces the FP role with a scenario fixed fuel price scenario; the Autobahn game is just the VP section of Autopia, with automated consumer players and completely exogenous fuel prices. Autobahn can also be run without human players as a pure simulation, however this operation mode has not been used for anything beyond system testing.

### AUTOBAHN COMPUTER PLAYER IMPLEMENTATION

Autobahn substitutes Artificial Intelligence (AI) for some or all of the human players. The consumer and VP roles have dedicated AI; the FP role is effectively eliminated, as fuel prices are statically set within the scenario. The essentials of the AI implementation for the consumer and VP are described here.

### CONSUMER – AGENT LOGIC

The consumer's game objective is to satisfy his drivers' demand for vehicle while getting the best vehicles he can for them, within his budget constraints. Recall that the S* score is used to signify the attractiveness of a vehicle to a consumer group; it is a reference value for the human player. The computer selects the Best Current Vehicle for the consumer using the following algorithm:

$$\text{Best Current Vehicle (BCV)} = \max\left(\frac{p_i + o_i}{S_i^*}\right);\ i \in [0, n]\ ;$$

such that:

$$p_i < 2 * \frac{\text{bank balance (\$)}}{\text{\# of vehicles left in turn quota}};$$

where:

$p$ is current vehicle sale price,

$o$ is the expected four-year fuel costs for the vehicle,

$S*$ is the S* score for the vehicle.

The game throttling mechanism applies to the computer consumer player just as it does to human player. This allows VPs to compete for computer consumer purchases within in a turn, as the computer can respond to small price changes amongst comparable vehicles.

### Vehicle Producer – Agent Logic

The VP AI logic is much more complex than that used for the consumer. It needs to make a lot of decisions in a short amount of time about things like margins, RD point allocation, and vehicle production. The implementation here is crude in many ways, but even so it routinely outperformed most human players and had to be crippled to keep things competitive.

The AI VP attempts to build two vehicles each turn. It first develops the vehicle, using one of several strategies, and then tries to fund vehicle production. If the AI VP lacks adequate funds to build a vehicle it will forego production of that vehicle product and not attempt to produce a replacement. In practice the AI VPs almost always produce both vehicles, failing to do so only if they have done poorly in the game.

The AI VP strategies for a new vehicle are, in order of preference: 1) Repeat a successful vehicle from his product set, 2) Copy a successful vehicle from another VPs product set, and 3) Produce a brand new vehicle. Repeating a successful vehicle is akin to establishing a long-running product line like the Toyota Camry. The AI VP executing this strategy may choose to make small changes to the vehicle's style and performance. These changes, if they occur, are never more than a point or two in either direction. This strategy is only selected if the base vehicle has a profitable sales history. If the player does not have a successful vehicle to repeat, it can choose to copy the successful vehicle of another player, i.e. a copycat strategy. This is a common strategy for real-world VPs. Small random perturbations to the vehicle are applied in order to ensure some variation in the market.

The third option is for the AI VP to produce a brand new vehicle. This is the least preferred option, by intent, being selected only about 10% of the time. In this case the AI VP begins by randomly selecting a consumer to build for (just as human VP players report doing). The AI VP is provided a veiled (fuzzy) view of the selected consumer's profile. This veiled profile is not saved or reusable in any form to prevent the AI VP from getting too accurate a picture of the consumer's true profile attributes. What then follows is a simple genetic algorithm. As the name suggests, genetic algorithms work by randomly combining and mutating objects within a set, filtering them for optimality, and then repeating the entire process until some terminal criteria is met. This game vehicle building process begins with AI VP randomly generating a batch of vehicles from all the possible drivetrains and a range of style and performance levels. Using the veiled consumer profile, the AI VP then filters the top scoring vehicle designs. It will repeat this initialization process until it generates at least three different vehicles within the consumers' expected price range. The random initialization set is then recombined and mutated to produce a new set of vehicles (the initialization set is included as it may contain vehicles that are superior to the offspring). The new set of vehicles is evaluated against the veiled consumer profile again, and a new candidate set is selected from the top vehicles. This process is repeated a number of times (the number of repetitions depends on the success the algorithm has at producing acceptable candidates) until a production vehicle is chosen from the final candidate set; this vehicle being the highest scoring vehicle from the final candidate set. The genetic algorithm approach is the riskiest of the strategies; it can produce some peculiar vehicles, but it can also open up new markets, which are much more lucrative than established markets.

The R&D allocation section of the AI VP is very simple. Each turn the AI VP spends its entire RD point allocation by randomly selecting an RD area and a random number of points, up to six to assign to the area. I originally intended to come up with a more involved strategy, but the AI VP was strong enough that it wasn't necessary. An added benefit of this strategy is that it helps prevent early lock in on popular drivetrains, thus reducing the range of possible diversity.

TECHNOLOGY SIDEBAR

I wrote all of the modeling and interface code for Autopia. I considered using existing modeling packages but found them all lacking in terms of being able to implement everything I wanted in the game. In retrospect using Adobe's *Flash* for the interface would have saved a lot of work, but it could not be counted on to be available on all of the computers I wanted Autopia to run on, so I wrote the interface in dynamic HTML. .The server side of the system is written in python using the Django web application framework. A web application framework is a system that handles the essential operations of a dynamically generated website and provides a maintainable system structure. System data is stored in a Postgres database.

The web client side is optimized for Mozilla based browsers (e.g. Firefox) but works for all of the popular browsers except some older versions of Microsoft's Internet Explorer. Client side page dynamics are handled with Javascript using the jQuery library. Asynchronous Javascript and XML (AJAX) is employed to handle instantaneous page updates; for example, when a VP changes a vehicle price it is updated in the vehicle auction for all players simultaneously, with no page reload required.

Autopia is hosted on a small (512 MB RAM) Ubuntu linux virtual private server (VPS), which is more than adequate processing wise. The hosting server should have high quality connectivity though to make sure games run smoothly. Organizing games is a lot of work; you don't want to risk a game session due to poor service from your webhost. I hosted Autopia on a $20/month VPS at Linode and always had good performance for my games.

# Chapter 4: Results of Autopia Game Play

## Game Record

In this section I present an overview of the Autopia and Autobahn games played in the course of my research. Autopia was run approximately fourteen times, in various forms, over the period of December 2010 through November 2011. These runs included Autopia and Autobahn games. The data shown here demonstrates the type of output that the games can produce.

The first runs of Autopia were in play testing sessions in December 2010. In these sessions undergraduate student testers were paid $20 for a 90 minute testing session. They were asked to complete a specified set of tasks in the game, for example, “build 200 gas hev cars.” The object of the testing was to discover source code bugs and interface problems.

**Table 5: Game Record**

| ID | Game | Game Type | Date | Description |
|---|---|---|---|---|
| 1-3 | Play Testing 1 | Autopia | 12/9/10-12/20/10 | Play and GUI testing. |
| 4 | Autopia Test 1 | Autopia | 1/6/11 | First full Autopia Test |
| 5 | STEPS Conf. Test | Autopia | 1/13/11 | Full test for STEPS conference game |
| 6 | STEPS Conference | Autopia | 1/19/11 | First full Autopia game with outside players. |
| 7 | Autopia Course | Autopia / Autobahn | 4/5/11-6/10/11 | Small games and tests in class. |
| 8 | Graduate School of Management – UCD | Autopia | 5/12/11 | Game played with GSM students and Autopia class students. |
| 9 | CAFÉ Test | Autopia | 6/2/11 | Game to test CAFÉ implementation |
| 10 | Asilomar 1 | Autobahn | 8/29/11 | Demonstration session 1 for Asilomar 2011 Transportation and Energy Conference |
| 11 | Asilomar 2 | Autobahn | 8/31/11 | Demonstration session 2 for Asilomar 2011 Transportation and Energy Conference |
| 12 | Autobahn 1 | Autobahn | 11/4/11 | Training game 1. AEO 2011 High fuel price scenario. Game initializes too many hevs in the beginning. |
| 13 | Autobahn 2 | Autobahn | 11/9/11 | Training game 2. AEO 2011 High fuel price scenario. Initialization works better. |
| 14 | Autobahn 3 | Autobahn | 11/22/11 | AEO 2011 with a volatility factor. 3 player game. |

These sessions were very productive. Testers were particularly confused by the play objective for the consumer player(note that this was an early version). The players could not figure out how much they should pay for vehicles while still making their turn quota. Nor could they understand how the consumer profile was supposed to influence their vehicle purchases in practice. Ranking vehicles on a four dimensional scale (style, performance, mpg, price) is a difficult task, especially within the short time period of a turn. This criticism, which was given with some frequency, led to the S* score feature (see The Consumer Vehicle Score Model – S* in Chapter 3).

One problem that came up very early in testing was the fact that the game design encouraged the use of a *quick-draw* strategy in which consumer players would choose their vehicles as soon as possible in the turn. Because there were limited amounts of each vehicle, a first mover could potentially buy a particular vehicle's entire production run, without giving other players a chance to bid on them. This was obviously not a realistic market behavior; however, at the time of the testing I thought that more knowledgeable and serious players in the real games would take more time. It turned out to be a large enough flaw in the game play design that I chose to restrict purchases with the throttled vehicle release system (described in the Chapter 3 *Vehicle Auction* section). The throttled auction significantly increased the technical complexity of the game, which is another reason why I initially resisted incorporating it.

VP players had problems gauging the size of the consumer market. They had no clue who was buying their vehicles or how (and why) they received RD points. This information was available in the interface, but it was not easy to find. Improvements on the data presentation were made based on the play testers critiques. Actual automakers can gauge the popularity of their vehicles by their dealer orders, inventory, and by market research.

Players also discovered some important bugs in the VP interface,. For example, it was possible to build a vehicle that got *zero mpg.* Also, consumers were able to buy more of a vehicle than actually existed, which was a great boon to the VP who did not have to pay for those additional sold units. Play testing was very productive in regards to finding these sorts of bugs.

## Autopia Testing: Autopia Test 1 and STEPS Conference Test

In preparation for the first real play of Autopia at the STEPS conference, a number of tests were performed. The first full system test was conducted with a group of graduate students and professors from ITS on Jan 6, 2011. There were twelve players. The system did well. Several bugs were found and a lot of good information came back on game play and interface design.

The second test, on January 13, 2011 , showed a much improved system. All of the major bugs were fixed, but there were still problems with the interface. For this test the participants were ITS graduate students, most of whom had participated in the test game from the prior week, and students from a energy efficiency course that was being run on campus: a mixed group primarily science and engineering majors.

Most games have a set of strategy options that emerge frequently in play, and Autopia is not an exception. The consumers and VPs played strategies that had been often seen in past games. Usually, the VP tries to create vehicles that will get high S* scores at a popular price points. Vehicles with high S*scores are likely to sell well. The VP must also take into account energy price trends and their implication for introducing advanced drivetrains. The advanced drivetrains are attractive to some of the consumers (e.g. *green)* and increase their S* scores, but for the more budget-conscious consumer (e.g., *young, family*), choosing an advanced drivetrain is an immediate welfare loss that he accepts with the hope that it will protect him from much more expensive fuel prices in the future. Fuel Producers typically experiment with their production strategies, under-producing so as to drive up fuel prices. The thing that made this game exceptional was the use of *quick-draw* strategy by a consumer player. In this case the player, I'll call her Sue, was an ESL student with a poor grasp of English; she didn't fully understand the game instructions.

Sue was assigned the *executive* consumer role. The *executive* is a high-income consumer who constitutes 5-10% of the market. The executive profile is weighted heavily towards style and performance (45% each), with the remaining 10% preference going to mpg. Not understanding her role, Sue bought every car she could as quickly as she could. She should have only bought her quota of vehicles (~200/turn), meeting the executive goal,and stopped but she didn't. She bought up everything she could, which was a lot considering the *executive* has a healthy allowance, intended for the purchase of more expensive vehicles.

Sue greatly exceeded the executive's normal purchase of 200 vehicles per turn. This excessive purchasing left an insufficient number of vehicles for the other consumer players, who were attempting to choose more thoughtfully. Sue ended up with the highest consumer score because the scoring algorithm did not take into account over-purchasing, and because the other players were not able to buy enough cars to make their own quotas.

The *quick-draw* strategies had arisen in earlier testing, but never to the point of Sue had taken it to. Novel, extreme, and even destructive ("grief play"  strategies can be a factor in any game(Foo, 2008; Girard, N., 2007; Gladwell, M., 2009). Game designers must come up with means of handling unexpected player strategies. War games use umpires to handle game adjudication (Brewer, G. and Shubik, M., 1979; Perla, 1990). Autopia has an administrator role whose job it is to run the game (usually game administration is just running turn updates). The administrator can make binding judgements when necessary and can even adjust player positions. In the case of Sue , however , the problem was built into the system itself and had to be resolved by redesigning to the interface code to prevent a *quick-draw* strategy from being executed. I implemented the throttling mechanism in the vehicle auction (see The Vehicle Auction – Chapter 3) to prevent players from using *quick-draw:* it worked.

## STEPS Conference Game

The STEPS Conference is an annual gathering for sponsors of the Sustainable Transportation and Energy Pathways program (http://steps.its.ucdavis.edu/) at the

Institute of Transportation Studies at UC Davis[16]. Participants in the conference were invited to a test session of Autopia. The players included employees of major automakers, oil companies, electric utilities, government agencies, NGOs, and researchers. All thirteen player roles were active in the game. Some roles were assigned to teams of two players.

**Picture 1: Autopia in play at STEPS Conference**

The game ran well. There were no technical or game play issues. Some players did have to leave early, however, so some roles were abandoned in the latter stage of the game. As the administrator I took over those roles.

As was the norm in the test sessions, the FP players had trouble getting their production volume right. The initial game scenario had FP gasoline production well below the demand

[16] I am a researcher in the STEPS group; Autopia is a STEPS project.

level, but even so FPs withheld production gasoline production from the market. This can be seen in Figure 26. In that chart, *demand* is higher than both *supply* and *capacity* (in the game excess demand is met by outside suppliers who enter the market when prices get high enough due to local game FP failures to provide). Supply in this case refers to the amount of gasoline (gges) that the FPs chose to produce. Capacity is the maximum amount that they could have produced had they run all of their available gasoline refineries. By choosing to run under their capacity the FPs increased the price of fuel for consumers, while simultaneously reducing the size of the revenue pool available to them.

FP's under-supplying the market was a recurrent pattern in the game, this despite the fact that they were told that that their maximum profit opportunity was at the point where they supplied the actual market demand for the fuel. Some of this under-supply may have been honest predictions of a declining market, as gasoline demand typically falls in a game due to a fixed size vehicle fleet and increasing fuel efficiency, but at least some of it was due to the FP players colluding to raise prices: I overheard the FP players talking about it openly. In fact, the truly superior strategy is for a player to persuade the other FPs to collude by cutting their production while staying at full production himself (see *Example 4* in the *Fuel Model* section). This strategy provides maximizes prices and quantity sold for the player. The problem with the strategy is that there is no way to verify that others aren't trying the same thing; and if that occurs everyone will receive less than the maximum amount possible. In the real world, overt collusion is illegal, however there are plenty of legal means for oligopolies to signal intentions (Gal-Or, 1985).

In Figure 27 a comparison is made between *actual / scenario base gas price*[17] against aggregate profits. As supply approaches demand the actual game price for a fuel approaches the base scenario price for the fuel (see the *Fuel Model* section of Chapter 3). The chart shows an improving ratio of the *base/actual price* (approaching 1.0), which corresponds to an improving level of profit (aggregate), as the Autopia fuel model is designed to do. *This is just a demonstration of the modeling dynamic in action.*

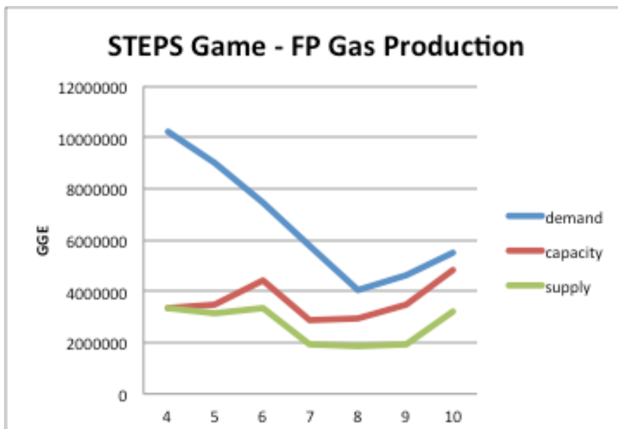



**Figure 26: Gasoline Sales Statistics**

Fuel price data for all fuels is shown in Figure 28. The fuel prices for the game had a mild increasing trend, for the most part. A failure to supply diesel by the FPs shot diesel prices up to $14/gge in the 2032 turn, which destroyed the diesel vehicle market for the rest of the game (2036 turn and beyond ) as consumer players feared another spike in later turns, and did not see any other advantage to buying diesel vehicles.

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[17] Base prices are set for each fuel for each turn in the scenario. The actual fuel price is the base price modified by the supply to demand ratio of the game. See Chapter 3 for further details on the fuel model.

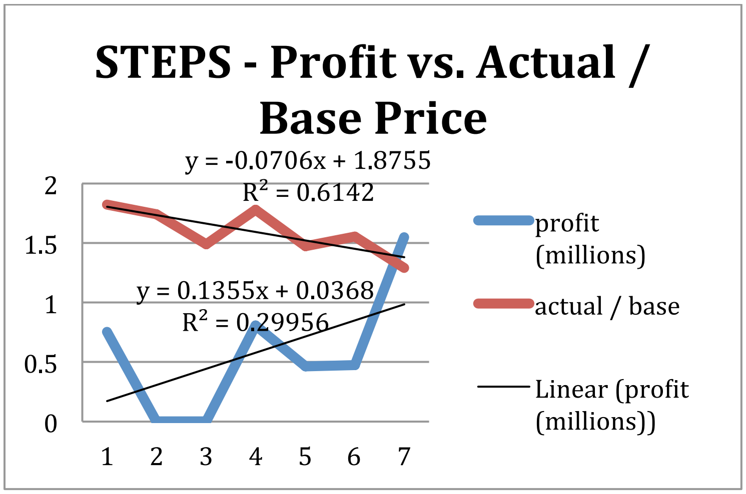



**Figure 27: Profits vs. Actual/Base Price Ratio**

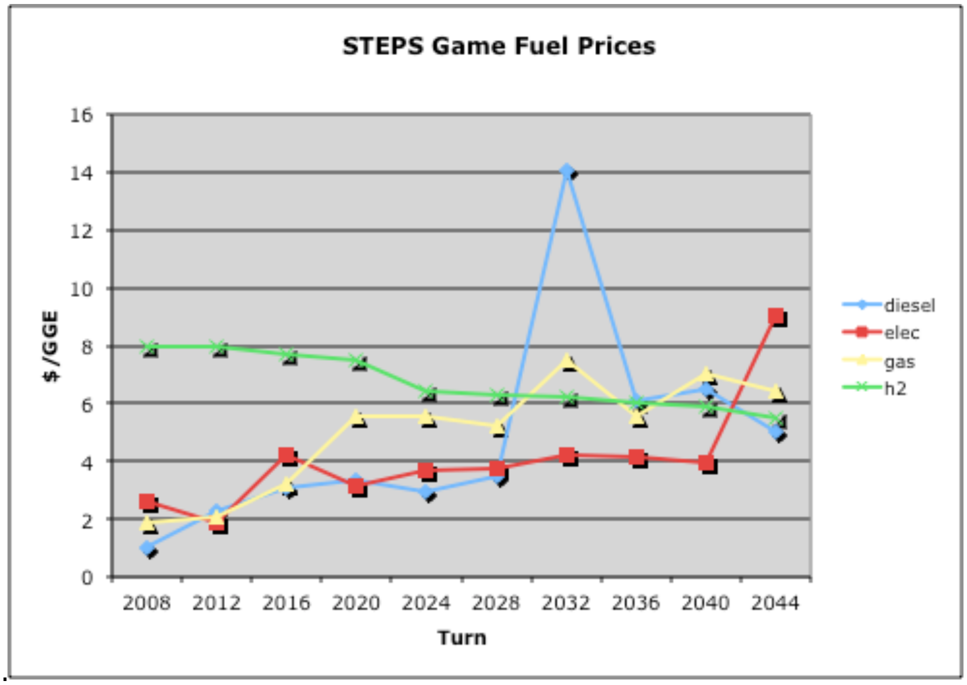



**Figure 28: Fuel Price Data**

The overall fuel story for the game can be seen in Figure 29. Gasoline consumption falls substantially, about 67%, between 2008 and 2044. Electricity consumption stays constant (note that electricity includes stationary consumption) over that time period. Diesel consumption makes steady progress until the great Diesel Drought Debacle of 2032 drove the price to up to $14/gge. No diesel vehicles were sold after that, and consumption thus falls as diesel vehicles are attrited from the fleet. Interestingly, hydrogen starts to become competitive with gasoline in 2024, but no hydrogen-powered vehicles are ever sold in the game. Hydrogen never became popular in any of the game scenarios, even when the scenario made it competitive on a $/gge basis. One possible explanation is that there is a lack of familiarity with hydrogen vehicle technology; VPs and consumers were much more willing to take chances with expensive PHEVs and BEVs than with hydrogen, even when the hydrogen vehicles were purposefully designed to be a good value, as in the STEPS Conference game. Another possible explanation is that, deserved or not, there is a fair amount of skepticism about hydrogen-fueled vehicles (Sperling & Ogden, 2004). This skepticism may have transferred into game play.

