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SUB-ORBITAL SPACE TOURISM: PREDICTIONS OF THE FUTURE MARKETPLACE USING AGENT-BASED MODELING

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ABSTRACT

There are currently multiple companies competing to develop new and innovative vehicles to support the potentially emerging sub-orbital space tourism industry in a post X-Prize environment. Each of the services these companies will provide can vary along with the potential pricing strategies employed by each company. This examination uses available market demand data, along with predictions about the most likely future vehicle suppliers, to examine the economic viability of companies in the sub-orbital space tourism market. An economic and market simulation is performed using the Nodal Economic Space Commerce (NESC) model. The NESC model is a dynamic, agent-based market simulation tool for the space marketplace. Each agent in the model is a representation of an entity within the space industry (consumers, producers, and the government) that provides or demands different products and services (in this case for the sub-orbital space tourism market). Each agent has certain behaviors and interacts with other agents, such actions possibly resulting in competition between firms and entrance of new competitors. The NESC model contains various future space markets and simulates the financial case of entities that undertake these projects. Within the NESC model, sub-orbital tourism companies seek to maximize profits while competing with one another for sales in a market composed of individual customers. The product offered by each sub-orbital tourism company can be differentiated in terms of the vehicle characteristics and customer experience. Companies autonomously decide the price they will charge for a flight aboard their vehicle and customers independently evaluate the products offered by the companies according to their individual price sensitivity, tastes, and preferences. Each customer may choose to purchase from among the company offerings or not at all. This examination includes an analysis of the sub-orbital space tourism market using an agent-based modeling approach.

NOMENCLATURE

ABM	Agent-based modeling
ISS	International Space Station
MASON	Multi-Agent Simulator of Neighborhoods… or Networks… or something
NESC	Nodal Economic Space Commerce
NPV	Net present value
RePast	REcursive Porous Agent Simulation Toolkit

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INTRODUCTION

The complex world consists of many interactions of multiple groups. These groups consist of simpler individual entities each with certain behaviors. As conditions around these entities change, so do their reactions based upon their behaviors. Multiple economic relationships exist between entities and need to be modeled.

Current conceptual level economic models do not fully capture the relevant interactions amongst all the players in a marketplace. From the diverse utility functions of each individual customer, to one's supply chain, to one's competitors, to the actions of the government; all these interactions are occurring simultaneously in the real marketplace. Higher fidelity models, optimization routines, and probabilistic life cycle simulation requires faster model execution times than currently available in spreadsheet-based formats. VBA coded functions and routines in Excel are typically much slower than similar coded routines in other programming languages such as C, C++, Java, or Python. Other relevant market modeling techniques that have been used extensively in other industries can be applied to current and future space markets.

There are different philosophies of modeling. Some are equation-based as in a typical spreadsheet model. Other techniques are simulation-based where there are actual steps for the simulation, perhaps in a certain arranged temporal order. Some of these simulation-based techniques include discrete-event simulation (DES) and what could be referred to as subset of DES known as agent-based modeling (ABM). ABM can provide a solution to the previously mentioned issues in spreadsheet-based modeling by allowing the simulation of dynamic and higher fidelity interactions. ABM is not just chosen to replace a conventional spreadsheet-based simulation because of the capability of higher fidelity that could easily be accomplished by use of programming language. ABM also allows the dynamic interaction of multiple entities within the marketplace.