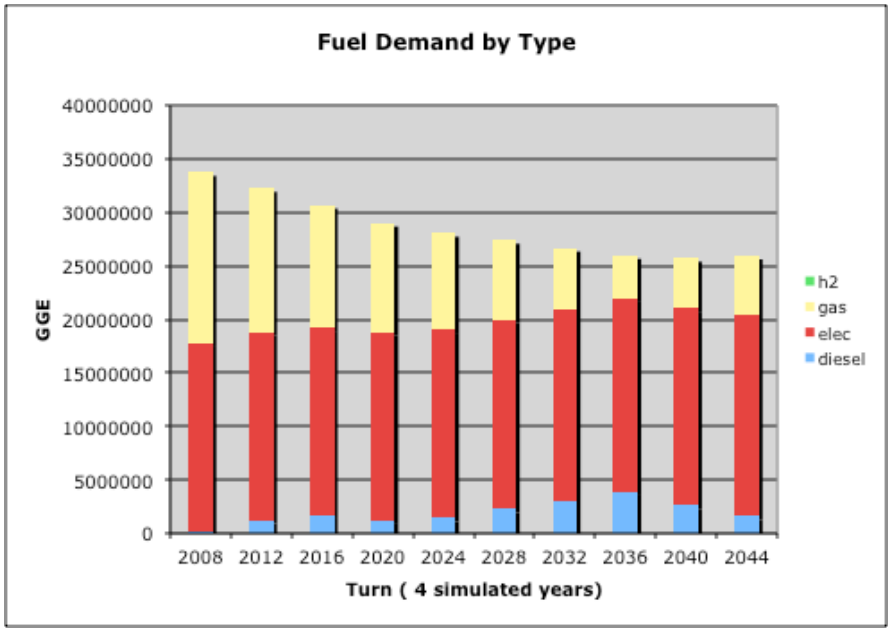



**Figure 29: Fuel Demand (includes stationary electricity usage)**

The breakdown of consumer vehicle purchases can be seen in Figure 31 and Figure 30. The game begins in 2008 with gasoline, diesel and gasoline hev vehicles[18]. In 2016 the first gasoline phev10's become popular in 2020 with the conventional and HEV diesels accounting for 25% of sales. The rest of the vehicles are the gasoline driven cars seen before, with a few gas phev40's being introduced for the first time. Diesel vehicles account for almost 40% of new car purchases in 2024 and gas, gas hev, and gas phev10s the remainder.

[18] I did not attempt to create a realistic starting scenario for this game. The gas hev and diesel drivetrains are over-represented. I chose the starting point in order to make the powertrain distribution diverse

BEVs are first introduced in 2028 at about 10% of the market; they remain at about that level for newly purchased vehicles for the rest of the game; they do not become a dominant drivetrain. Diesels of the conventional and HEV varieties stay popular through 2032 and then are never seen again in the game.

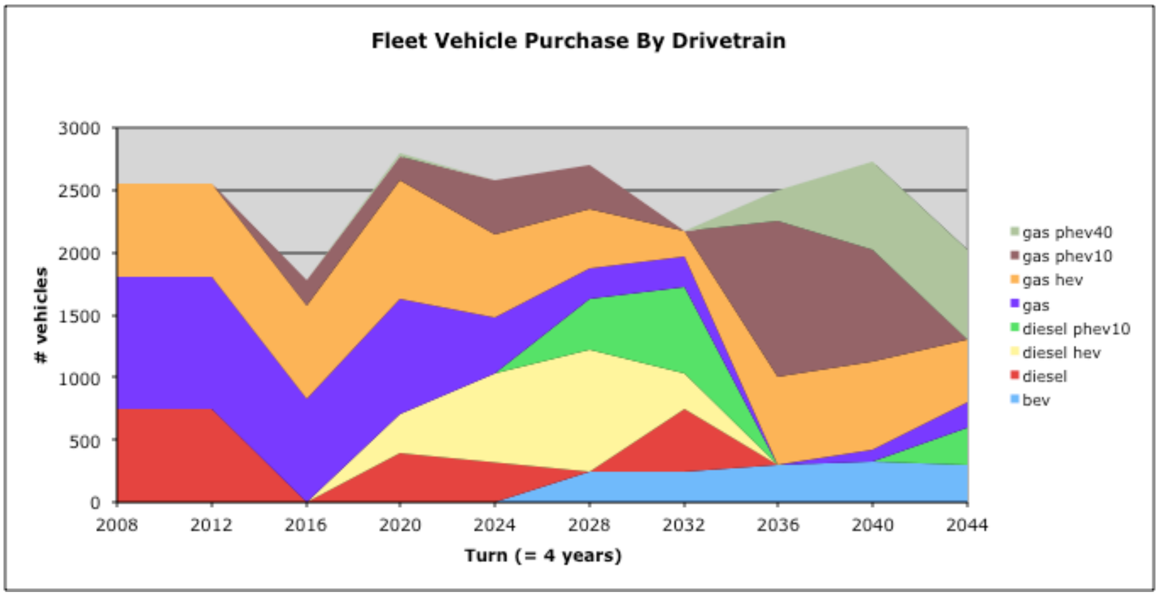



**Figure 30: STEPS Drivetrain Purchase Volume by Drivetrain per Turn**

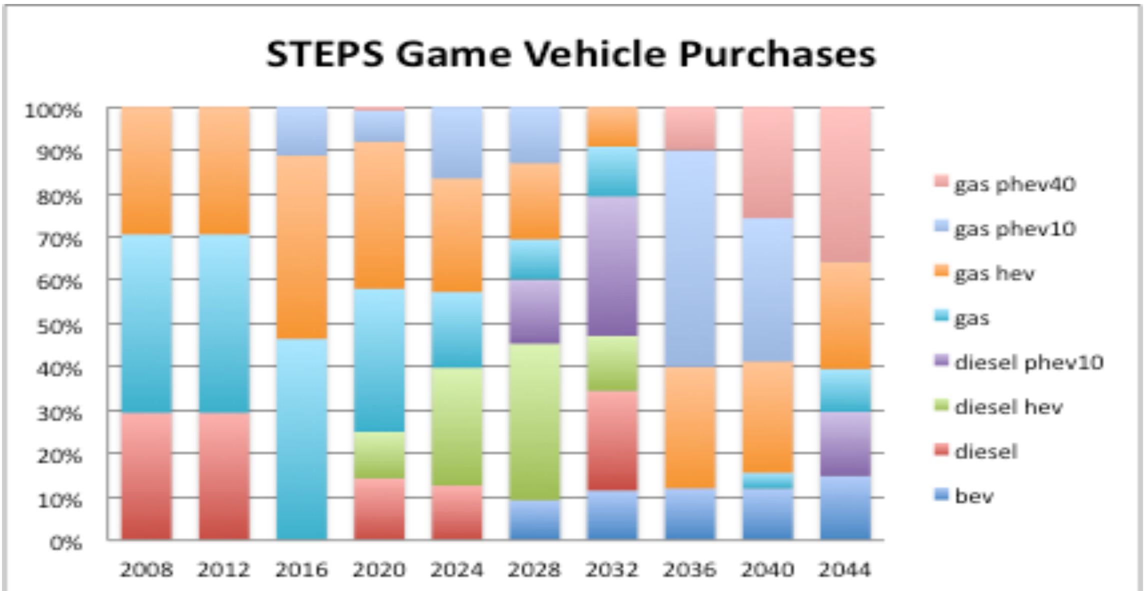



**Figure 31: STEPS Game New Vehicle Purchase Breakout**

Efficiency (mpg) trends can be seen in Figure 32 for the STEPS game, which shows the averaged mpge for all produced vehicles by drivetrain. A strong increasing trend is visible; gasoline engines, for example, nearly double in efficiency within the game going from the low 20's to almost 40 mpg. Gasoline hybrids (*gas hev)* start out averaging 40 mpg and reach 60 mpg by the 2036 turn.

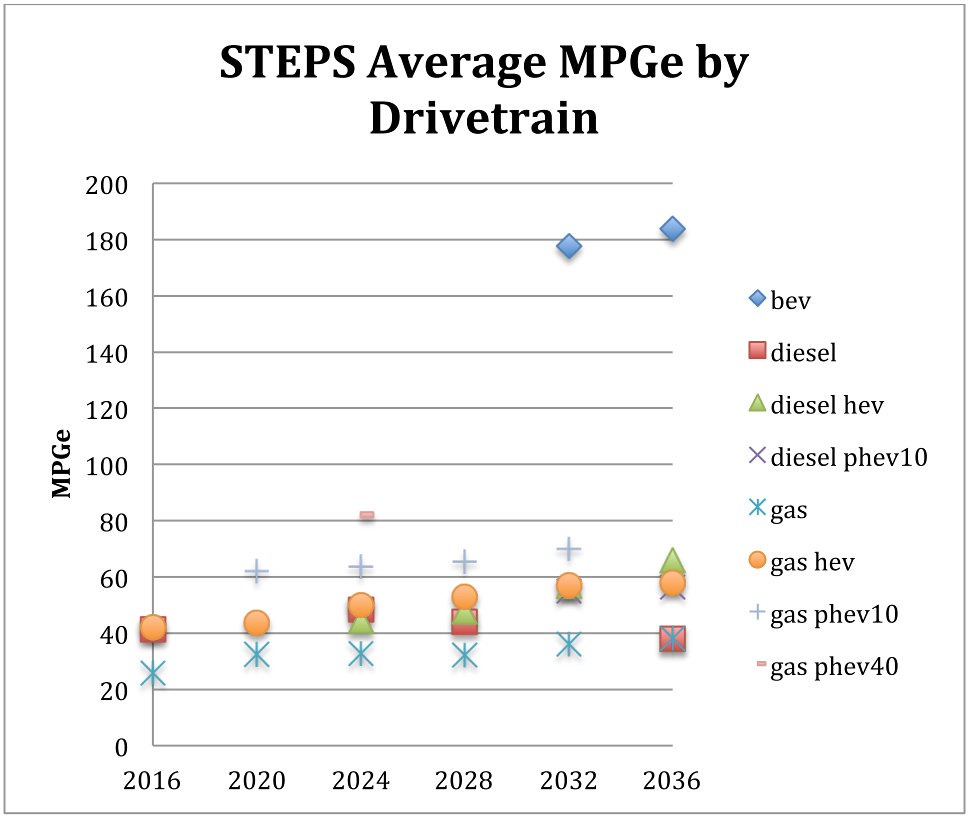



**Figure 32: STEPS Average MPGe by Drivetrain**

### CONSUMER GAME

Average value/turn charts are shown for style and performance, for the consumers (Figure 33, Figure 34). The trends are similar; the higher income consumer groups, *executive* and *green* are able to maintain their initial style and performance values across the game, while the other consumers, *family, enthusiast*, and *young* see a trend of declining values for these characteristics, to the point that they are buying minimally featured (i.e. very low style and performance scores) by the final turn. This behavior is driven by rising fuel prices over time.

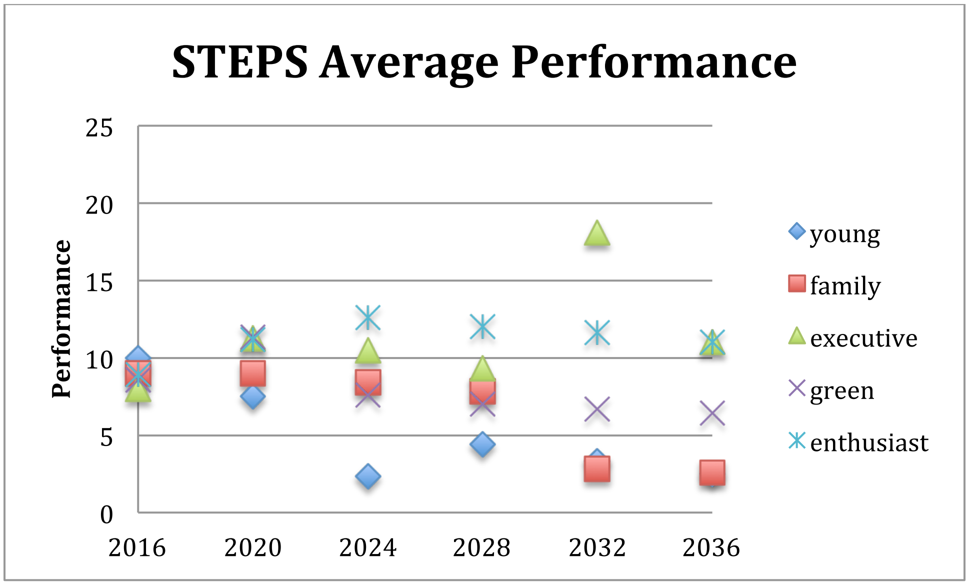



**Figure 33:Avg. Performance Purchase / Turn by Consumer**

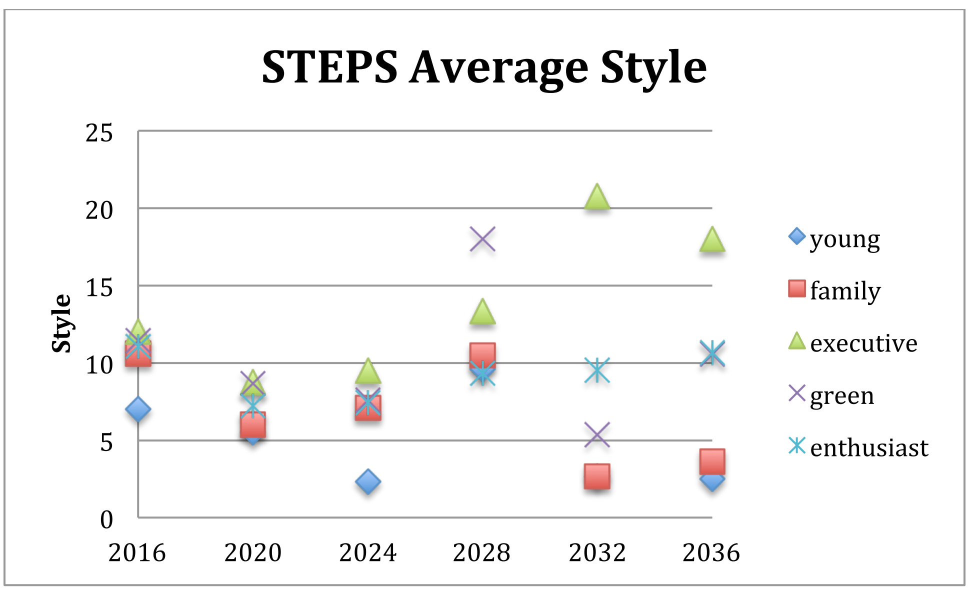



**Figure 34: Avg. Style Purchase / Turn by Consumer**

## GSM GAME

This game was played on May 12, 2011 in a computer lab on the UC Davis campus. There were nine players in the game, covering the consumer and VP roles. The FP game was a programmed scenario handled by the computer. Several of the players came from the Autopia workshop class and the rest were MBA students at the UC Davis Graduate School of Management (GSM) who were recruited by a member of the Autopia workshop who was also a MBA student. This was a peculiar game. Backus warns that overly homogenous player groups lead to weaker game outcomes, and this game certainly supports Backus' assertion (Backus, 2005). Just as random participant selection improves the quality of survey data, player diversity helps protect game outcomes from the inherent biases of closely associated player groups. Game results are the most interesting when they reflect on the game experience itself rather than the peer relationship traits of the group playing the game[19].

[19] Game play that exists outside of a dominating social context can often be hard to achieve. In war games, for example, ranking officers who find themselves in losing situations have ordered the games altered to fit their preferences. War gamers have learned that effective and impartial adjudication is required in order to obtain useful results(Caffrey, 2000; Perla, 1990).

In this case the GSM students employed some aggressive strategies. At least one of the consumer players was withholding vehicle purchases on alternate turns in order to save money to buy better vehicles on the subsequent turn. This affected the vehicle auction in that there was an excess of vehicles produced on the turns in which that consumer player withheld his purchases. This drove VPs to dump their vehicles at low prices on those turns, which was a boon to the other consumers.

As the game administrator I thought the low vehicle purchases were due to a lack of funds of the consumers. I assumed there was a problem with the scenario and I corrected it by increasing consumer allowances. Following the correction the consumers had far more money than I intended them to have. This led to a second extreme strategy, this time by the vehicle producers who sold cars at exceptionally high margins. No prior VP player group had been so aggressive with their vehicle prices before. Average margins (grouped by drivetrain) for the GSM game, for example, were typically as least double those seen in the STEPS Conference game (see Figure 36, Figure 37). In the debriefing session one of the VP players explained that he was setting his margins according to what the market would bear and not according to the cost of building the vehicle.