Overview of Agent-Based Modeling (ABM)

ABM involves the interaction of heterogeneous agents with varied and dynamic behavior. Simulation can represent plants and animals in ecosystems, vehicles in traffic, people in crowds, or autonomous characters in animation and games. These models typically consist of an environment or framework in which the interactions occur with some number of individuals that are defined in terms of their behaviors. Each individual can be perceived as an autonomous decision-making entity referred to as an "agent." The characteristics of each agent can be tracked through time. Each agent decides for itself which actions to perform at what time, based on external conditions and private internal aspects (current beliefs, desires, etc). General benefits of ABM include:[1]

1) ABM captures emergent phenomena: Emergent phenomena result from the interactions of individual entities. The whole is more than the sum of its parts because of the interactions between the parts. For example, a traffic jam, which results from the behavior of and interactions between individual vehicle drivers, may be moving in the direction opposite that of the cars that cause it
2) ABM provides a natural description of a system: The model seems closer to reality. For example, it is more natural to describe how shoppers move in a supermarket than to come up with the equations that govern the dynamics of the density of shoppers
3) ABM is flexible. It provides a framework for tuning the complexity of the agents: behavior, degree of rationality, ability to learn and evolve, and rules of interactions. There is an ability to change levels of description and aggregation (e.g. aggregate agents, subgroups of agents, and single agents, with different levels of description coexisting in a given model)

As some have stated ABM involves "Global consequences of local interactions of members of a population."[2] Another explanation of ABM includes[3]:

> The new models combine lessons from biology with a bottom-up analysis. The aim is to create a society-in-miniature inside a computer…the new models create virtual worlds with hundreds of miniprograms. Each miniprogram represents a real-world economic entity--such as a factory, store, bank, or household. These get tossed together in a silicon realm where they evolve as they interact with other entities, creating a dynamic economic model.

Through ABM one can better understand both an overall environment and the individual participants in that environment.

As “complexity science” has emerged as a field of inquiry in other disciplines, more investigation has been performed into the interactions of swarms, networks, biological evolution, etc. Coupled with more rigorous analysis of decision-making from the field of economics, techniques such as Agent-Based Modeling (ABM) have emerged. ABM has been used in multiple areas for analysis of dynamic interactions including voting, computer networks, biological investigations, social behavior, product sales, financial analysis, and macroeconomic analysis.

Agent-Based Modeling (ABM) Computational Frameworks

Agent-based software (and Object-oriented programming) provides the framework for creating an agent-based model. A wide range of agent-based modeling software tools are available to assist in building such models. The advantage provided by agent-based toolkits is the availability of standardized libraries for building simulation environments, collecting data, and creating user interfaces.[4] After evaluation of several ABM software frameworks, SEI has been using the RePast library of JAVA routines perform its agent-based modeling since 2005.[5,6] RePast (Recursive Porous Agent Simulation Toolkit) was created at the University of Chicago and is now maintained by the non-profit RePast Organization for Architecture and Development (RePast.sourceforge.net/). A large support base is available for RePast including tutorials and a searchable mailing list. Its libraries are well suited for economic and social modeling, and it features additional libraries for regression, Monte Carlo simulation, Genetic Algorithms, Neural Networks, and basic Game Theory. Version 3.0 of RePast is available for three different model development languages: RePast for Java (RePast J), RePast for the Microsoft.Net framework (RePast.Net), and RePast for Python Scripting (RePast Py).[7,8]

GOALS OF THE NESC PROJECT

Theoretical Framework and Capabilities of the NESC Model

The Nodal Economic Space Commerce (NESC) model is a dynamic, agent-based market simulation tool for the space marketplace. Each agent in the model is a representation of an entity within the space industry (consumers, producers, and the government) that provides or demands different products and services (Earth-to-orbit launch, habitats, resources, etc). The simulation makes use of the RePast discrete event simulation engine to execute company, market, and customer actions (see Figure 3). Each agent has certain behaviors and interacts with other agents, such actions possibly resulting in competition between firms and entrance of new competitors. The NESC model can contain various future space markets and simulates the financial case of entities that undertake these projects. Each company autonomously decides its pricing strategy given its unique capacity, costs, and vehicle characteristics. NESC outputs the financial health of each company (cash flows, Net Present Value, market share, etc.) and can be used to explore various scenarios including supply vs. demand effects, customer preferences, and company strategies (including product differentiation and cost leadership).

CURRENT IMPLEMENTATION

The first market that was modeled in NESC was a sub-orbital space tourism market with companies competing for customers with the goal of maximizing revenues. In this version of NESC (Case A) for the sub-orbital space tourism market, each company autonomously decides its pricing strategy given its unique capacity, costs, and vehicle characteristics. NESC outputs the financial health of each company (cash flows, Net Present Value, market share, etc.) and can be used to explore various scenarios including supply vs. demand effects, customer preferences, and company strategies (including product differentiation and cost leadership).

Program Overview

NESC Case A demonstrates agent-based modeling as a tool for analysis of the commercial space environment by simulating a suborbital space tourism market. Suborbital tourism is a nascent industry pioneered by companies such as Virgin Galactic, RocketPlane Limited, and Blue Origin. The typical suborbital experience will feature a small craft which carries passengers vertically up out of the atmosphere to around 150km. Near the top of their climb passengers will experience several minutes of weightlessness and observe the black sky and curved horizon before descending back to the surface of the Earth.

In NESC Case A, suborbital tourism companies seek to maximize profits while competing with one another for sales in a market composed of individual customers. The product offered by each suborbital tourism company can be differentiated in terms of the suborbital vehicle characteristics and customer experience. Companies autonomously decide the price they will charge for a flight aboard their vehicle and customers independently evaluate the products offered by the companies according to their individual price sensitivity, tastes, and preferences. Each customer may choose to purchase from among the company offerings or not at all.

The RePast framework simplifies the output of any variable values, calculations, and results of the simulation. NESC Case A features four key outputs in the form of three line graphs and a text output window. The three line graphs track company price, market share, and cumulative discounted cash flow over time. The text output window displays statistics such as total number of customers in the market, total number of customers purchasing from any company, and the number of sales and flights sold by each company. Diagnostic outputs such as key calculations for the pricing process of companies are also sent to the text output window.

The simulation makes use of the RePast discrete event simulation engine to execute company, market, and customer actions as depicted in Figure 1. A single time step in the simulation represents one year. Thus, companies can only change their price once a year and purchases by customers represent yearly revenues for the companies. In the first year, companies set their price to achieve a desired return on investment. Once all the companies have set their price, information on the spaceflight experience offered by the company, including the price and vehicle characteristics, is passed to the market and the sales process begins.

The process by which companies make sales is the same in every time step. The market collects the price offerings and vehicle characteristics from each company and then iterates through all the customers. In this loop, the company offers are passed to each customer where they are evaluated on the basis of price and the degree to which they meet the needs of the customer. Each customer has an initial probability of purchasing a ticket for suborbital spaceflight that is increased or decreased depending on that customer's own preference for the product offered by each company. Whether or not the customer actually will buy from each company is determined by evaluating the purchase probability and the customer's willingness to pay the asked price. The customer agent returns its buying preferences to the market where supply is matched to demand by distributing customers to the companies according to the buying preferences of the customers. When company supply or customer demand is exhausted, the market returns the number of sales to each company. The companies calculate their financial health and use profit information to evaluate future pricing.

After the first year, the return from different price settings is estimated by the companies. The companies then charge the price which they believe will maximize their future cash flows. Companies evaluate pricing options by probing the market. In probing the market, the company receives an approximation of the sales it would make by changing its price. This estimate is accomplished in the same manner as that described for sales except that only a portion of the total customers are evaluated. This approach simulates limited intelligence about the market.

Firm Modeling

The simulation assumes the suborbital tourism market is underway with companies already operating. Each company has spent a certain amount of money on development and production of a fleet of suborbital vehicles with certain characteristics. Variables defining these costs and other characteristics of each company and its fleet of vehicles are defined by the user in text input files. Table 1 summarizes the types of variables that define companies in NESC Case A.