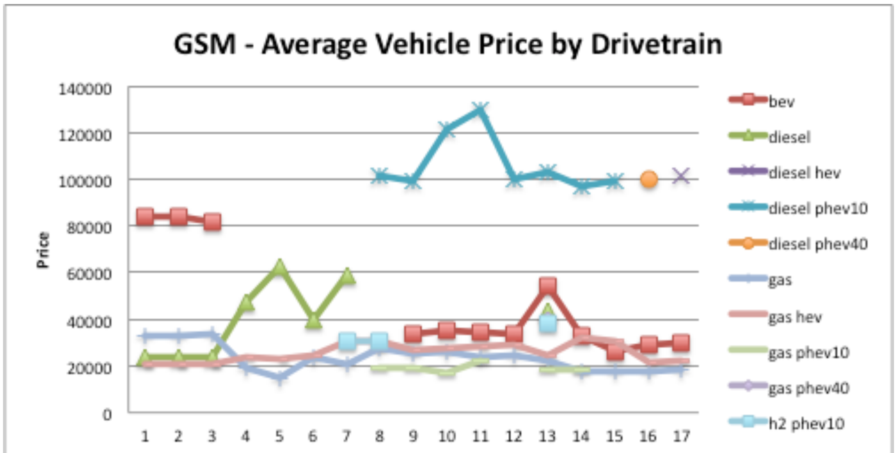



**Figure 35: GSM Average Prices per Drivetrain**

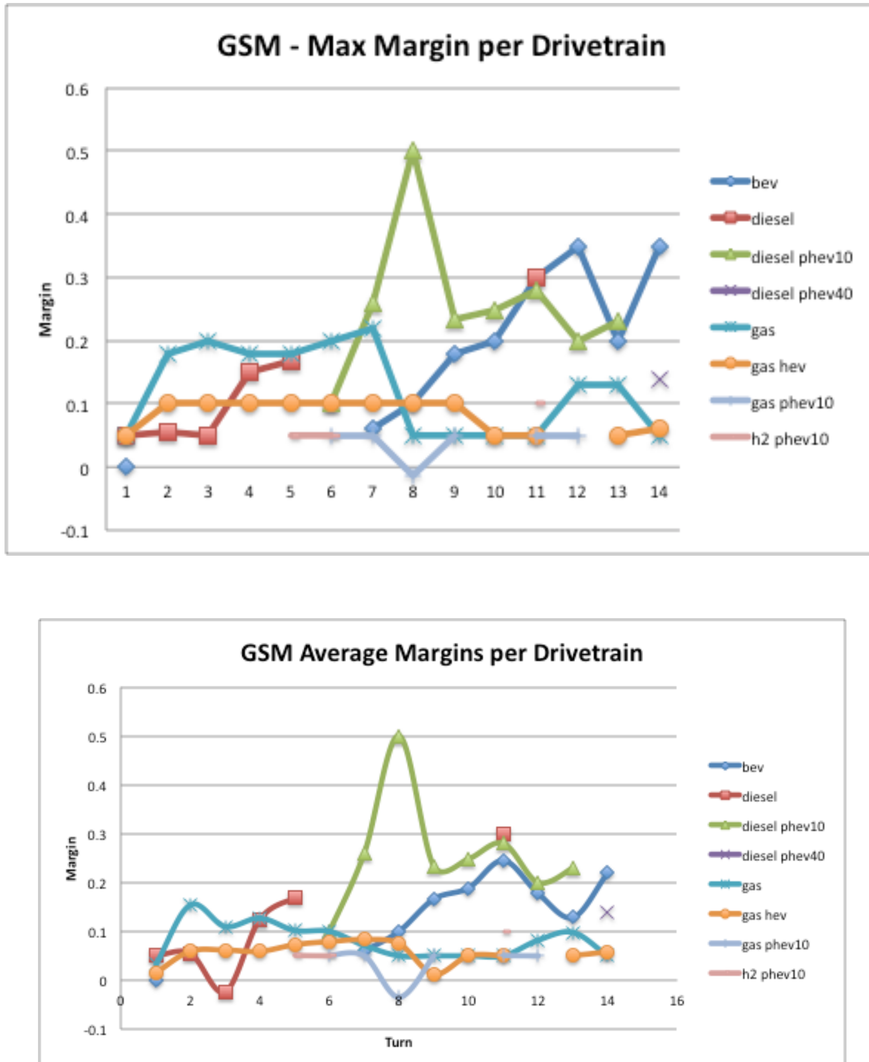



**Figure 36: GSM Average Margins by Drivetrain**

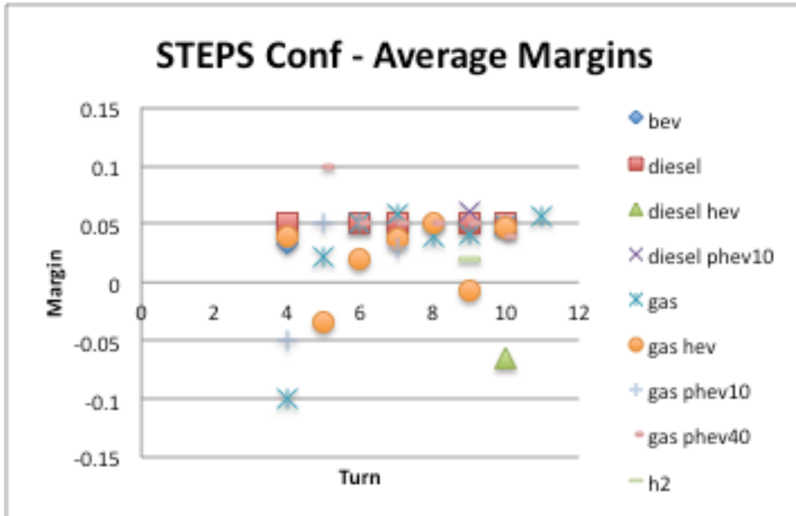



**Figure 37: STEPS Conference Average Margins by Drivetrain**

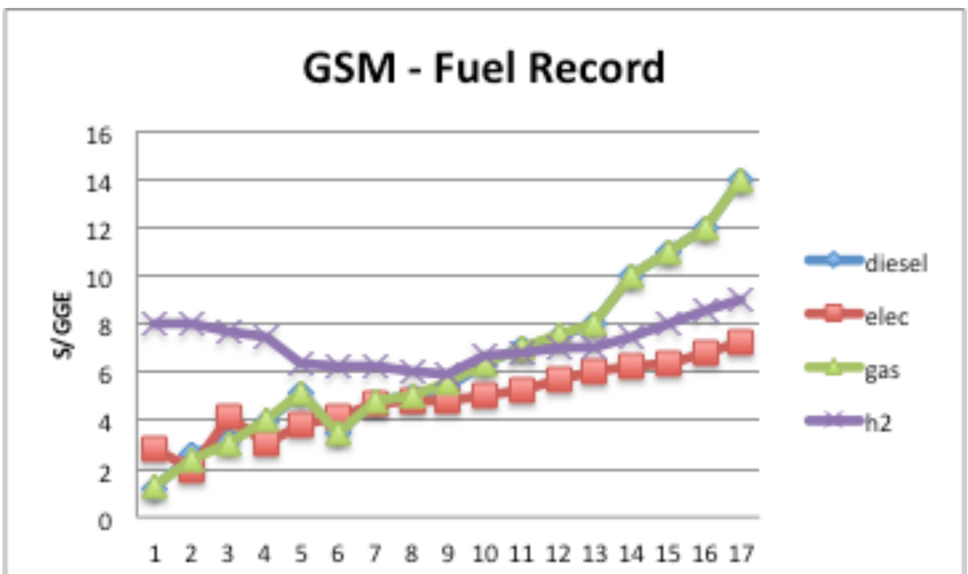



**Figure 38: GSM Game Fuel Record**

Margins are calculated using this function:

$$\text{margin} = \frac{\text{sale price}}{\text{production cost}} - 1$$

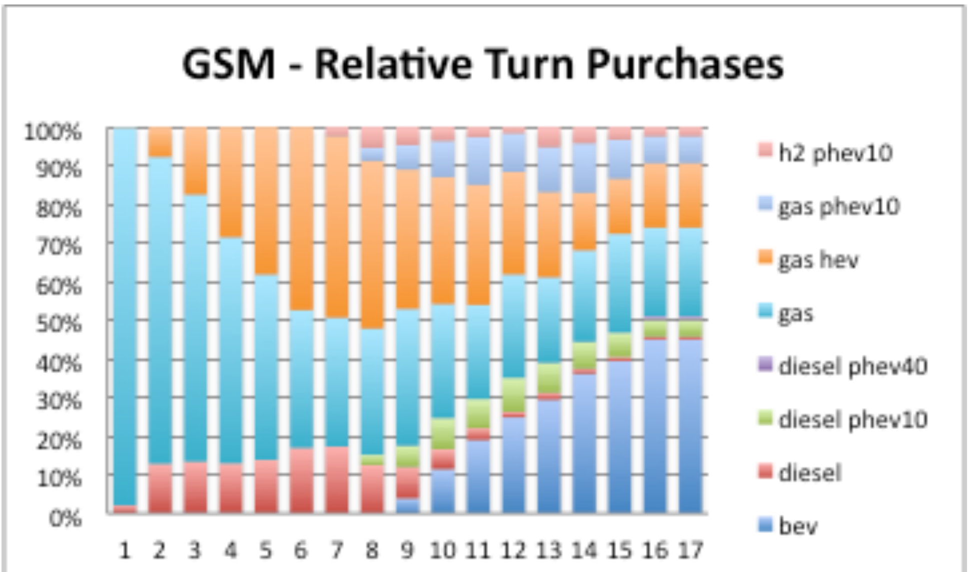
The GSM game ran through turn 17, at the players request, an unusually high count. Typical games ran through turns 10-12[20]. The prices of gasoline and diesel increase steeply over the last 5 turns, ending at around $14/gge for both. These prices, along with my reversal of the additional allowance granted to consumers, contributed to the more typical sort of margins that appeared in the final five turns.

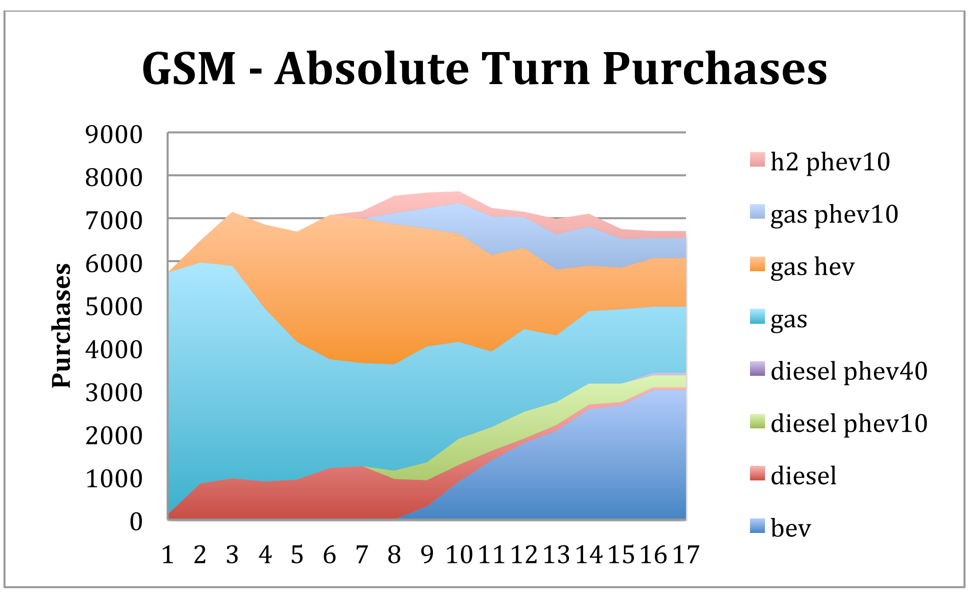
### GSM Drivetrain Trends

The game was initiated with mostly gasoline vehicle purchases (98%), with diesels accounting for the remainder. In turns 2-6 the percentage of standard gasoline vehicles readily declines, with gas hevs responsible for most of the replacements and diesel picking up the rest. By turn 6 (2020) , CFVs (i.e. gas, diesel) account for half of all new vehicle sales, with *gas hevs* and a few *h2 phev10s* making up the remainder of the market. The *h2 phev10* holds on with a few percentage points of sales per turn for the rest of the game; no other hydrogen vehicles types are sold. Hydrogen fuel starts to get close to gasoline/diesel in

[20] Game play starts at turn 3 and the game is not under full player control until turn 4 so a game that ran until turn 17,for instance, actually had only 14 actual player turns.

price in turn 7 and eventually soon enough cost less than gasoline/diesel, substantially less by the end of the game. *Bevs* enter the game on turn 9 and account for almost half of all vehicle purchases by turn 17. *Gas* and *gas hev* vehicles stay popular through the end of the game with about 40% of purchases.



## Asilomar Games

The Asilomar games were demonstration sessions. Autobahn was run for those sessions. Attendees watched the game, participating if they were interested. If no human player was available, the computer run VP player managed game decisions. The data from these games was not suitable for analysis.

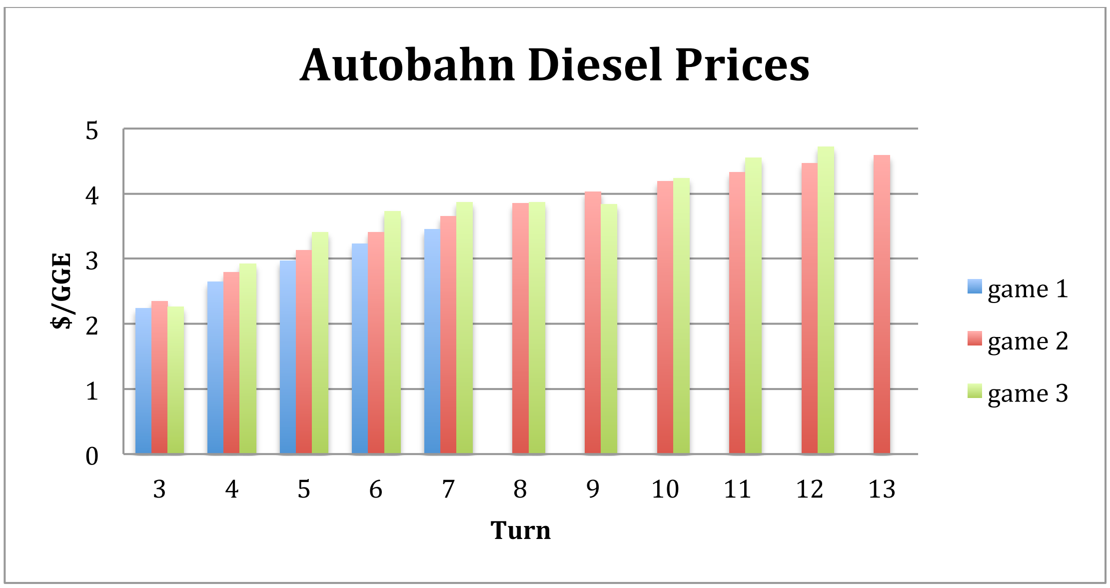
## Autobahn Games

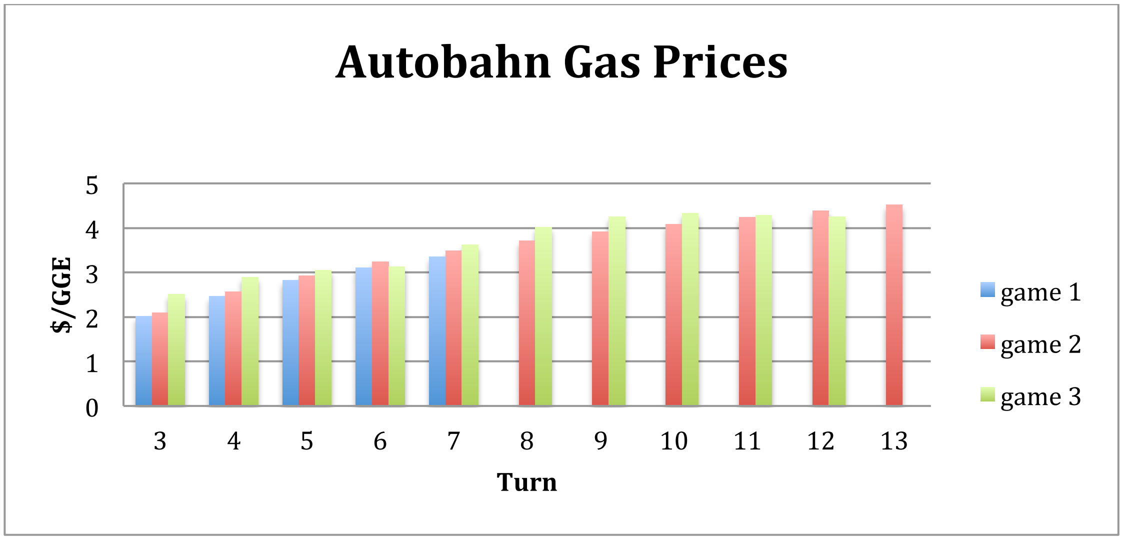
Three Autobahn games were run in November 2011 on the UC Davis campus. Autobahn is a reduced version of Autopia in which human players only take VP roles (see the *Autobahn* sidebar in chapter 3). The computer handles the consumer and FP roles. In order to improve the game results and speed up play, a small group of students were selected as the player population from which all games would draw. Reusing the same players for multiple games created an experienced player group. This sped up game play and reduced the amount of error-play. The players were UC Davis students, mostly undergraduates. The players were paid $25 for attending the 90-minute sessions.

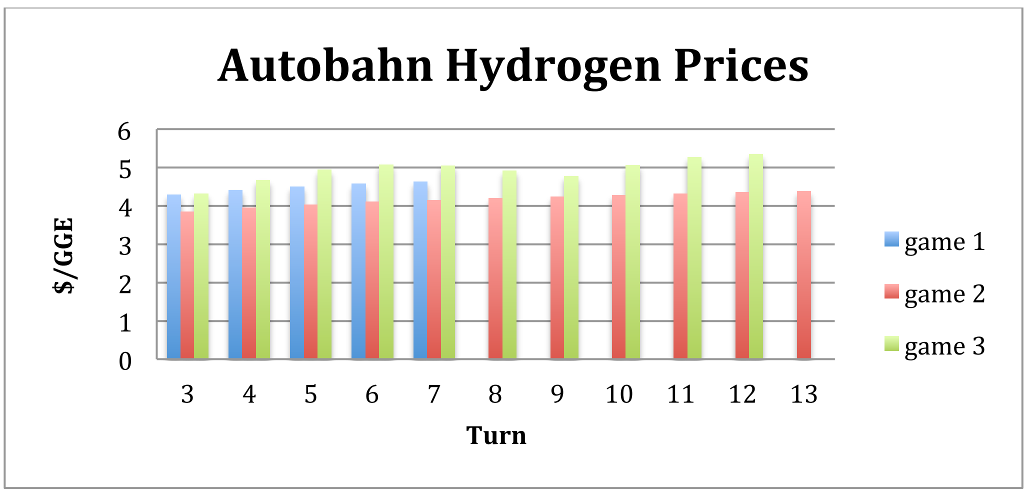
## Autobahn Game Multi-Analysis

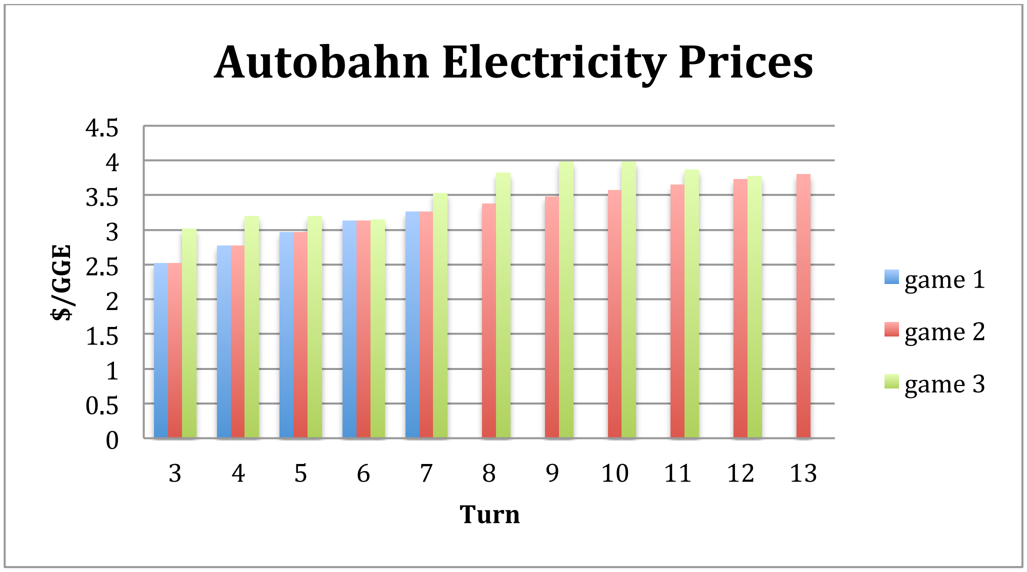
### Fuel Price Scenarios

The fuel price scenarios for gasoline, diesel, hydrogen and electricity can be seen below. The games were all based on the AEO 2011 High Fuel Price Scenario(EIA, 2011b), with the third game introducing a small volatility factor that could alter the price 50 cents in either direction. The fuel prices in these games were entirely exogenously determined: consumer fuel demands had no bearing on prices. Fuel prices are preset and do not change in all Autobahn games.