Cost and vehicle variables are fixed in NESC Case A. Companies have autonomous control over their own price with no knowledge of the price their competitors will charge. As previously discussed, the first year price offered by each company is the price it believes it must charge to achieve its desired return on investment in the specified number of years taking all costs into account. In subsequent years, the decision to raise, lower, or remain at the current price is determined by probing the market whereby the companies receive limited information about the returns for their pricing options.

Consumer Modeling

For NESC Case A to provide meaningful insight into the suborbital space tourism industry, the customer population must be accurately represented. Three factors are of concern: the size of the potential market as represented by the total number of customers in the model, the willingness of customers to purchase a suborbital flight experience, and the different preferences of each customer. The last two factors are closely related in that a customer's willingness to pay is likely greatly affected by their perception of the product offered in relation to their preferences. In the NESC model, whether a customer will purchase or not is determined by considering these two factors in combination.

Since suborbital space tourism is a new industry, little data is available from actual sales. Data on customer characteristics and behaviors must be determined from market surveys, inferred from other industries, or deduced using intelligent assumptions. One such source is the Space Tourism Market Study conducted by Futron Corporation in cooperation with Zogby International.[9] The market study involved telephone interviews of 450 people with household income of at least US $250,000 annually or net worth greater than US $1 million to examine the size, growth potential, and customer characteristics of the suborbital and orbital tourism markets.

From this data and shown in Figure 2, the percentage of potential customers willing to pay for a suborbital tourism experience levels out at higher price points. The additional potential customers gained by decreasing price from a $200,000 to $150,000 is small (a four percent increase) by comparison to the additional customers gained by decreasing price from $100,000 to $50,000 (a twelve percent increase). This suggests that the market for suborbital space tourism is relatively inelastic at high prices, but elastic at low prices.

The size of the customer population in NESC Case A is a user input. In setting this variable, the user might consider the number of high wealth individuals in the United States or the world. The population can be further limited by considering vacation spending habits, health qualifications, and general interest in suborbital spaceflight in a manner similar to that outlined in the Futron Space Tourism Market Study.

To achieve the increased fidelity that agent-based modeling affords, the characteristics of the individuals that make up the customer population are just as important as the size of that population. Price is certainly one important criteria considered by customers. When customers are created, their price sensitivity is randomly assigned from distributions of the Space Tourism Market Study survey responses. A customer will only purchase from a company if the customer is willing to pay the price charged.

In addition to a customer's willingness to pay, whether or not a customer purchases from a given company is determined by a purchase probability. An individual customer's purchase probability is increased or decreased due to that customer's preferences. For example, one customer may desire the freedom to remove his or her seatbelt at the peak of the flight to better experience weightlessness, whereas another customer may be indifferent to this aspect of the experience. The Space Tourism Market Study survey responses provide insight into the preferences of actual potential customers, and are used in conjunction with other data to define customer preferences in the model.

The potential population of sub-orbital space tourism consumers can be estimated using existing wealth data. After review of recent data, the number of customers in 2006 for the NESC sub-orbital model is estimated to be around 53,000. This is the number of customers who are interested in purchasing a sub-orbital experience and able to do so. It is derived by the following parameters:

1) Number of Millionaires in World
2) Take proportion who have requisite net worth (assume willing to spend 1.5% of net worth)
3) Apply percent interested in participating (somewhat, very, and definitely likely) from Futron survey
4) Reduce for fitness requirements (split between those over and under age of 65)

Market Clearing Process

The market agent completes the sales process matching supply to demand by distributing customers to the companies according to their buying preferences. The customers buying preferences are fulfilled in random order on a first-come first-served basis. In some cases a customer may prefer to buy from one company, but also be willing to purchase from a second company. In these cases, if the most preferred company does not have enough capacity, the customer purchases from the second company.

Program Operation

NESC Case A is archived in a Java JAR executable file for ease of portability and execution. Since RePast and NESC are programmed entirely in Java, NESC will run on nearly all computer platforms and operating systems including Windows PC, Macintosh, and Linux. When opened, the standard RePast toolbar appears. The user can change the values for model parameters such as number of years to run the simulation. The RePast toolbar contains buttons for initialization of the model (Initialize button), advancing a single time step (Step button), and continuously advancing time steps (Start button). When initialized, the display appears along with the output charts. In the display, the user can click on the boxes representing the market and each company to adjust the initial variable values. As the user advances time with the step or start buttons, outputs are displayed in the charts for each time step. Pause and stop buttons are available for the user to further control the simulation. Figure 3 is a screen capture of NESC Case A on a PC desktop showing the RePast toolbar, NESC display, and major output windows.

SAMPLE RESULTS

NESC Case A can be used to examine the impact of different company/product types and impact of business decisions for the sub-orbital space tourism market. Sample simulation results shown here used 50,000+ potential sub-orbital space flight consumers with 1) the financial means to pay, 2) physical condition to fly, and 3) the interest in sub-orbital flight have been categorized into over 20,000 "agent types" based on personal characteristics such as: pioneer vs. imitator, influence of perceived vehicle reliability, willingness to pay at various ticket prices, influence of cabin freedom (e.g. seat belt requirements), influence of perceived vehicle uniqueness/intrinsic appeal, etc. This simulation also included three user-defined number of sub-orbital passenger vehicle developer/operators. Each provider has a realistic business model including development and production costs, operating costs, vehicle capacity, perceived reliability, etc. Each 'CEO agent' can adjust its market price for a ticket from year to year in an effort to improve profitability.

The three sub-orbital space tourism companies can be described in the following manner:

1) One is high-end operator with a more reliable, better experience (larger windows, getting out one's seat), higher development, production, and operations cost
2) Low-end operator with a less reliable vehicle (compared to the high-end operator), reduced experience, but also a reduced cost structure.
3) Mid-tier operator in between the first two but closer to the high end operator.

Given multiple assumptions about financial parameters of these companies, a NESC simulation was run over a 12 year flight period, where all three companies started at the same time. A trade study was done to see the impact of delayed entry (only with two operators). Simulation results are shown in Figure 4 for both same-year entry and delayed entry. It can be seen that both the higher-end operator and lower-end operator have a positive discounted cash flow within the timeframe of the simulation. The higher end operator achieves this sooner. The mid-tier competitor cannot compete with the higher end operator. The effect of delayed market entry is to increase the time it takes for the lower tier operator to have positive cash flow, enough so that they do not even achieve this state in the simulation time period. The above simulation results are sample results given many assumptions of consumers and operators and may not be fully representative of the existing space tourism marketplace (but may be better with better input data).

CONCLUSIONS

The Nodal Economic Space Commerce (NESC) model is a dynamic, agent-based market simulation tool of the space marketplace. NESC is of higher fidelity than existing models utilizing more advanced financing, acquisition, and overall decision-making strategies throughout the full supply chain of space products and services (from vehicle developers to operators to consumers). Multiple lessons have been learned from initial development of the NESC model that will help guide future development. Limited exposure of the model to commercial and government viewers has generated genuine interest on the part of the potential of this activity. The timeliness of this activity cannot be understated given the initiatives from commercial industry (e.g sub-orbital space tourism) and new programs within the government to utilize this community (e.g NASA's new Innovative Programs office and the a potential NASA ISS re-supply Broad Agency Announcement).

The NESC philosophy allows for a more realistic and dynamic simulation of traditional and emerging space markets. The NESC model is proposed to help determine the shape of future space sustainability that will be reliant on both government actions and commercial competition.

FUTURE WORK

Additional upgrades to the sub-orbital NESC model include inclusion of vehicle reliability into the simulation. This enhancement would include simulation of vehicle failures, return-to-operation schedule/cost impact, fleet replenishment, etc.

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REFERENCES

1. Bonabeau, E. "Agent-based modeling: Methods and techniques for simulating human systems," Proceedings of the National Academy of Sciences of the United States of America, Vol. 99, National Academy of Sciences of the USA, Washington, DC, May 2002, pp. 7280-7287.