Autobahn Gas Prices
$/GGE
0
1
2
3
4
5
3
4
5
6
7
8
9
10
11
12
13
Turn
game 1
game 2
game 3


Autobahn Hydrogen Prices
$/GGE
0
1
2
3
4
5
6
3
4
5
6
7
8
9
10
11
12
13
Turn
game 1
game 2
game 3


Autobahn Electricity Prices
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
$/GGE
3
4
5
6
7
8
9
10
11
12
13
Turn
game 1
game 2
game 3

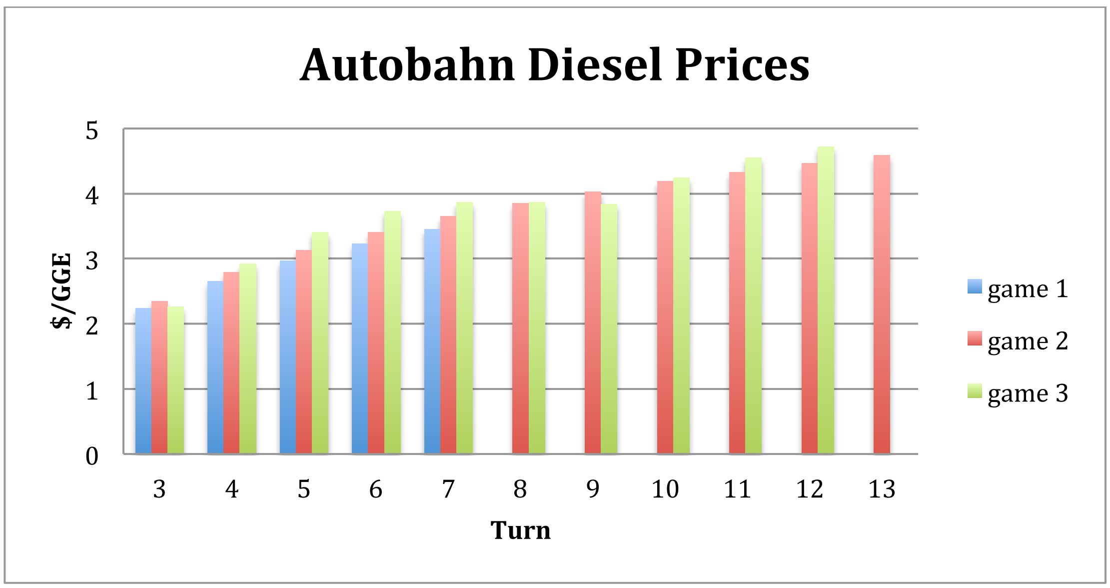
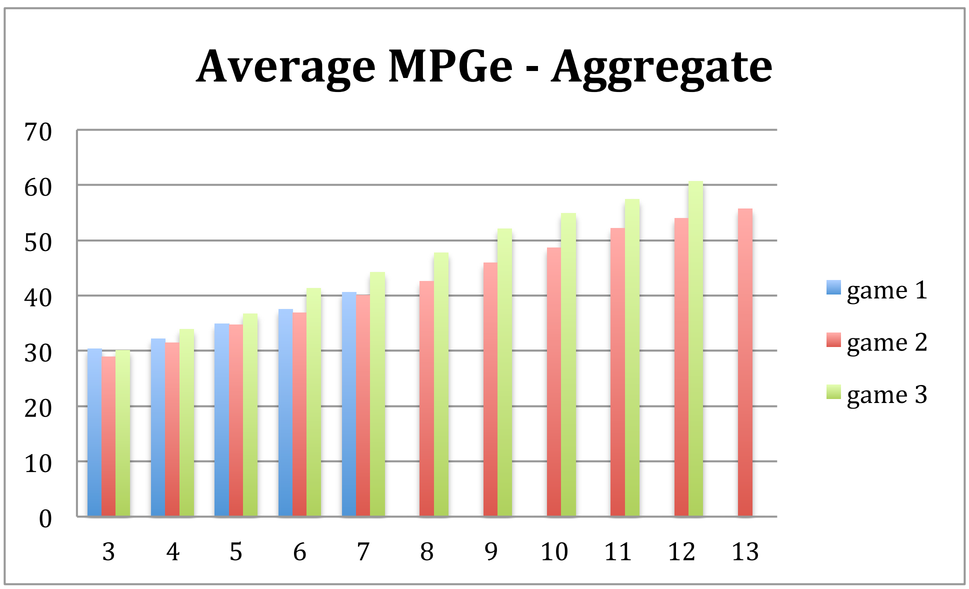
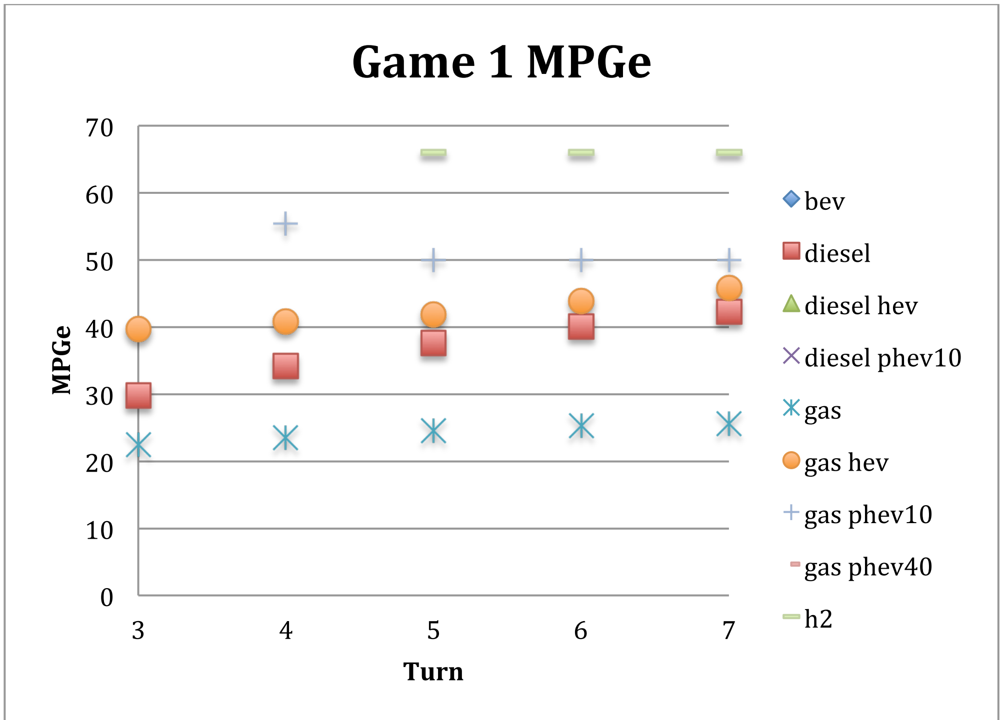

Autobahn Diesel Prices
5
4
3
2
1
0
$/GGE
3
4
5
6
7
8
9
10
11
12
13
Turn
game 1
game 2
game 3

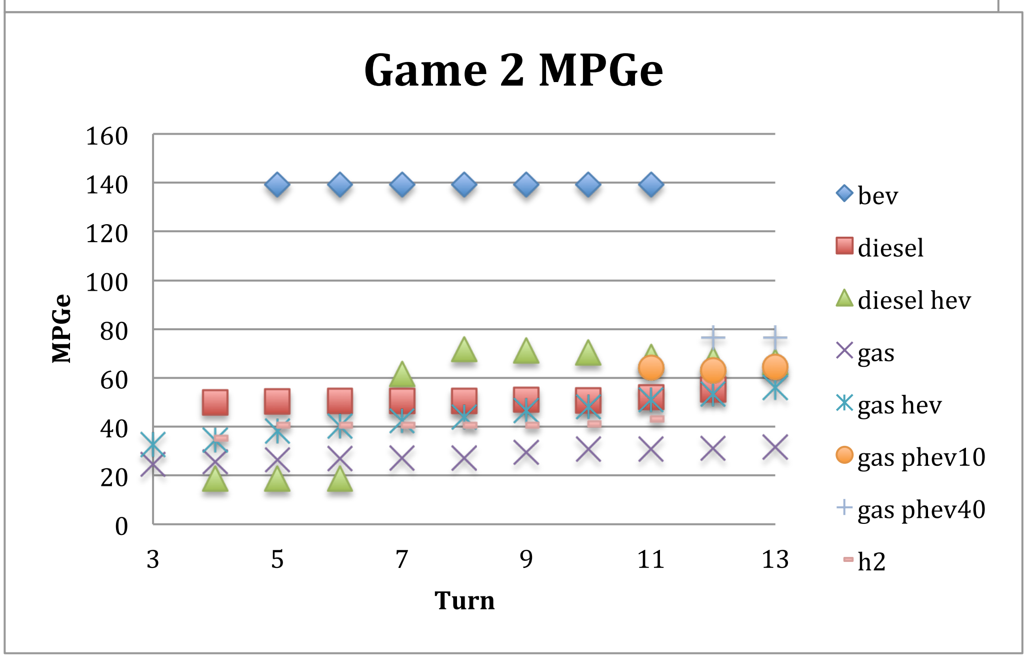
**Figure 39: Autobahn Game Fuel Price Scenarios**

MPG RECORD

Fuel economy records for the three games are shown below. Fuel economy increases as the VPs increase their technological capabilities through R&D strategies over the turns. By the third game, at which point all of the players were familiar with play, the progression appears to become more orderly. The VPs are targeting the consumers more efficiently and sticking with their product lines as they find favor with the various consumer groups. The charts shown below cover the aggregate mpg data for the consumer fleets.




Game 1 MPGe
MPGe
70
60
50
40
30
20
10
0
3
4
5
6
7
Turn
bev
diesel
diesel hev
diesel phev10
gas
gas hev
gas phev10
gas phev40
h2


Game 2 MPGe
MPGe
160
140
120
100
80
60
40
20
0
3
5
7
9
11
13
Turn
bev
diesel
diesel hev
gas
gas hev
gas phev10
gas phev40
h2

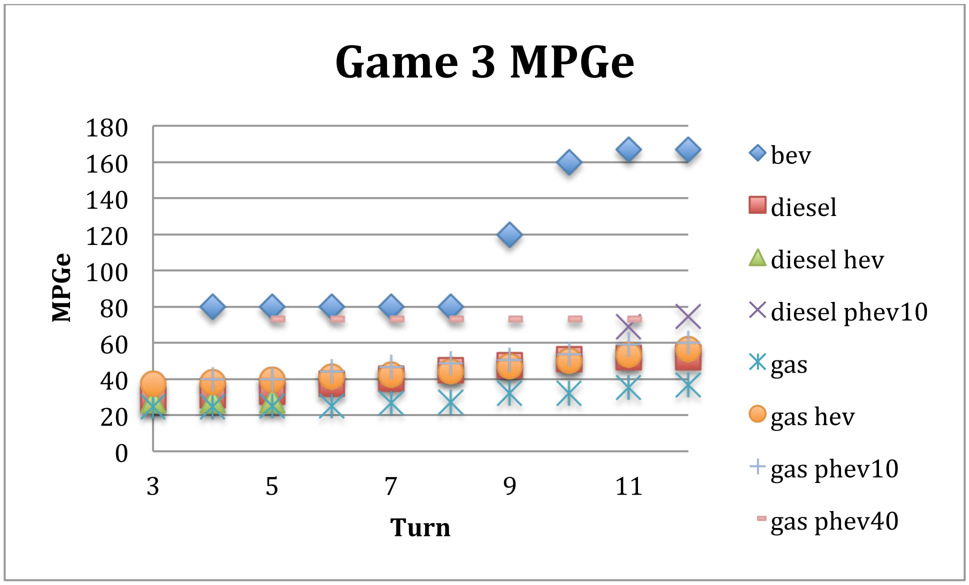



**Figure 40: Autobahn Game MPG Data**

The average MPGe charts shown in Figure 40 show game MPGe for each of the three Autobahn games, per drivetrain. All games show a general upward trend in MPGe. Game 3 shows a major increase in BEV mpge in turn 9. This happened because the early BEVs sold in the game came from one producer who was selling a small number of high luxury vehicles. Later in the game (turn 9) the BEV market expanded with a larger volume of high mpge vehicles.

### VP Margin Performance

Average vehicle margins stabilize over the three games. The third game begins with high average margins for the VPs (10%+) but soon stabilize to around 5% . This is a result of the VP players learning to effectively target consumers with vehicles. Part of that targeting is being price competitive; this competition drives down the prices of vehicles and thus margins.

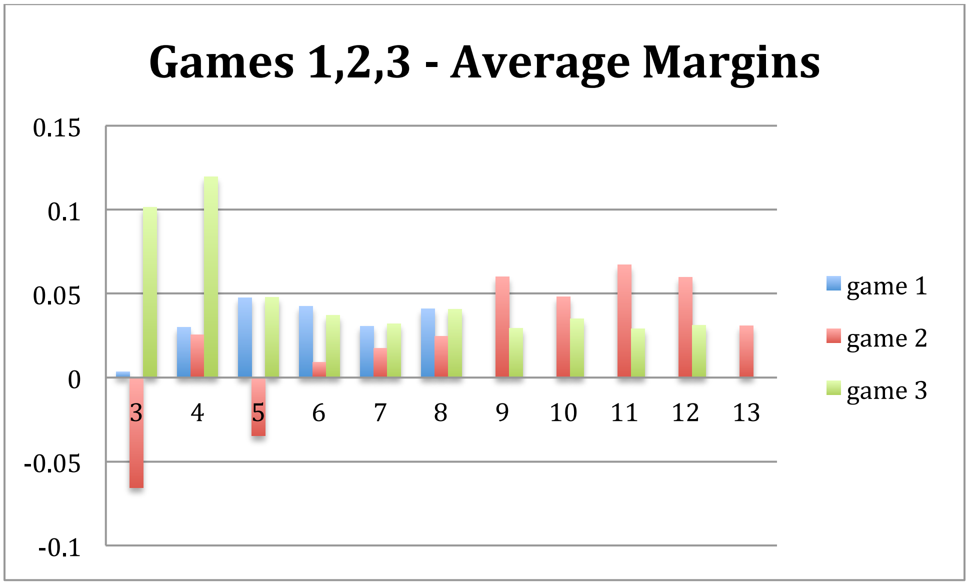



**Figure 41: Autobahn Average Margins Across Games**

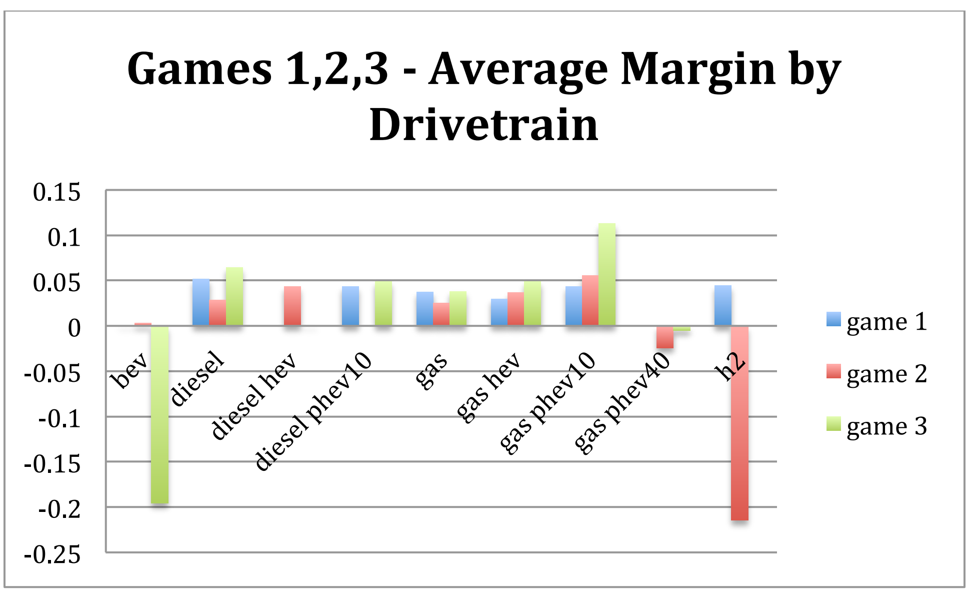



**Figure 42: Autobahn Average Margins by Drivetrain, per Game**

In Figure 42 average margins per drivetrain are shown. Note that the margins for all drivetrains in *game 3* are higher than the other games on everything except for the *bev;* but looking back to Figure 41 the *game 3* margins are mostly inferior to the *game 1* or *game 2* margin for the turn (i.e. the *game 3* margin is either the second or third of the three). This can be explained by the unusually high margins that were achieved for *game 3* in the first two turns. These two charts tell different, but complementary, stories.

The charts in Figure 43 delve further into the margin question across the games. With the exception of a few outliers, the average margins are all within a few percentage points of zero. Higher margins generally indicate a special circumstance such as a new vehicle type that consumers have a strong positive response towards. In *game 1* the margins are dispersed in a convex pattern; the players started out the game under-selling themselves (i.e. negative margins), testing the market for highs in the middle of the game, and then finding the 0-5% margin range that appears frequently in the game. It is important to note however that *game 1* is a short game and so the convex pattern should not be weighted highly in the analysis. In *game 2*, which was a second game for some of the players, the margins are steadier. The convex pattern is replaced by a linear pattern: most margins are within 0-10%. The *gas hevs*, a popular platform when gasoline is in the $4-$6/gallon range, are achieving margins of over 5% in the last turns of the game. Finally *game 3* has the most orderly average margin distribution. This is interesting in light of the fact that this was the most volatile fuel-price scenario. It suggests a couple of things: 1) that the volatility wasn't a substantive factor within the game, and 2) that the player group representing the VPs was learning how to successfully build and price their vehicles for the computer operated consumer players. The fact that the computer operated the consumer players may be a factor, but the gentleness and predictability of the fuel scenario was probably most responsible for the game dynamics. A more spiky, volatile, fuel scenario makes the game much more difficult.

Having played against the computer many times myself for testing, I have noticed that there is a consistent logic within the system that will reward strategic play and careful pricing[21]. The Autobahn player group made the same observation. A safe strategy for the game was to target a drivetrain type for one's R&D to attempt to become the technology leader and then. Then one needs to find a popular configuration (i.e. style and performance levels), and stick with it. A potentially more lucrative but riskier approach is to aggressively try different drivetrains and configurations. If the VP discovers a winning combination that has no competitors he can receive outsized margins on the vehicle, but only until competitors notice the popularity of the vehicle. The profitability of this strategy is short-lived.