2. Reynolds, C., "Individual-Based Models," red3d.com [online article], October 1999, URL: http://www.red3d.com/cwr/ibm.html [cited 8 August 2005].

3. Port, O., "A New Laboratory for Economists: Computer models now mimic consumers and businesses," businessweek.com [online article], June 1997, URL: http://www.businessweek.com/1997/11/b351897.htm [cited 8 August 2005].

4. Gilbert, N., and Bankes, S., "Platforms and Methods for Agent-based Modeling," Proceedings of the National Academy of Sciences of the United States of America, Vol. 99, suppl. 3, National Academy of Sciences of the USA, Washington, DC, May 2002, pp. 7197-7198

5. Charania, A., DePasquale, D., "Economic Modeling of Future Space Markets," NewSpace 2006 Conference, Las Vegas, Nevada, July 20-23, 2006.

6. Charania, A., Bradford, J. E., Olds, J. R., "Economic Development of Space: Examination and Simulation," IAC-05-E3.3.08, 56th International Astronautical Congress, Fukuoka, Japan, October 17-21, 2005.
2005].

7. Tobias, R., Hofmann, C., "Evaluation of Free Java-libraries for Social-scientific Agent Based Simulation," Journal of Artificial Societies and Social Simulation, Vol. 7, no. 1, 2004.

8. Dugdale, "An Evaluation of Seven Software Simulation Tools for Use in the Social Sciences," [online article], 2002, URL: http://www.irit.fr/COSI/training/evaluationoftools/Evaluation-Of-Simulation-Tools.htm [cited 8 August 2005].

9. Beard, S.,Starzyk, J., "Space Tourism Market Study: Orbital Space Travel & Destinations with Suborbital Space Travel," Futron Corporation, Bethesda MD, October 2002.

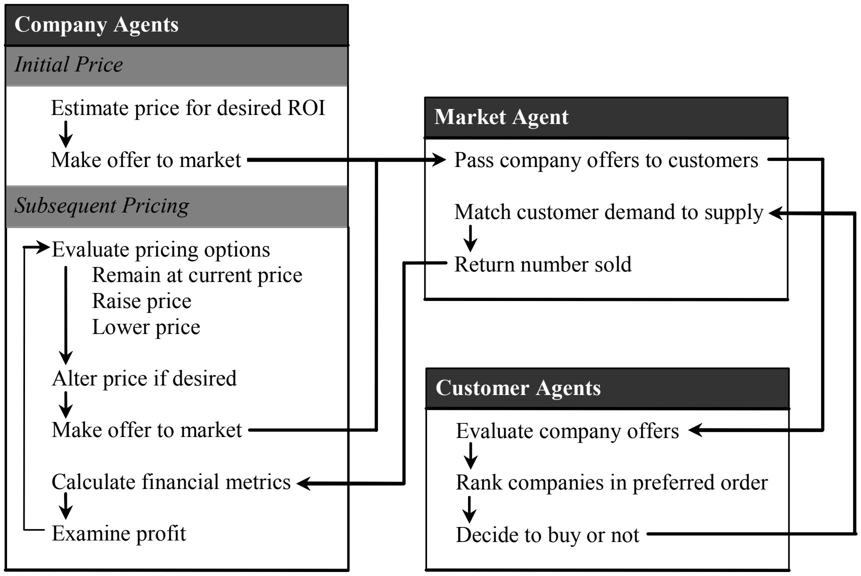

Figure 1. NESC Case A Formulation (Suborbital Space Tourism Market Simulation)

Table 1. Firm Variables in NESC Case A

Variable Type	Examples
Development	Development cost, years of operation
Financial	Discount rate, desired return on investment, desired years to breakeven
Operations	Fixed operating cost, operating cost per flight, flights per year
Vehicle	Capacity, reliability, qualitative appeal to customers
Customer Experience	Ability for passengers to leave seat to experience weightlessness, length of training

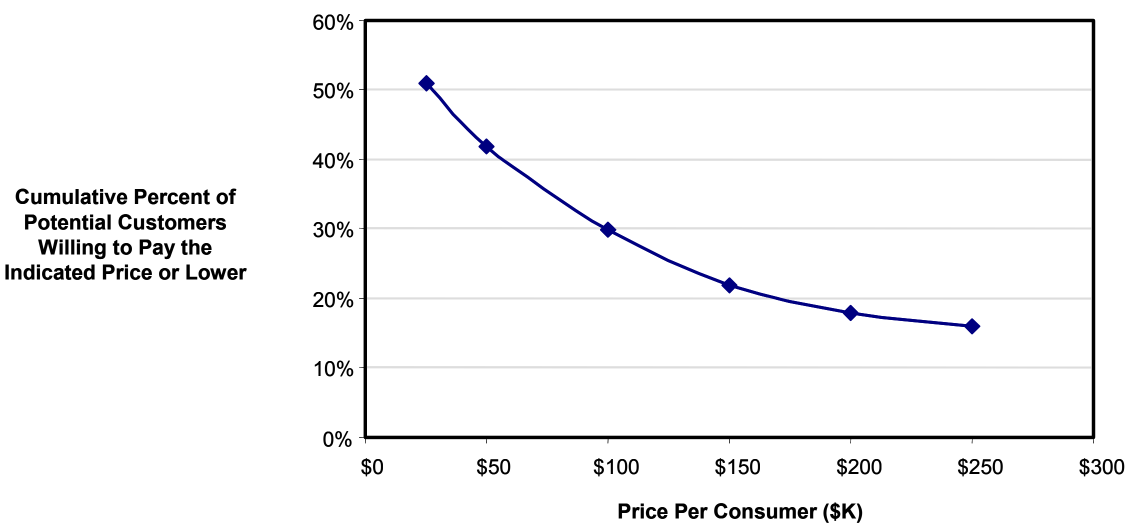

Figure 2. Cumulative Percent of Potential Customers Willing to Pay for a Suborbital Space Tourism Experience at Various Prices (Source: Futron Space Tourism Market Study)