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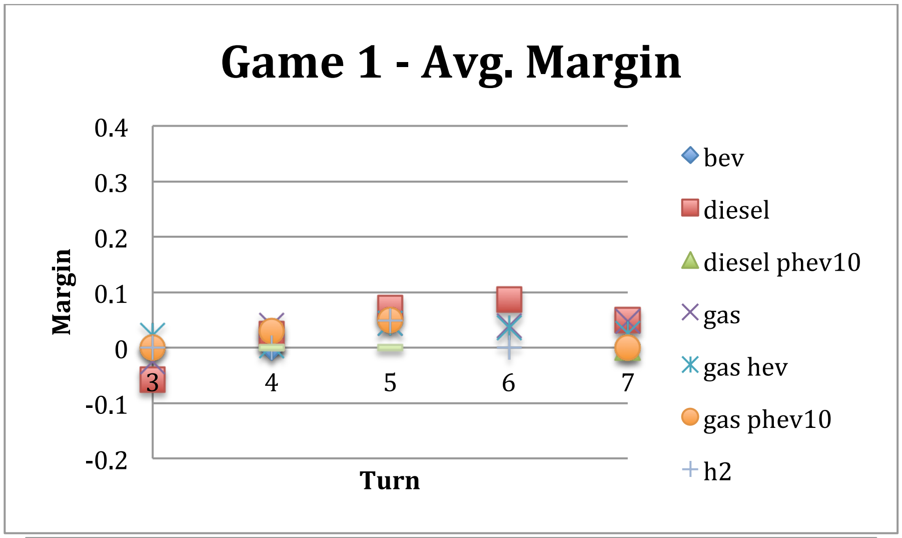
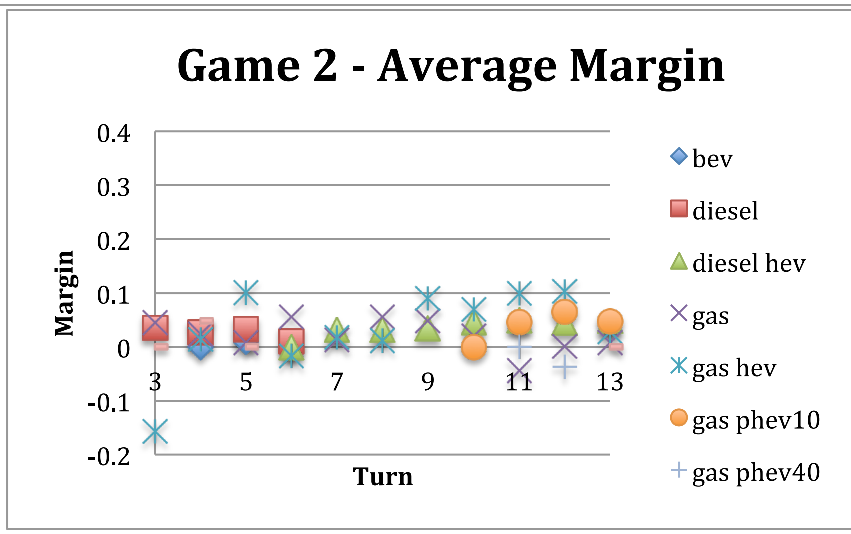
[21] This consumer allowance portion of the economic scenario has been constant across all games. Changing the allowance structure, tightening or loosening it, would make the game harder or easier, respectively, for the VPs.


Game 1 - Avg. Margin
0.4
0.3
0.2
0.1
0
-0.1
-0.2
Margin
3
4
5
6
7
Turn
bev
diesel
diesel phev10
gas
gas hev
gas phev10
h2


Game 2 - Average Margin
0.4
0.3
0.2
0.1
0
-0.1
-0.2
Margin
3
5
7
9
11
13
Turn
bev
diesel
diesel hev
gas
gas hev
gas phev10
gas phev40

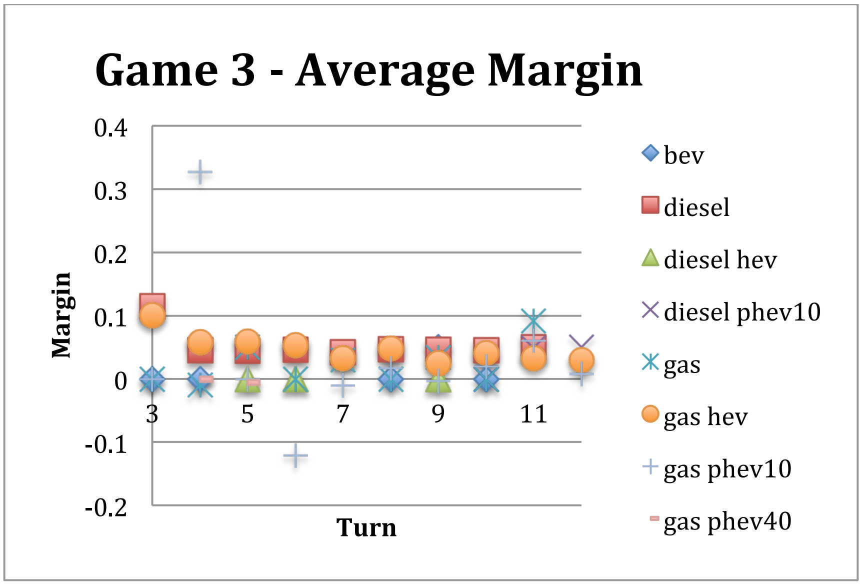



**Figure 43: Autobahn per Game Average Margins by Drivetrain**

**Sidebar: Challenges in Early Development and Testing of Autopia**

Much work went into developing and perfecting the Autopia game and interface. Although many games were played in this process, a statistically significant approach to the games was never undertaken. Developing game scenarios, recruiting players, and arranging the associated logistical factors for a 4-5 hour event that requires a minimum of 13 people is a non-trivial task even for a single play. Expanding the play counts to a point where statistically significant results could be achieved (10 games minimum) is a major endeavor when relying on volunteer players. As the game organizer I had to post ads, answer emails, arrange suitable space (campus computer labs are not easily obtained for four hours at preferred times of day), and design repeatable game administration and player training procedures so as to keep game sessions as uniform as possible. Given the amount of time I was putting into the game (scheduling work while trying to obtain volunteer players for free ) I soon realized the false economy of the approach: it made more sense to pay players for their time than to expend hours of my time, paid by graduate student stipend , to try and obtain it for "free" from volunteers.

Several approaches were taken to find players. Early testing was done with undergraduate students who were paid $20 for participating in a 90-minute game testing session. These were not full games; these were sessions where the interfaces were exercised and discussed. Fresh eyes quickly uncover bugs and other problems in software that are otherwise invisible to developers. This was soon after followed with full test games using graduate students associated with my graduate group (Transportation Technology and Policy). Two or three games were played with this group. These sessions were full Autopia games, but they were not interesting analytically, because there were still too many flaws in the game: games featuring substantial error-play, as these did, are not useful results.

Different tacks were taken to fill the games. I taught a seminar on Autopia one quarter with the hope of enrolling enough students to play full Autopia games. I ended up with three students. In the course I described the game, its development and theory, and we played smaller versions of the game with fewer players. Autopia is functional with less than thirteen players; it can be played with four – 2 consumers, 2 vehicle producers and a fixed fuel market. It's not an optimal configuration, but it works well enough to test features. The class was used as a core for recruiting MBA students at the UC Davis Graduate School of Management (GSM). Two games were played with the class students and GSM players, but neither reached a full 13 player contingent. Many students who said they would show up did not.

To fill the games I tried the idea of going to on-campus clubs and offering them $300 if they could come up with a full 13 player contingent. Two games were scheduled with two campus groups, but I had to cancel them due to a family issue. By the time I was ready to get back to running games, it was Summer and the groups were unavailable.

What I eventually realized was that Autopia was too big and took too long for most players. This gave rise to Autobahn which was designed to be fully functional with 1-4 players and an hour of playing time, excluding player training. Autobahn is the VP game of Autopia with an artificial intelligence component that operates consumer vehicle purchasing and any VP roles for which a human player is unavailable. In fact, Autobahn can be run as a complete simulation, no human players at all, although that is not what is designed to do and is of limited analytical value; the whole idea of Autopia/Autobahn is to bring human-decision making into the modeling process.

I ran two demonstration sessions of Autobahn at the Asilomar 2011 Conference on Transportation and Energy. These sessions were attended by high-level professionals in the vehicle and fuel industries, among others; I received valuable feedback on Autobahn. An executive with a major American automaker commented that they regularly played strategic games and that Autobahn compared favorably with those. One attendee, Martin Lee-Gosselin, a professor emeritus at Université Laval, Quebec, Canada, with an interest in simulations offered an in-depth and useful critique of my work. In response to my problems getting players, he suggested that I train a group of players and then reuse them across Autobahn games rather than only use them for a single play. I ultimately did implement this player recruitment methodology. Between the flexibility of Autobahn and having a ready pool of players who were willing to show up for 90-120 minutes for $25 I was able to easily put together several games. I had to stop at that point though due to other time constraints.

The literature on serious games covers the difficulties of player management and recruitment in a fair level of detail. Recall poor Lt. von Reiswitz, who introduced war gaming to the Prussian Army in the 1820's was so despised and ostracized by some members of the officer corps who thought his games to be a waste of time that he was driven to suicide (Caffrey, 2000). Many serious games are played in classroom situations in which play is included in instruction(Abt, 1971), or is a routine part of the job in the case of wargames(Brewer, G. and Shubik, M., 1979; Perla, 1990). Games without a preset audience should be designed while keeping the question of where the players will come from in mind from the beginning. Toth (1986) recommends that the central designer of a game should be a well-known, established figure who can recruit and develop from amongst the community of interest in the game. The simulations Toth describes are 3-5 day events: serious time commitments. But such a time intensive approach makes a lot of sense if your goal is to develop new perspectives to challenging problems. The reality is that players of a game must feel like their participation is compensated in some way if play cannot be otherwise compelled. The compensation can take many forms; it may be the privilege of being invited to participate by a distinguished presenter (e.g. the President asks you personally), or it may be a gift, such as the $25 I paid Autobahn players. Whatever it is, the compensation must correlate to the time commitment expected of the participants.

# Chapter 5: Analysis of Game Results

The work I am presenting here should be considered an advanced working prototype. I have designed, built, and demonstrated results from the system showing that it works and can produce interesting results. The obvious next step is to run a rigorous set of games on a set of scenarios of interest, but that is beyond the scope of this dissertation. An immense amount of work went into getting Autopia to the point it is at now. A rigorous game trial is a major undertaking and beyond the resources of this project.

Serious games are usually concluded with a lengthy debriefing session in which the players characterize the lessons learned from their game. In the course of this research however I was the sole primary observer of results. Although this is not an optimal outcome it is acceptable given that that this is a prototype. Presented here are my major observations on the dynamics of vehicle and fuel market transitions that have come from developing and observing this system.

## Reflections on Transition Dynamics: The Role of Consumers, and Vehicle and Fuel Producers

Vehicle and fuel production for the mass market are complex technical and logistical processes that can only be undertaken by large and well-organized groups. The basis of the market is the end user: the consumer. Unlike the producers, consumers do not deeply consider the long-range (beyond 3-5 years) strategic implications of their choices when it comes to vehicle and fuel decisions(T. Turrentine, Kurani, & Heffner, 2008). The typical vehicle purchase process for most consumers is probably a repeated iteration of the questions "What do I like?" and "What can I afford?" until a convergence is reached. The concept of "like" refers to a combination of aesthetics, peer approval, and attitudes towards technology and efficiency; and "afford" is a similarly nebulous concept of what the buyer can manage given his income, assets and credit(Axsen, J., Kurani, K., 2010). In Autopia the "like" concept is represented by $S^*$ and the "affordability" is represented by the dynamically updated remaining average vehicle cost [22]statistic that is shown to the consumer on his vehicle auction screen. Consumers do not choose vehicles for purchase using a rational, objective evaluation process: other factors are at work in the decision(T. S. Turrentine & Kurani, 2007). Even if they did attempt to make it a rational decision process, one that took into account the impacts of various energy price scenarios on operating costs, people aren't very good at assessing long term risks so the value of that assessment is dubious (Kahneman, D., Tversky, A., 1979; Taleb, 2010).

Modeling the infrastructure decisions of fuel and vehicle producers on the production side is a tractable problem because it is built on a science and engineering foundation under the assumption of profit maximizing behavior. The consumer end of the market is not as tractable an entity for modeling. Discrete Choice Models (DCM) can be built from stated and revealed preferences, but they can never approach the levels of certainty available in domains that are governed solely by natural law(Ben-Akiva & Lerman, 1985; Bunch, 1993).

[22] Consumer players are constantly appraised of the how much money they can spend on an average vehicle, given their remaining quota and budget, on their auction screen.

Models like HyTrans (D. Greene, 2007) and TAFV (P. and J. R. Leiby, 1997) as well Bunch's work on clean fuel vehicle demand(Bunch et al., 1993) integrate DCM components to represent consumer decisions, but consumer decisions are hard to predict – people are sensitive to a wide variety of factors (Gigerenzer, 2000). The purpose of Autopia is to provide insights that aren't available from other currently available models.

The modeling objective in Autopia was to try to capture the critical dynamic interactions and decisions of the market. In building and running the Autopia models, I observed several patterns of recurrent player behavior. These observations cannot be quantitatively validated, as a statistically significant trial was not attempted; they are instead examples of observations that are possible within the system. They indicate the possibilities of what can be learned using Autopia as part of a rigorous exploratory process(Toth, 1986).

## Trends (Findings)

### High Fuel Prices Can Mean Low AFV Penetration

It is generally assumed that people will want high mpg vehicles when faced with high fuel prices, and indeed it has been empirically observed in recent years(Spain, W., 2012). But that does not necessarily mean consumers will choose to buy alternative fueled vehicles AFV[23]; gasoline powered economy CFV[24]s now in production can achieve highway fuel

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[23] AFVs are defined within the Autopia context as a vehicle with a motive battery. This includes HEVs, PHEVs, BEVs and HFCVs.

efficiencies of over 40 mpg, which is a substantial improvement for most buyers(Gale, Z., 2012; RITA, 2012).

When fuel prices are high, $5-$12+/gge, in Autopia consumers have less money to spend on vehicles. The high income groups, *executive* and *green,* incorporate more AFVs (gasoline hybrids and phevs) into their fleets as the additional cost of the AFV is much smaller percentage of the cost of an expensive vehicle than for an economy vehicle. The much larger lower income consumers (*young, family,* and *enthusiast*) however, turn to high economy gasoline CFVs because they don't have the extra funds to buy large numbers of AFVs: the high fuel prices have depleted their budgets.

How realistic is this response? For example a $1 increase in gasoline prices would mean additional $600/year fuel expenditure in order to maintain a constant VMT of 12000 miles/year on a vehicle that gets 20 mpg. That might not seem like a lot of money, and for some it would not be a factor. However it is important to remember that the Autopia consumer works off of a vehicle and fuel budget and not a household budget. There is no credit in Autopia, nor are there other budget categories, such as clothing or prepared meals, from which the consumer can shift funds. A dollar spent by the consumer to buy fuel is a dollar of potential revenue lost to the vehicle producers. The Autopia representation of the impact of fuel costs is more extreme than what occurs in the real world because there are no other budget items that can be adjusted. Perhaps a good context to put it in is that of a

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[24] Conventional Fuel Vehicle – standard gas or diesel vehicle with no hybridization.

consumer spending an extra $600/year on fuel has $50/month less to put towards a car payment, which means a substantially less expensive car given a five-year loan.

In high fuel price scenarios the trend that invariably arises is the bifurcation of the vehicle market. The high end of the market, the top 30%, gets AFVs that span the range from basic hybrids (*gas hev, diesel hev)* to *bevs.* These vehicles are often not very efficient, compared to the average light duty vehicle. The VPs design them with high style and performance to appeal in the high-end market, and these features cost mpg. The advanced technology serves to keep the VPs CAFE mpg up, so as to minimize penalties and allows them to offer more attractive features on the car while still meeting the minimum mpg requirement for the game. For example, if there is a 10 mpg minimum rule in a game, a *gas hev* can carry more style and performance than a *gas* car; the added efficiency of the *gas hev* is translated into features rather than mpg.

The bottom 70% of the market in high fuel price scenarios, in contrast, struggle to hold on to their vehicles. A large market develops for *gas* cars with low scores on style and performance. These drivers cannot afford the luxury of a long-range view of the value of AFVs. Consequently, if fuel prices continue their increases, drivers get into even worse financial shape; they lose some of their cars and transition to alternative modes. The higher-end consumers, who have invested in AFVs, are less vulnerable to fuel price increases and volatility because they buy less fuel (i.e. higher average fleet mpg), and because they can choose to moderate their style and performance desires in AFVs to get increased mpg, should they need to do it.

So the counter-intuitive effect is actually straightforward economics: people will not adopt more efficient technology if they cannot afford it, and high fuel prices can make AFVs unaffordable for many of the consumer players by sapping their financial reserves. On the high end of the market consumers can justify buying AFVs either because they increase the feature level of the car or because they can rationalize the added initial expense with the expectation of future cost savings due to the increased efficiency of the vehicles.

### Feature Gap

It is safe to assume that AFVs will always be more expensive than CFVs. The reason for this in HEV/PHEVs is that the electric drive system is added to a conventional gasoline or diesel drivetrain that is capable on its own of driving the vehicle. Batteries, especially large batteries, are costly, with prices projected to be $150-$325/kwh in the year 2030 (Plotkin 2009). This translates to a battery cost from $3750-$8125 for an economy class BEV, like a Nissan Leaf, with 80-100 miles range (25 kWh battery), which may need to be replaced in the vehicle's operating life. In contrast, the fuel tank of a CFV is a small contributor to the cost of the vehicle and is unlikely to need replacement. Hydrogen fuel cell vehicles include a motive battery that is typically comparable in size to that of standard HEV. It is possible that HFCVs might achieve cost parity with an CFV because a hydrogen fuel cell stack is much simpler than an ICE, but there are still important technology and refueling network challenges to be overcome for HFCVs

Given that the duplicating the feature set of a CFV in an AFV will cost significantly more money, the *feature gap* is the distance between feature comparable AFVs and CFVs. For instance, for the price of Chevy Volt ($40,000), a PHEV 40, one has a number of attractive options from prestige brands such as BMW and Lexus. The Volt compares, functionally, to the Chevy Cruze Eco at about half the price(Sherman, 2011) . How many Cruze buyers are going to be willing to pay an extra $20,000 for a vehicle whose only benefit is improved gasoline mileage (albeit substantially) for short range driving? Likewise, how many buyers in the entry-level luxury market are going to be willing to trade substantial style and performance premiums for increased mpg if they must drive a far more modest economy-trimmed vehicle?

SIDEBAR: SOCIAL UTILITY VALUE

The feature gap can be alternatively posed as in terms of a social utility value. In short, a consumer is willing to pay the additional amount for an AFV over a comparably featured CFV if he perceives the non-monetary value of the vehicle, what I'm calling the social utility , compensates for the additional cost.

Consider the simplest case, a consumer has a choice between an AFV and CFV version of two vehicles. The vehicles will be leased and include maintenance, so he does not need to consider those issues. He will choose the AFV over the CFV if:

$$\$CFV\_Cost + \$Perceived\_Mpg\_Benefit + \$Social\_Utility > \$AFV\_Cost,$$

rearranging:

$$\$Social\_Utility > \$AFV\_Cost - \$CFV\_Cost - \$Perceived\_Mpg\_Benefit.$$

The social utility of a vehicle is the value that the vehicle represents which cannot be directly monetized. People will spend above and beyond the cost of a basic utilitarian vehicle because it provides them with some sort of emotional satisfaction. It may be the privilege of HOV lane access or impressing the neighbors. In fact, the concept of social utility applies to all vehicle purchases and not just those where an AFV is set against a comparable CFV. One way to bridge the feature gap is to look for ways to improve the perceived *social utility* value of AFVs.

Toyota's Prius offers a market based approach to dealing with the feature gap. The Prius is only offered as a hybrid. There is no gasoline-only version of the Prius that can be compared with the hybrid. Furthermore, Toyota has designed the vehicle to provide a specific driving experience. The vehicle is stylistically distinctive inside and out. Buyers appreciate the fuel economy and the opportunity to drive a high profile vehicle at a relatively modest price(Klein, 2007). The Prius closes the feature gap by being impossible to compare and by offering a unique driving experience that appeals to a small market niche[25].

A policy approach to closing the feature gap is to simply set rules on the technologies that are permitted in new vehicles. For example, if there were a regulation that said that all gasoline or diesel vehicles had to be hybrids there would be no feature gap between hybrids and CFVs (hybrids would become the de facto CFV). Such a rule would in effect be

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[25] Hybridcars.com, a hybrid and electric vehicle site, reports that hybrids accounted for just under 4% of vehicle sales in March, 2012 (HybridCars.com, 2012).

regulating certain engine configurations out of existence. It would close the feature gap by eliminating options.

### Elasticity Testing

In the short run we expect consumers to be inelastic (price insensitive) in their fuel consumption, but in the long run they will find ways to adjust their consumption by buying new cars or making lifestyle choices that will reduce their need for private vehicles (Hughes, Knittel, & Sperling, 2007). Fuel producers who have made major infrastructure investments must balance their profit maximizing behavior against their ability to use, and thus pay for, their production infrastructure. Ideally they will seek price points such that the maximum consumer willingness-to-pay is tapped without provoking excessive long-term demand destruction via the mechanism of long-run elasticity.

Fuel Producer players in Autopia have one thing in common: they always explore their pricing power. They understand that their consumers are a captive market. Thus it is only natural that they would want to explore the boundaries of that captivity in order to maximize profit, as it is the most obvious pathway in the game.

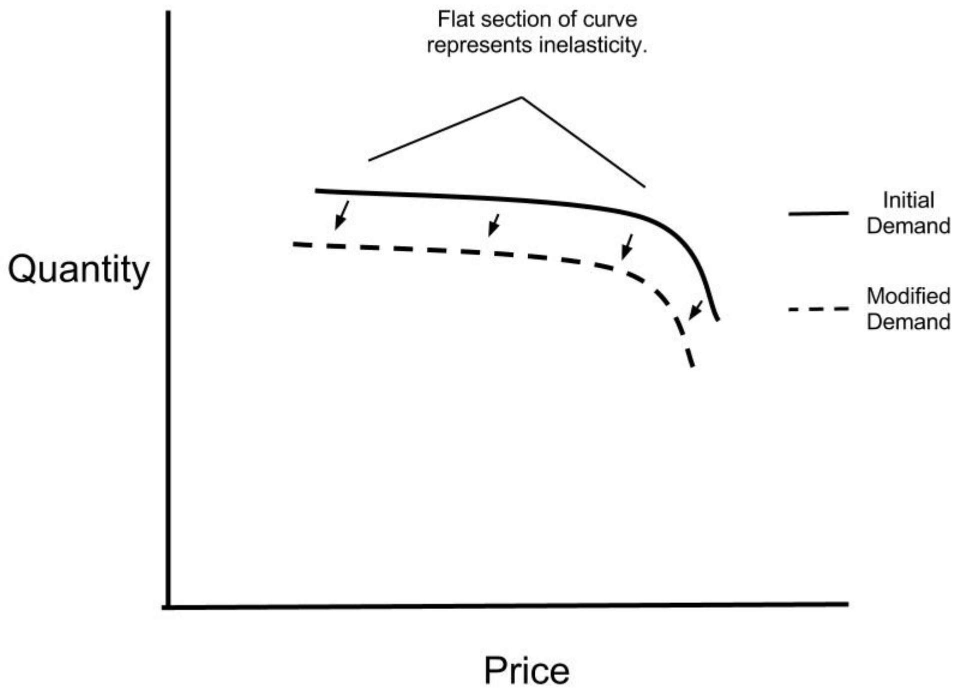



**Figure 44: Example Demand Curve Shift**

The dynamic is shown in Figure 44. The solid curve represents an initial state of demand. The flat portion of the curve shows the inelastic range of prices. In this section of the curve consumers do not have substantial reactions to price changes, so a maximizing producer will price as far to the right side of the curve as he can in order to maximize revenue.

However, since the market is operating at that inflection point it is vulnerable to behavior of the consumer at the margin. This consumer, who is barely hanging on to their desired fuel consumption will eventually find ways to adapt to the high prices by reducing her VMT (a soft adaptation i.e. reversible) or perhaps by switching to a more fuel efficient car (hard adaptation).

This pressure at the margin will eventually cause the demand curve to shift downward into a *modified demand curve (*dashed line). In the modified curve[26] the optimal price point has shifted back to the left, reflecting that the market has gotten smaller, given that the most vulnerable consumers have found ways to reduce their consumption. If consumers haven't made too many hard adaptations the market can shift back to its original volume, given the prices are right. However, if consumers make hard adaptations, like buying more efficient cars and switching to alternative modes like bicycles and transit, that original volume will be difficult to attain again.

The mechanism by which the marginal consumer reduces demand volume enough to shift the demand curve begins at the refueling station. As the price of fuel reaches their conversion point into price sensitivity they reduce their fuel consumption. As more consumers decide to cut back their fuel usage, due to high price, it is eventually reflected in a smaller fuel order by the station to the refinery. If the market softness continues the refinery will eventually find itself with too much fuel in inventory and have to cut back production. This will lead to a smaller oil purchase by the refinery, which will weaken the oil market on the margin. If the trend continues to grow the oil market will have to adjust to it, either by lowering production, prices, or some combination of both. This is how gasoline prices can go "Up like a rocket, down like a feather," as the popular observation goes (Lag, 2009; Shand, 2012).

[26] The modified curve shown here is a simple example of what a downward shifted curve might look like.

I use the term *Elasticity Testing* to describe the overall dynamic of this market. Fuel producers seek to maximize their profits by discovering the point at which the consumer's inelastic behavior begins to fail. This would be a standard strategy for a seller in any inelastic market, however energy is probably the largest inelastic market, which is why I mention it–it is a system dynamic that should be considered within this market.

### Sidebar: Gasoline Refinery Shortages?

In Autopia games fuel producers routinely choose to under-produce gasoline, even though they are clearly told that the game model would best reward them for meeting actual demand. Was this failure to produce a cynical ploy by the FP players to raise fuel prices? Sometimes: they admitted it. However, the under-production can also be explained as a rational strategic response to a declining demand for gasoline. As time passes in Autopia, the improving efficiency (mpg) of the vehicle fleet causes a substantial reduction in fuel demand. Players can clearly see the pattern in game charts. Given that running a refinery has a fixed per turn cost, the players have an incentive to not run refineries that they predict will not be needed. This thinking is reinforced by the knowledge that reducing the supply will increase prices, whereas over-supplying will leave them with both extra fixed costs and lower fuel prices. Real-world refiners must contend with the same scenario: it is safer to under-produce than to over-produce.

## Future Work

The work presented here is the building, testing, and cursory findings from the Autopia system. I believe I have demonstrated a working system that can produce interesting results in regards to the dynamics of the long-range transition vehicle and fuel markets. What remains to be done is to actually run Autopia for an actual policy exploration.

Since player training and scenario design are non-trivial aspects of the game experience, the optimal game configuration would be a three - five-day session in which Autopia was part of a specific policy exploration in a format as described by Toth (Toth, 1986). The participants would begin discussing their research objectives months before the meeting took place. Once the parties agreed upon a set of exploratory objectives and scenarios the Autopia code would be modified, prepared, and tested for the event. The games themselves would be used to provoke the exploration of the possible implications of specific policy implementations: they are a precursor to decisions about where a research agenda should go, a place to ask *what should we think about when we think about this?*

Game results from Autopia could be further analyzed with a model like MARKAL and vice versa. Autopia could be used, for example, to reduce the effects that the perfect foresight assumption imparts to MARKAL results. This could be done by creating Autopia scenarios from selected MARKAL runs, and watching what happens in the more open gaming environment.

Military war-games are developed not for specific predictions, but to explore the contingency and resilience factors of possible tactics and strategies. As early war-gaming advocate Helmuth von Moltke said, “No battle plan survives the first contact with the enemy.” The games are not intended to answer questions but rather to improve the quality and specificity of the questions that we attempt to answer. Indeed, the process of designing the game and scenarios is as important to the outcome as the actual results.

A more modest, but still interesting option, would be to continue the Autobahn games under the same methodology. A pool of trained players would play multiple games using various scenarios on a research topic of interest. The results could be analyzed for interesting patterns and trends as demonstrated in the Autobahn games sections.

## Concluding Remarks

From developing Autopia, watching numerous games, and analyzing their content I have developed a vision of what the future of the vehicle market might look like over the next 40 years. It is a general vision that is specific to the modeling assumptions made in Autopia.

The first trend is the power dynamic that fuel producers, and in this case I mean oil producers and not just refiners, have over consumers. As long as gasoline is not substitutable and only available from a limited number of suppliers, and consumers require it as a commodity vital to their daily activities, fuel producers and traders can use their position to test the willingness-to-pay of consumers on a regular basis; I call this elasticity testing. However, fuel producers will temper their profit taking in order to preserve an adequate long-term market, given their infrastructure commitments.

### MONEY MATTERS

In the final analysis, economics drives vehicle purchase decisions. People do not buy what they cannot afford. High fuel prices can increase the attractiveness of alternative fuel vehicles, but they also increase the attractiveness of efficient conventionally fueled vehicles, which will generally be less expensive than AFVs. In fact, if fuel prices get too high for average consumers, the market bifurcates into a low-end niche that consists of cheap gasoline cars and a high-end niche of electrified vehicles (HEV, PHEV, BEV). This occurs because the lower income consumers do not have the money to pay for the alternative fuel vehicles, despite the fact that they are substantially more efficient in mpg terms; while the higher income consumers can rationalize the costs of the electrification because it is a smaller percentage of the total vehicle cost and can be construed as a value-added feature (e.g. faster acceleration, mobile power) that offers them some protection against higher future fuel prices.

Given the current preference for private auto transport in most areas, it is probably safe to assume that the drivetrain platform doesn't matter all that much as long as it is safe, affordable, and convenient. Consumers who have learned how to deal with high and volatile transportation fuel prices will be able to adapt to new drivetrains, like hydrogen fuel cell vehicles, if that's what they need to do to keep on driving. What they won't do, according to Autopia game results, is buy alternative vehicles absent a clear financial incentive. The buyer of a $30,000 vehicle does not perceive the choices of a near-luxury sedan and an alternative drivetrain economy type vehicle within the same class; the alternative vehicle buyer and the near-luxury buyer are considering vehicles and options that compose different choice sets at the same price point. Nor is a buyer at the $15,000 price point likely to reach up far enough to buy the $30,000 economy vehicle with the advanced drivetrain. If we assume that people prefer private vehicles, have specific preferences about them, and are price sensitive (i.e. *Feature Gap)*, it is hard to see how alternative drivetrain vehicles make significant penetration given the current paradigm of moderately priced fuels and high premiums for the alternative drivetrains. Policy makers and automakers can seek to raise the social utility of AFVs to help them overcome the feature gap

The market as it stands will continue until (when, not if) it is subject to an exogenous shock. Some would say that Peak Oil is that shock. Given that there is only a finite amount of fossil fuel in the world Peak Oil is a given, but nobody knows exactly when it will start to make a difference. Like the end of the world, the inflection point for Peak Oil has been predicted many times over the last 40 years, but doesn't seem to have come true yet in a meaningful way.

An important emerging trend that was not addressed in Autopia but probably should be in any future analysis is that younger Americans are reducing their demand for vehicles and driving(B. Davis, Dutzik, & Baxandall, n.d.) . The implications of this trend have relevance within the long term transition context, however they are not clear – which makes them a good subject for introspection with a serious game.

In the end, money matters in transportation choices. Consumers will do what they have to do to maintain the lifestyles that their private vehicles afford, and if they cannot keep as many vehicles, they find adaptions that enable lower usage of private vehicles.

## CONCLUSION

The long-range future of the vehicle and fuel markets is an open question. Multiple historical, environmental, social, and technological factors will play a role in the outcome. The standard forecasting tools do not work under these conditions. As an alternative approach, I have built a simulation game through which the dynamic relationships in the vehicle and fuel market can be explored in a rigorous setting.

The work described here is only a beginning. Much of it is the construction of the models and metaphors upon which the game is constructed. A number of games were played, in various formats. The games demonstrate the data the system can generate. The general trends from the games are analyzed. The trends illuminate many of the challenges that we can expect to face as the transportation system adapts to an unknown future. I believe further pursuit of this methodology can yield important insights in how to best manage this uncertainty.

People often think of games as a kind of toy or leisure activity. However, games can be much more than that. A well-designed game can generate powerful insights into the fundamental dynamic relationships within complex problems that are unavailable from other investigatory modes. I hope this work has contributed to the growing sentiment that games are more than just toys and diversions, that they can also be tools that allow people to engage difficult problems with the full breadth of human intelligences and capabilities (Abt, 1971; Mayer, I. and Veeneman, W. (eds.), 2002; McGonigal, 2011).

# CHAPTER 6: APPENDICES

## APPENDIX A: GAME REPORTS

### GAME 1: APRIL 21, 2011

On April 21, 2011 an Autopia game was played at UC Davis in the Autopia course. There were six players. The game was played with three vehicle producers: mega, Asian and euro, and three consumers: enthusiast, young and family. The consumers groups were high volume purchasers, but did not have the income necessary to purchase higher-end vehicles. The game had no policy scenario. There was no effort to push any outcome on players such as a carbon tax. The energy scenario featured a steadily increasing set of fuel prices.

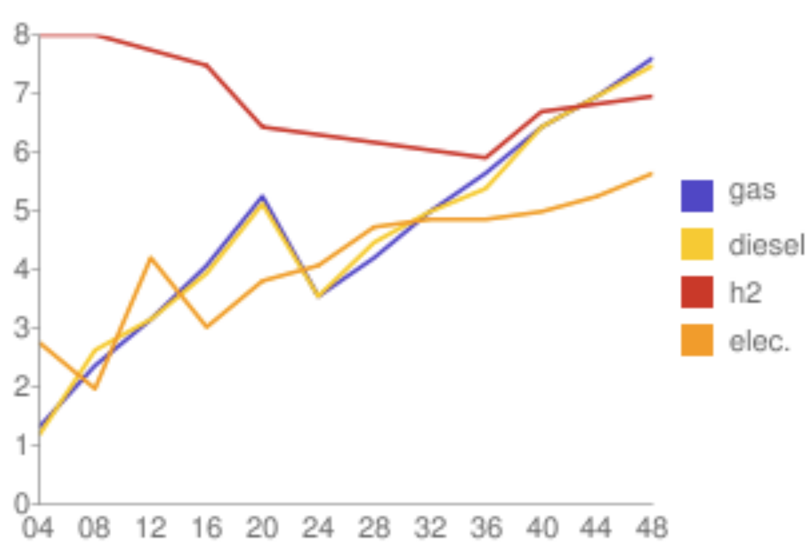


**Figure 44: Fuel Price Plot ($ vs year)**

The fuel scenario has gasoline and diesel closely tied to each other and increasing steadily in price except for the 2024 turn in which prices fell sharply. By 2048 gasoline and diesel are close to $8/gallon. They are actually more than hydrogen but hydrogen is not being produced for the vehicle market so it is irrelevant.

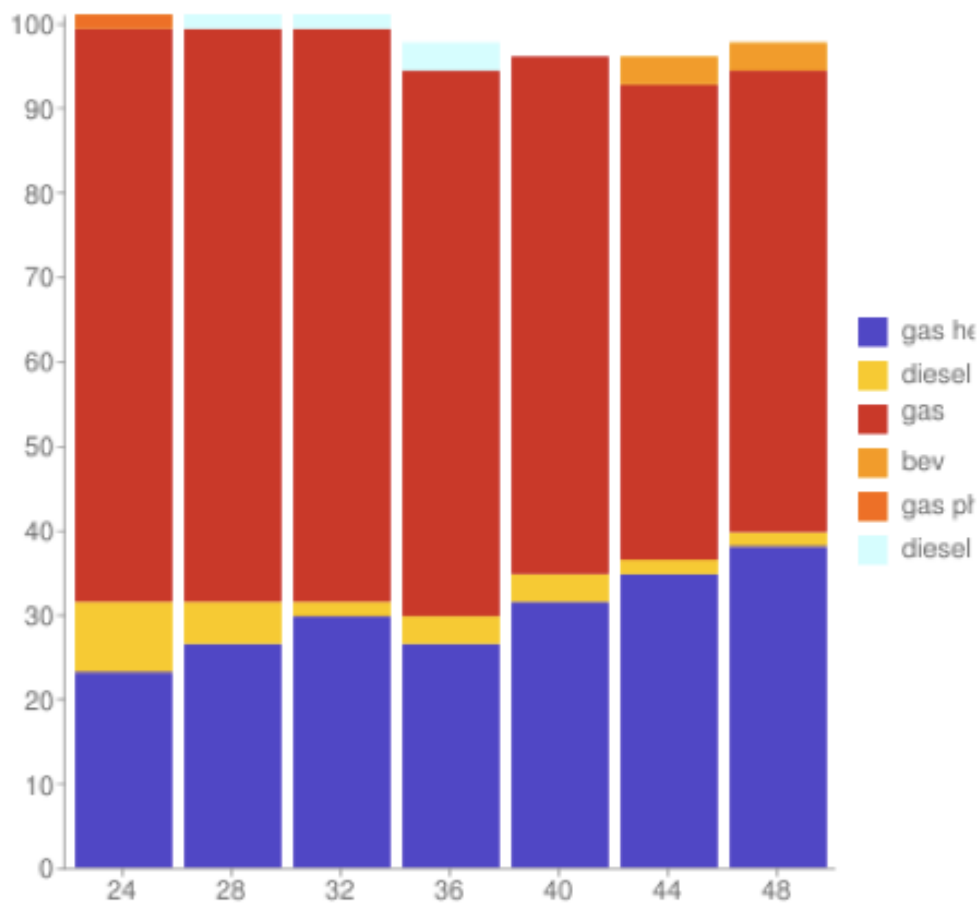



**Figure 45:Drivetrain Breakdown (2024-2048)**

This game had no policy interference at all. The result was a market that turned towards inexpensive gasoline cars sold at low margins. By the end of the game gasoline vehicles accounted for about 60% of the vehicles on the road, gasoline HEV accounted for about 35% and diesel and BEV account for the remainder. See Figure 45.

This game instance can be characterized as conservative. Consumers were squeezed by fuel prices. They were fighting to make their vehicle quotas because they were spending too much on fuel. However, they were not able to look further ahead and buy more efficient vehicles to control fuel costs in the future, because doing so would have cut into their fleet size. It was a vicious cycle to some extent -– the consumers could never get ahead of their fuel costs enough to buy vehicles that would cut down their exposure to fuel prices. This game lacked the executive and green players who do have enough money to buy their vehicles using a long term strategy.

The vehicle producers had to build inexpensive cars to meet the demand. Asian and euro both produced vehicles with 0/0 style/performance numbers. These would be the equivalent of a stripped down micro-car. Consumers were not willing to pay a premium for diesel vehicles that offered substantially better mileage. Overall fuel consumption did fall however. The final vehicle selection set had a mpg values for gasoline vehicles (including hev) from 40-77 mpg. Consumers were eventually willing to pay a premium for HEV.

No Vehicle Producer was able to take a distinct lead in the game or make much of a profit or a loss. The three vehicle producers held their own in the market. Each held 30-35% of the market by the end of the game.