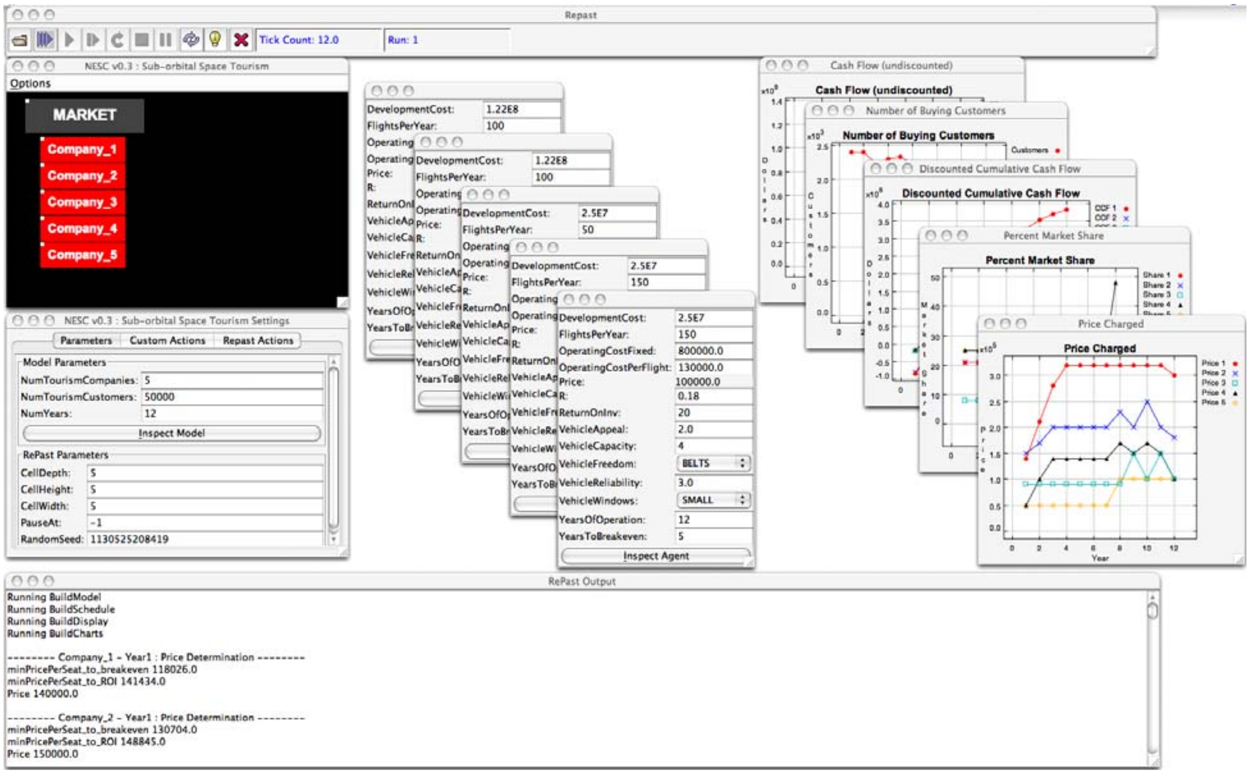

Figure 3. NESC Case A (Sub-orbital space tourism market) in RePast Framework on PC Desktop

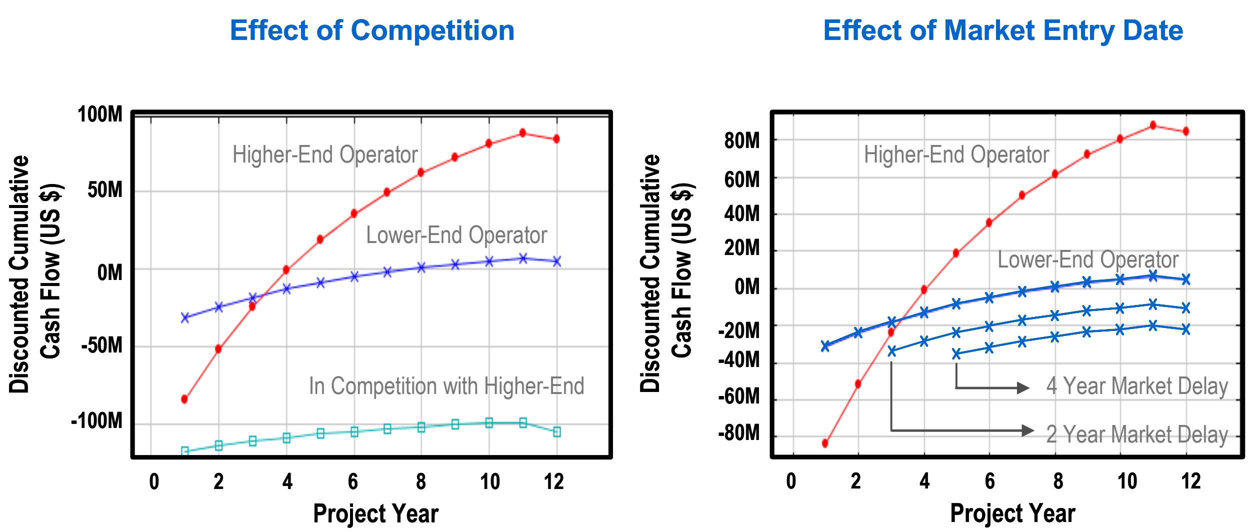

Figure 4. Sample Simulation Results: Sub-orbital Public Space Flight Market