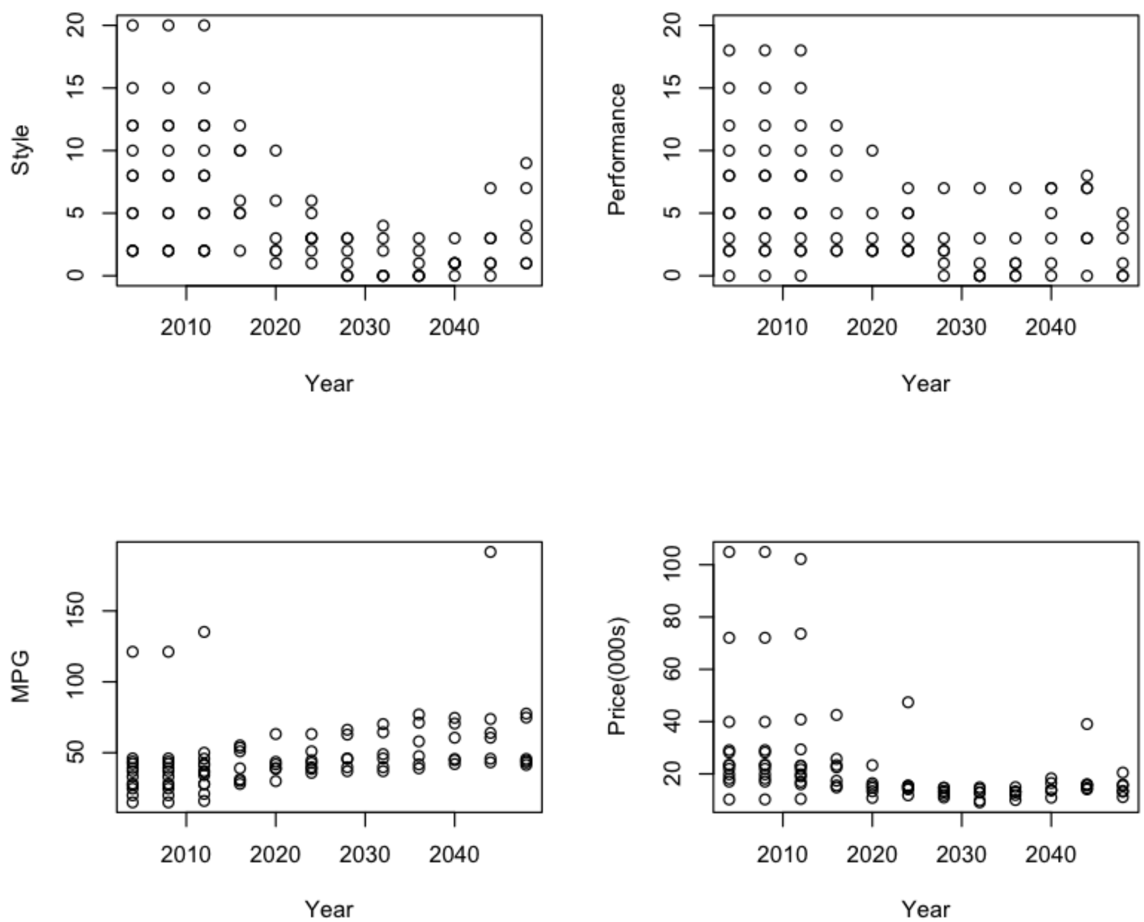
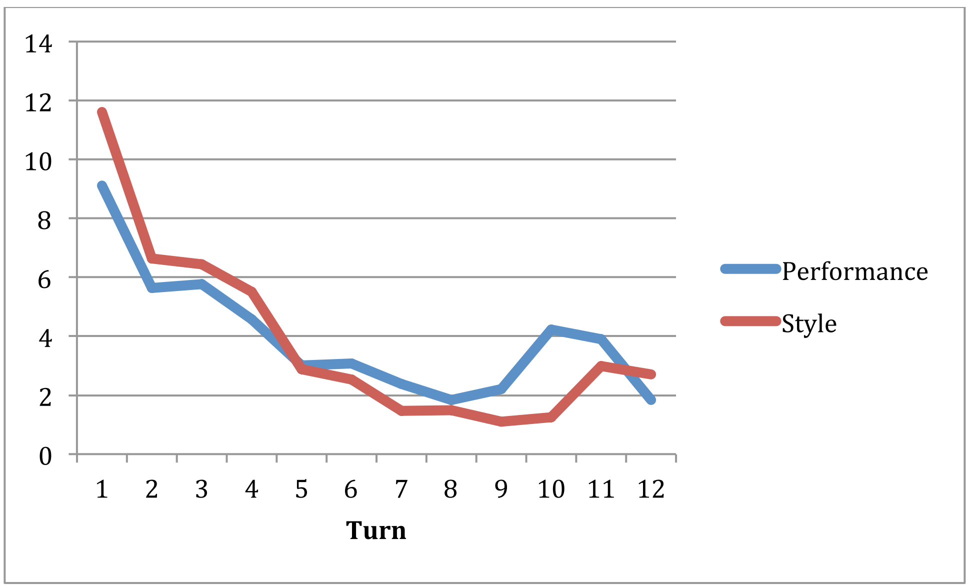
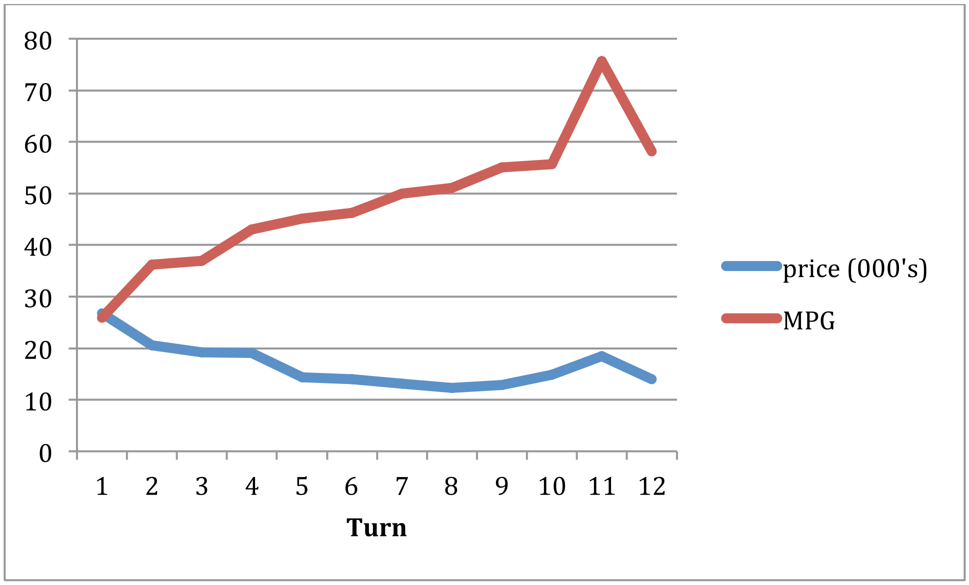


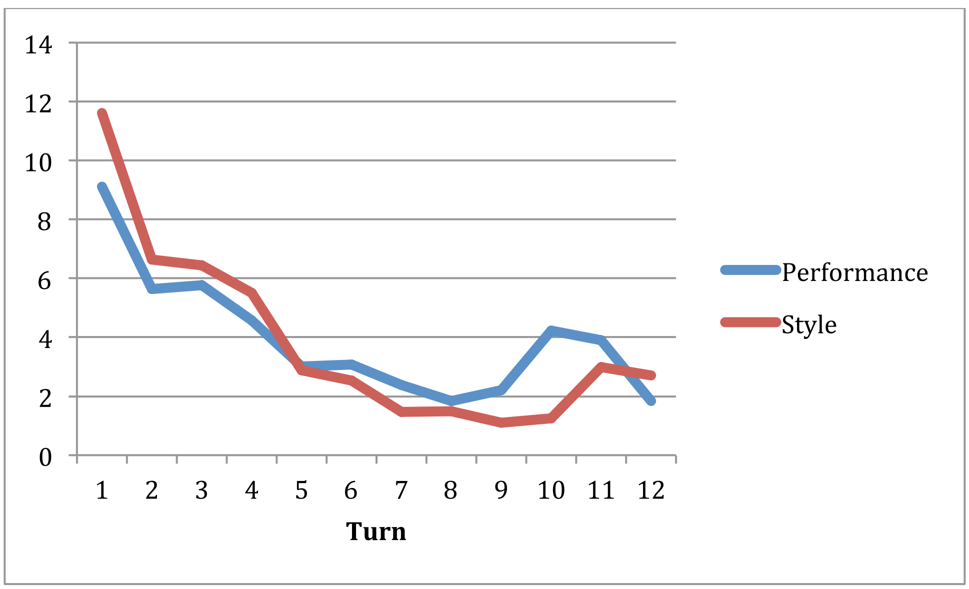

**Figure 46: Quantitative Game Summary Statistics**

Quantitative data for the game can be seen in Figure 46. The plots refer to the vehicles available for sale during the game over time (each dot is a vehicle that was produced –- some dots are overlaps). There is a negative trend for style and performance over time.

This is a reflection on consumers feeling squeezed by high fuel prices. Style starts to move upwards at the end of the game probably because it is a way for the manufacturers to distinguish their products without using the more fuel costly performance attribute. MPG sees a steady if moderate increase. Over the course of the game the worst car, mpg wise, in 2040 is about as fuel efficient as the best car available in 2008 (there was one BEV model sold in 2044, an outlier). The gasoline hybrid vehicles after 2040 manage MPGs in the low-mid 70's, about a 75% improvement over the best of 2012. Finally, the price chart shows a market converging towards low priced vehicles.




80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12
Turn
price (000's)
MPG


14
12
10
8
6
4
2
0
1 2 3 4 5 6 7 8 9 10 11 12
Turn
Performance
Style

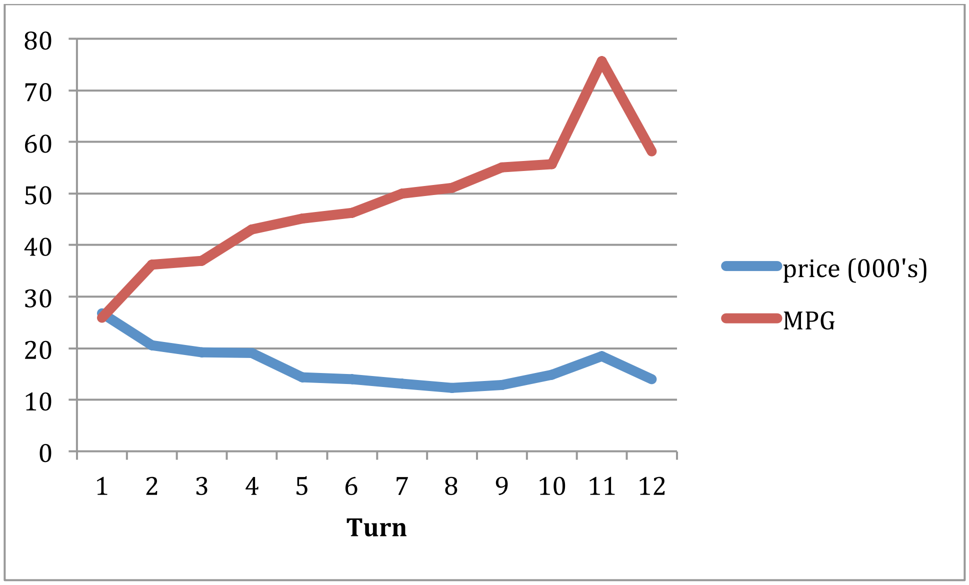



**Figure 47: Consumer Choice Aggregates**

In Figure 47 the average consumer vehicle choice statistics are shown. The game is initialization until turn 4. After that we see a slight preference for style over performance attached to an overall negative trend. The enthusiast consumer has a strong preference for performance which explains this outcome. For the price and mpg trends it can be seen that MPG steadily improves as price falls. There is a mpg bump in turn 11 which is probably explained by the sale of some BEVs, but the players return to their old trend line in the following turn.

GAME CONCLUSIONS

Absent policy and given increasing fuel prices that bite into consumer disposable income the system travels a conservative path, sticking with gasoline fuel and slowly transitioning to hybrids as they are able. Lacking a high margin consumer in this game, the vehicle producers were constrained to producing inexpensive vehicles. They could not use the high margin market segments to introduce new technologies and help them push them towards the mass market.

This suggests the notion of a prosperity feedback loop. Poor consumers who simply want to own cars in order to meet their travel needs cannot afford new and more efficient technologies, even if they might save them money over the course of the vehicle's life. When high energy prices make consumers poorer, they are forced to operate on a short term financial basis. Conversely, wealthier consumers posses the means to consider the long term energy outlook. A $5000 premium for hybridization is much easier to justify on a $30,000 vehicle than a $10,000 vehicle. Paradoxically, the higher that energy prices go the more difficulty that consumers have in purchasing new technology vehicles, which makes them even more vulnerable to increasing energy prices

# Appendix B: Player Comments

*Following the Autobahn games (Autobahn 1-3) I asked the players to write about their experience. I instructed them to write quicky and not to concern themselves with punctuation and grammar. I wanted them to emphasize volume of information rather than good form.*

## Autobahn Game 1 Strategies

So here are my observations from the first game play:

In the beginning I tried to work strictly with gasoline cars because that's what I can relate to personally. That seemed to work for me as far as car sales are concerned. After a while I tried hybrid cars along with gasoline cars and I began noticing trends among buyers along with fuel prices. So whenever I made an R and D investment I considered how to make my gasoline cars more attractive for the most part. Later on I started considering how to make my cars more efficient and also how to boost the appeal of my hybrid models. I mostly focused on fuel prices and appeal of gas and hybrid cars (along with car efficiency) throughout my game play. Toward the end of the game I started trying to figure out the buying habits of different categories of consumers. I noticed that my cars tended to attract enthusiasts and young people, but later I tapped into the green market and garnered attention from some executive bots. So far I think I'm mostly successful with car enthusiasts and green people, but I haven't figured out the right combination of qualities to attract these or other groups of consumers. I think that executives tend to buy based on the right combination of style, performance and price. I think they tend to buy pricier cars in the 30 to 40 thousand range. And they prefer cars with higher mpg like 40+. I think they prefer slightly higher style to performance since cars may be more a matter of status than utility. But they still want cars that perform at the same level or better than the average car. I'm still hypothesizing the buying habits of the other groups, but my current habits seem to work for green people and enthusiasts.

Kendra

Euro play

Overall, my initial investments were based on what had been selling in the market previously. I looked at consumer preferences and price ranges, and played around with performance and style until I could build a car that was nearish the price range or in a market that seemed to have sold previously.

I had, at one point, played with the Tesla Roadster selling at 200,000 -- which was flop. I then decided to invest in BEV technology with the end goal of perhaps selling a BEV vehicle for around 30,000 – but unfortunately, the game ended before I got there (37000 at end of game with no features or performance).

After an initial investment of R&D in gasoline and diesel technology, mostof my R&D went to improve HEV and BEV vehicles (predominately investedin BEV). I was capturing markets that other vehicle producers weren't and because of my investment in gas at the early stage, I managed to produce a higher styled gas vehicle at cheaper than the rest of the market. This, and my reliable diesel (the only diesel vehicle in the market) gave me good market share and reasonable revenues to invest in BEV. Toward the end, managed to release a very affordable diesel PHEV vehicle, that sold reasonably well on the market. I still made a loss, as I didn't drop the price significantly enough.

The best route to take seems to be to capture a niche share of the market early on with a vehicle that is profitable, and rely on R&D points to invest in another area extensively so that later in the game you can undercut the competitors and release a HEV or PHEV vehicle at substantially below cost.

The strategy i used was advancing my gasoline r&d initially, and trying to sell as much cheap gas cars as i could. On all the cars i lowered my style and performance of the car drastically in order to get a lower prices and make my cars more marketable. I experimented initially with selling higher-end H2 cars, but sold none and did very poorly. Overtime i shifted to hev in r&d and incorporated gas in as well. I marketed a cheaper hev vehicle at around 19,000 which saved me when i tried to market h2 cars that sold poorly. All my attempts to sell H2 ended poorly so i canceled selling H2. Overtime i increased the performance and style of my hybrid to market a more expensive and higher-end model as opposed to my lower-end hybrid. My final sell amounted to having all my cars sold, but i undermarketed my cars because i initially thought they were not selling when in fact the computer was just slow showing the effects. I would again employ the same strategy.

Kevin

I decided to invest nearly 100% in gasoline and gasoline hybrid. I did not think consumers were interested in diesels or diesel hybrids, and their reaction to my PHEV was tepid. I kept the "Young gas" car since it always sold well. It had average specs but great mileage, which is what consumers wanted. However, as the name suggested, my buyers were usually younger people, enthusiasts, and families. That's good, but I wanted to branch out. I tried to make a car for the executives with worse mileage, higher performance, and higher style. It sold decently, but not nearly as well as young gas. In conclusion, the only car that worked was young gas.

-Chandru - "Asian"

## Appendix C: Testing Autopia

### Introduction

Autopia needs to be ready for play at the January 17,2011 STEPS meeting. In order to be prepared for that it must be adequately tested. There are two types of testing that must be done.

Interface testing – Make sure that all game interfaces are bug free and makes sense to users.

Load testing – Make sure that the system responds properly under a normal game usage load.

### Testing Interfaces

Interface testing can be done with individuals working remotely. Automated QA testing uses scripted QA tools to ensure that the interfaces pass certain basic feature tests when changes are made to the code base. The Autopia code base is now over 10,000 lines of code. Small changes in one part of the system can affect seemingly unconnected parts. I could do the QA test design myself but it is better to have someone else who doesn't know the underlying code does manage this: an outside perspective is more effective.

Interface testing is also to be handled with small group partial game testing. In this type of testing small groups of players take on a single sub-game, such as Vehicle Producers, and play through the game. The purpose of this testing is to understand the flow of play. I want to answer questions like: do the interfaces make sense? Are the game scenario variables set reasonably? And so on.

Interface testing can be handled onsite or online. Onsite testing is preferable because it captures instantaneous player reactions on both the game interface side and the live game interaction side. This requires a testing facility. Piece testing can be done with a minimum of 4 computers. Full tests will require 15 computers and a dedicated room. Online testing can be done for convenience and lighter interface testing.

The computers at the testing facility must have the Firefox browser loaded. Autopia appears to run on browsers other than Firefox, including Chrome and Safari. However, it is not guaranteed to run on them and I will not fix Autopia to make those browsers work in the event browser specific bugs are found

### Load Testing

Load testing means putting the system under it maximum expected stress to make sure that it responds properly. This will require an actual playing of the game with a full contingent of players. The server and system as set should be able to handle a full contingent of 14 players. If it doesn't that means there is a problem with the server tunings or insufficient RAM on the server. These are both solvable problems. Autopia shouldn't create more than 15-20 hits per second on the server, and the database is small. It should be manageable, but we have to make sure.

### Testers

Preferably there will be an automated QA tester and then a number of play testers. The play testers will work online and onsite at designated times play testing the system.

Paid testers will be paid in American Express Gift Cheques to avoid having to hire multiple short term staffers. The cheques are the functional equivalent of cash. They can be deposited directly into a banking account at full face value and are accepted at most retail locations.

### TESTS

There are multiple sets of tests that need to be run.

#### PIECE TESTING

Piece tests take parts of the game in isolation. Each role is a subgame that can be played without the players.

##### VEHICLE PRODUCER

Test vehicle producer vehicle build process, R and D awards, R and D investment and various game feedback mechanisms, both specific to the vehicle producer and global.

##### CONSUMER

Test vehicle purchase mechanisms and play feedback systems.

##### FUEL PRODUCER

Test refinery building and refinery management. Global game feedback too.

Vehicle Producer / Consumer

Test the two sub-games together.

Vehicle Producer /Consumer / Fuel Producer

Test the three sub-games together without attempting load testing. These games could be run online for example, or with a small group of testers playing multiple roles.

### Load Testing

Load testing simulates the load of an actual game. The methodology is simply to play an actual game and watch how the system responds. If the system is overloaded various problems will appear. Data will not update, graphs will fail and pages will time out or fail with error messages.

### Testing Schedule

Testing will make use of volunteer and paid testers, as needed. The target date for testing completion if 1/14/2011, in preparation for the play at the STEPS conference on 1/17/2011 and for TRB demonstrations the on 1/24-1/27/2011.

### Online Testing

Online testing can occur at any time for the piece tests using paid and volunteer testing.

### Live Testing

Live testing must work around holiday and exam schedules. Dates are approximate depending on room and tester availability.

| Date | Test |
|---|---|
| Mon. 12/13/2010 | 2 hr live testing – 4 testers |
| Wed. 12/15/2010 | 2 hr live testing – 4 testers |
| Friday 12/17/2010 | 2 hr live testing – 4 testers |
| 12/20/2010 – 1/4/2011 | Online testing – multiple tests |
| Tue. 1/4/2011 | Full Test 1 – 15 testers minimum. Feature freeze. Only bug fixes after this test. |
| Tue. 1/11/2011 | Full Test 2 – 15 testers minimum |
| Thu. 1/13/2011 | Final Testing – testers as necessary |

## Appendix D: Player Instruction Sheet

Autopia

***Player Guide***

# Consumer Info

The **consumer** represents a certain demographic of vehicle consumers. Once cars are available for marketing, the consumer is to purchase the **highest number of cars attractive to his demographic** during the allotted buying time. During purchase, the consumer may contact the vehicle producer to discuss which vehicles are more appealing for the next turn.

Buy cars in *Global Screens* > *Buy Vehicles*.

# Vehicle Producer Info

The **vehicle producer** builds and provides as many vehicles as possible for the consumers to sell on the next game turn. The objective is to **sell as many as possible**. Vehicle producers have **R & D Investment points** in which they can upgrade their vehicles with better capabilities.

Invest R & D points in *Private Screens* > *R & D Investment*.

Build cars in *Private Screens* > *Create Vehicles*.

Choose the number of cars to produce, its style, performance, and what type of fuel it runs on.

# Fuel Producer Info

The **fuel producer** manages fuel refineries based on self-predictions of fuel movement over time. The objective is to **earn as much profit as possible**. The fuel producers may build, buy, or sell their refineries based on current trends and refinery retirement, as well as activate or eliminate them.

Create refineries in *Private Screens* > *Build Refineries*. Note that the larger the refinery, the more time it will take to build the refinery.

Buy refineries in *Private Screens* > *Buy Refineries*.

Sell refineries in *Private Screens* > *Home* by checking the *Put For Sale* box, putting in a positive integer, and clicking *List*. The number in the box is represented in thousands.

Activate and deactivate the refineries in *Private Screens* > *Home* by selecting *On* or *Off* on your list of refineries at the bottom of the screen.

Eliminate refineries in *Private Screens* > *Home* by clicking *Eliminate* on your list of refineries at the bottom of the screen.

## APPENDIX E: TURN ADVANCE MODEL INFORMATION

The Autopia Game Turn Advance Model

Central to the Autopia game is the turn advance model set. Between each turn in an Autopia the game calculates things like fuel prices, vehicle technology advacnces, scores,

CAFÉ penalties, fleet attrition and others. This document explains how these models operate.

The steps up to the actual turn advance occur at the end of the turn. Steps after that occur at the beginning of the next turn.

Step 1: Record State

The first thing that the model does is record a duplicate of the database in its current state. This recording allows an easy way to recover from an error, or just to jump back and allow a sequence to be replayed again. The recording is called 'bottom<year>.sql where <year> is the turn year. The file is stored in the directory pointed to by settings.RECORD_DIR (defined in the file settings.py).

Step 2: Allocate Vehicle Producer R and D Points

The first actual model call is to the class method *allocate* of the RuleBase object. The Rule Base object handles the awards of RD points to vehicle producers based on how they performed in their sales. VPs are given freely allocatable points for revenue ( 1 per 100,000) . They are called free because the VP can assign the RD point in any way he wants.

The next group of the rules are the direct area allocations. These points are assigned to areas based on what the VP actually does. The VP receives, for example, RD points for selling various increments of vehicles. The amount depends on the vehicle. Points are given for selling a first BEV or H2 vehicle, and for each 100 units sold subsequently. These are awarded most aggressively under the assumption that much learning will occur in the early phases of these vehicle releases. Alternatively gasoline and diesel conventional vehicles have to sell 400 to get a single point of credit because the knowledge curve is more shallow for these vehicles.

The settings for these rules are in the file settings.py. They are listed under section '# divs' and notated by the letters DIV at the end of their variable name. The current set is as follows:

```
# divs - increment based awards

HEVDIV=400 # hev point given for every x sold

H2DIV=100 # "      "

GASDIV=400

DIESELDIV=400
```

```
BEVDIV=100

PHEVDIV=200.
```

Step 3: Buy Fuels

A critical step occurs here. The actual call is to a class method Fuel.buy_fuels(). This method encapsulates the pricing of fuels using a model built on game demand, game supply, an price sensitivity constant (settings.ELASTICITY) , and the seeded base price of the fuel. The full rationale and details of the fuel pricing model are covered in the document

The essence of the fuel pricing model is this: the fuel producers maximize their collective income if they produce the amount of fuel the market demands. If they under-supply it drives the price up and lets competitors enter the market. If they over-supply it drives the market price down, to the benefit of consumers. The object of the fuel producers is to guess correctly how much of various fuels will be bought and to supply it. They will need to trust each other to regulate themselves for the optimal price. Like Prisoner's Dilemma, there is an advantage to the player who chooses not to cooperate while the other fuel producers manage their sales more carefully in order to maximize price.

In the real-world OPEC serves as a bulwark on price because they are large enough to effect supply to the world on their own. In the game there is no OPEC-type player. This may lead to price instability in the game that is undesirable, i.e. serves no research purpose, but is instead an artifact of the play model.

After prices are set, fuel is purchased by the game admin player from the fuel producers. Fuel producers are awarded a share of the market for the fuel based on the amount of active refinery resources they declared for the turn. For example, a player declaring 150 units of hydrogen production in a turn when 300 total were declared would receive 50% of the gross revenue for that fuel for that turn. From the gross revenue the fuel producer would receive the actual sum equal to that of his margin (for the fuel) multiplied by his share of the gross revenue. So if his margin was 10% , total fuel revenue was $2 million, his gross revnue would be $1 million and his net revenue would be $100,000.

Deducted from his net revenues are the operating costs of the refineries. Large refineries offer the best margins and the best per unit operating costs, but small refineries are better for making sure that the FP produces as a close as possible to his market target. The FP optimizes his returns when market demand is as close as possible to market supply.

Diagram

f(Supply (from FP), Demand (from Con), Elasticity (settings), Base Price (settings) ) = Real Price

Admin buys full demand D from FP

FP profit = gross revenue * margin – operating costs

FP sells fuel at level D to Admin ( a single transaction)

Consumer buys his share of D from Admin

Admin sells fuel share to Consumer

The consumer buys his share of the global demand D at the game set price. The consumer cannot influence his VMT behavior directly within the game model. His demand profile is a function of the number of vehicles in his fleet, their mpg, and their age. If he wants to reduce his fuel consumption, his options are to buy fewer vehicles or to buy more efficient vehicles. He cannot decide he wants to drive less. There is no game mechanism for that.

The game could account for failure to make some average VMT by charging players foralt transportation, but it does not at this point and the basis for explaining that to players is not clear.

Step 4: Score Turn for Consumer

Consumer scoring is intended to keep consumers performing in their assigned roles. The scoring is built around the consumer profile functions. These profiles are shown as a pie chart on the consumer's home page. Consumers will do best in the game if they stick to buying vehicles that have the best rankings. Vehicle producers will discover that they need to offer a product in the top ranking group to be competitive for a consumer. The VP can almost always earn a top ranking by lowering his price enough.

At present , there is no mechanism for the VP to actually know how his vehicles are ranked by the players other than asking them verbally. It wouldn't be that hard, however, to record the rankings of the vehicles when the consumers view them so that VPs could see the current standings of their product lines . This would be computationally inexpensive. Since grading and ranking vehicles is a complex task that is run in real time (the rankings are live), they should be used with conservation in mind.

Step 5: Vehicle Distress Sale

A vehicle producer's unsold vehicles are disposed of in this phase.  The current mechanism simply pays 75% of the producers cost for each vehicle remaining unsold. The abstraction assumption is that these vehicles are sold off in other markets.

A superior model would have a curve, in it that caused the distress sale discount to correlate with the number of vehicles remaining unsold. One such model might be to set the distress discount as 1% times the number of unsold vehicles, with a maximum of 75% . That would penalize small failures with small penalties and large failure with large penalties.

Step 6: CAFE Penalty

This phase checks to see if the vehicle producers have met their CAFE standard for the turn. A penalty is assessed to those who do not. In reality CAFE has a mechanism for credit banking good years against non-compliance years. Autopia does not have that mechanism.

Step 7: Vehicle Producer Score Turn

A performance rating algorithm is run for the VP. Since the VP has a clear performance feedback mechanism this may be dropped from the game. A complicated scoring mechanism may cause more problems for players than it solves.

Step 8: Advance Turn Counter

The turn counter is advanced to the next turn. Subsequent actions occur at the beginning of the new turn.

Step 9: Fleet Attrition

Since the turn has advanced all consumer vehicles are 1 turn ( 4 years) older. As vehicles age, they leave the fleet via attrition. These attrition model comes from the Transportation Energy Data Book (S. Davis, 2008).. The attrition data are modeled in settings.py in the variable VEHICLE_SURVIVAL.

VEHICLE_SURVIVAL =[1, 0.93, 0.75, 0.54, 0.35, 0.20, 0.10, 0]

The attrtion function calculates the turn age of the vehicle and adjusts the remaining count for a vehicle type to match the appropriate age in settings.VEHICLE_SURVIVAL.

Step 10: Advance Vehicle Models

VP's register RD points by accumulation of RD Awards. Some of these are free RD points that the vehicle producer chooses and some of these are experience based and assigned directly, for example a gasoline RD point is assigned for selling 400 gasoline vehicles.

The RD areas are translated into direct drivetrain proficiencies using the '<drivetrain name>_level ' functions in the models.py file under the *plotkin* directory. For example, the vps maturity for diesels is expressed by this function:

```
def diesel_level(rd):
```

```
        """Diesel level is 1/3 road load + 2/3 diesel."""

        return round(.334*rd['road_load']+ .666*(rd['diesel']), 0)
```

This function takes the diesel maturity level to be a combination of a third of the vp's road load knowledge with two thirds his diesel knowledge.

The particular drivetrain maturity levels are translated into the ANL Plotkin models in plotkin/models.py file (same as RD point levels) in the functions that are named directly after the drivetrains. Here is the Diesel PHEV 10 function:

```
def diesel_phev10(input):

    out = {}

    out['mpg'] = f2D(33.481*(input**0.280))

    out['cost'] = int(0.0467*input**2-24.2*input+19800)

    return out
```

The *input* value set to the function is generated by the corresponding <drivetrain>_level function. It yields the a dictionary object consisting of the an 'mpg' entry and a 'cost' entry. These values are entered into the Vehicle Model table on the basis of the unique key of vp + turn.

The Vehicle Model table is referenced by the vehicle build process. A Vehicle Model entry corresponds to a vehicle with style and performance both set at 10. The vehicle building process modifies the Vehicle Model base objects.

Step 11: Consumer Allowance

Each consumer is paid his allowance for the turn at this time. The allowance covers his fuel and vehicle purchases. The consumer allowance is based on the product of his base_car_cost ( an object attribute) and the number of vehicles he wants in his fleet. A fuel allowance is added to the allowance. The fuel allowance is calculated by multiplying the vehicle allowance by settings.FUEL_ALLOWANCE_PERCENT (settings.py).

Step 12: Record Turn

This is the same as Step 1 except that the name of the recorded file will be *top<year>.sql.*

## APPENDIX F: FUEL MARKET HEURISTICS

Fuel markets

Consider a heuristic approach to profit maximization for the fuel producer. The fuel producer has a set of refinery assets for fuel production. The operation, maintenance, and financing of these refineries represent a substantial fixed cost, call it *F.* The fuel producer is responsible for *F* whether or not he produces fuel at all of the refineries or not. The fuel producer has a maximum production capacity Q' and variable feedstock unit cost, *V*. Ideally for the FP, he would sell an optimal quantity of fuel, *Q** at a corresponding price *P** (assume at a given moment there is one *(P*,Q*)* optimal combination). This is the greatest profit he can achieve at any given moment.

$$\text{Profit} = Q^*(P^*-V) - F.$$

To simplify this analysis for the moment let us ignore the feedstock cost *V* by setting *V=0.*

We can say think of *P** as the optimal profit given some feedstock cost V. Then,

$$\text{Profit} = Q^*P^* - F.$$

Simplifying further, we can say that the FP seeks a minimal operating context at which the actual quantity sold , *Q,* at the actual sales price *P* is greater than *F:*

$$QP > F.$$

Specifically, the FP wants to sell at quantity *Q* such that :

$$Q > \frac{F}{P} \quad (\text{unit: } gge) \ ,$$

and at price $P$ such that:

$$P > F / Q \quad \text{(unit: \$)}.$$

In order to be profitable, the FP wants to be able to set the price P such that:

$$h(P) > F/P \text{ and } P > F/Q,$$

where $h(P)$ is the demand curve for the fuel producer, as shown in (Lag, 2009; Shand, 2012).

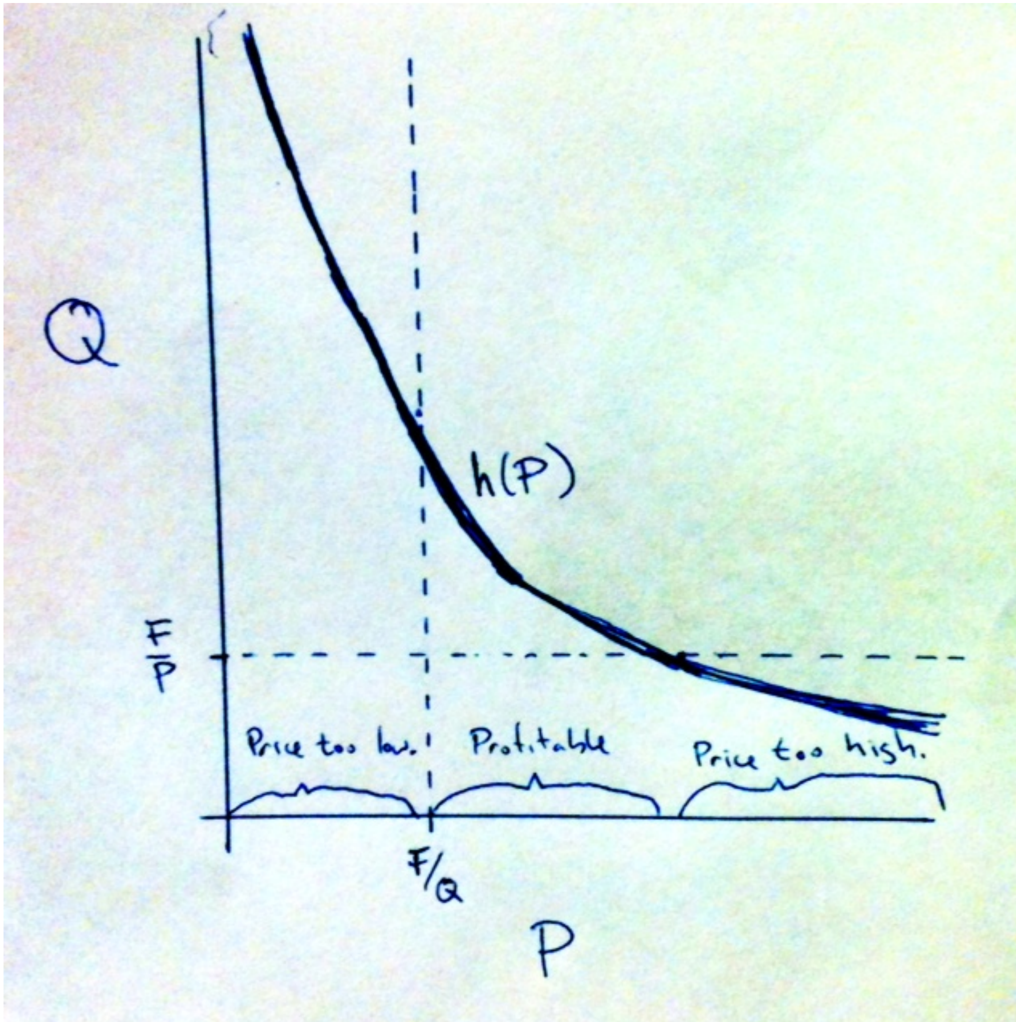



**Figure 48: Fuel Producer Demand Curve – *h(P)***

Working from this formulation leads to fact that the fuel producer's fixed costs F, limit his price range and production range. He is limited to a center range of the demand curve in which he seeks to find the optimizing price *P** for the demand curve *h(P)*. The greater the burden of his fixed costs *F* the more constrained he is in his pricing options; increasing *F* shrinks the profitable section of the curve. The value *F* should correlate positively with *Q**.

Given that the fuel producer is stuck with an enduring *F value,* he should be interested in keeping his sales quantity in a range that is comfortable given F. Recall that he is profitable only when $P > F/Q$; when $Q$ is decreasing $P$ must increase alinearly ( as $Q$ is the denominator).

From the strategic perspective, the fuel producer should seek a $(P^*,Q^*)$ pair such that: 1) $P^*$ is as high as possible and 2) Market demand is conserved. Indeed the alinearity of the pricing constraint $P > F/Q$ works in his favor whenever he can increase $Q$ to the maximum; utilizing his entire infrastructure gives him the greatest possible flexibility in setting prices. However, setting prices is not a static problem, as fuel consumers are operating in a complex dynamic environment.

The standard assumption about fuel buyers is that they are short-term inelastic, or price insensitive , on fuel purchases. They are committed to their businesses and transportation needs in the short run and cannot alter them radically in response to increases in fuel prices, within a reasonable range. The inelasticity of the market means it can be squeezed; a brief price hike can be supported that consumers will have no choice but to accept, given that they do not have the ability to respond to it (given the conservative assumption that the consumer fuel market operates as an oligopoly). The FP thus has the ability to exploit the dependence of the consumer on his product, just as any other monopoly or oligopoly can.

However, the fuel producer is limited in his ability to exploit the consumer's fuel dependence because the fuel producer is bound to his infrastructure. In the shortest run the consumer cannot adapt to expensive fuel with much potency. If high prices persist for long enough to cause the consumer discomfort, he can adapt with strategies that reduce fuel usage (e.g. eco-driving or hyper-miling) and reduce VMT (e.g. trip chaining , alternate modes). These are *soft adaptations;* they are reversible. When prices return to comfortable levels he may well discontinue his adaptations and return to his old habits. However, when prices get too high and remain there for too long, the consumer will begin to consider *hard adaptations.* Hard adaptations are infrastructure changes: more efficient cars, moving to a home that requires less driving, and reducing vehicle ownership are hard adaptations. When the fuel price goes back down, if it does, those who have made hard adaptations will not return to their prior consumption levels. *Given a substantial and persisting value of F, and no new markets to absorb the fuel production, leads to the inescapable conclusion that increased vehicle fuel efficiency that is unexpected by fuel producers leads to higher fuel prices, as the fixed cost expenses of the refining infrastructure must be spread across fewer units of fuel.*

Real world fuel producers must pay attention to their production volume and capacity ratios in order to make sure they can produce competitively in the future(Meyer, 2012). Fuel producers do not want to maximize the immediate profit on their product by gouging their consumers. Their long-term financial contexts require a less greedy approach to pricing. However, this analysis leaves out an important side of the market: oil speculation(Leopold, 2012). Oil speculators don't have a long-term fixed infrastructure costs around fuel production and thus do not have the same structural resistance to short-term market gouging. This dynamic suggests that there is a tension in the fuel market between producers and speculators. However it gets more complicated because one of the ways for producers who are also actual oil producers to resist the market speculators is to become speculators themselves; oil producers have a distinct advantage against ordinary speculators in that they know more about the state of the oil market than anyone else and can even manipulate it by increasing or withholding production, if they are large enough.

In summary, elasticity testing is the net effect of the two types of market interests involved in the fuel market: producers and speculators. Producers are interested in the long term health of the market because they must cover the repayment of large, long range investments that they have put into production and refining infrastructure. Producers want to see a fuel market in which prices and demand volume work predictably within their financial and production constraints. Speculators, in contrast, have no long-term interest in the viability of the oil market; they seek maximum short-term profits.

The differing profit maximization strategies of the producers and speculators are independent forces within the fuel market; they may coincide or oppose each other, sometimes simultaneously. Fuel producers want to keep prices within the strategic demand ranges and will raise or lower prices to do so. If prices get too high, consumers will make hard adaptations that will permanently lower demand in the local market. Elasticity testing is the sum effect of the differing profit strategies between the producers and speculators, and the adaptation strategies of consumers; the test is that of the pivot point of the consumer through his adaptation strategies.


**Picture 2: Car of the Future (source: JP Group)**

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