

Agent-Based Modeling of the Space Tourism Market

A. Charania* and J. DePasquale†
SpaceWorks Engineering, Inc. (SEI), Atlanta, Georgia, 30338

Agent-Based Modeling (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 being able to determine emergent phenomena, able to describe a system in amore natural manner, and flexibility to add more behaviors and complexity. SpaceWorks Engineering, Inc. (SEI) has developed a specific ABM model for space markets, referred to as 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 (Earth-to-orbit launch, habitats, resources, etc). 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. NESC is of higher fidelity than existing models, and utilizes 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). ABM allows one to simulate the impact of decisions before applying them in the real world. These choices include behaviors such as end-user price changes, product differentiation, insurance charges, and vehicle cost increases. Additionally, the impact of government actions can be incorporated (price elasticity, technology investment, anchor contracts, tax credits, regulation, etc.). The current model is still in development and this paper is designed to provide an update as to the NESC model and its particular application to space tourism economic modeling. The NESC philosophy allows for a more realistic and dynamic simulation of both traditional and emerging space markets.

Nomenclature

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

I. Introduction

Multiple economic relationships exist between entities and need to be modeled. Typical, spreadsheet-based models strain to model the complexity both within these individual entities and their interaction with other entities. Additionally, spreadsheet models may also require more computation time for optimization and

* Senior Futurist, 1200 Ashwood Parkway, Suite 506.

† Project Engineer, 1200 Ashwood Parkway, Suite 506.

probabilistic analyses for very advanced models. Complex financial calculations for an adequate model require more processing than typically handled in such environments.

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. Agent-Based Modeling (ABM)

A. 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 include¹:

- 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 includes³:

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 the universe as a whole and the individual participants of that universe.

B. Examples of Agent-Based Modeling (ABM) Application

As complexity science has emerged as a field of inquiry, 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. Examples that can be found of previous investigations using ABM include:

- 1) School voucher programs
- 2) Decision making in closed regimes
- 3) Modeling the size of wars
- 4) Voting dynamics
- 5) Self-organizing computer networks

- 6) Multi-cellular tumors
- 7) Simulation for the everglades/big cypress region of south Florida
- 8) Growth of individual plants and interactions with individual insects
- 9) Social behavior in rat pups modeled by simple rules of individual behavior
- 10) Individual and collective actions of people in large temporary gatherings (crowds, mobs, etc.)
- 11) Modeling of prehistoric settlement systems in southwestern North America
- 12) Individual-based models of the music CD business
- 13) Electricity markets of how customers respond to different price patterns for electrical power
- 14) Movement of individuals across the transportation network (use of cars or buses by the second)
- 15) Seating in a theater, how the appropriate number of people decide to show up for an event
- 16) Micro-analytic model to simulate the U.S. economy (agents represent various decision-makers)

ABM has been used in the financial community to help evaluate decisions. One example comes from the world of retail⁴:

“The client, Macy’s group vice-president William M. Connell, is amused and oddly pleased, if only because he can see that the team is making some progress toward an incredibly ambitious goal: to harness the emerging science of complexity, the notion that complicated behavior emerges from the interaction of many components, and create a powerful new tool for top executives. Farrell’s team [K. Winslow Farrell Jr. of PricewaterhouseCoopers Emergent Solutions Group] is creating artificial worlds of evolving, reactive software creatures. If all goes well, the actions of those “adaptive agents” will so closely mimic human behavior that managers for the first time will be able to use them to test the impact of their decisions before implementing them in the real world.”

C. Various Agent-Based Modeling (ABM) Computational Programs

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 interfaces⁵. Over 20 agent-based software toolkits were evaluated by the authors as potential NESC frameworks including NetLogo, Ascape, Ptolemy II, AgentSheets, TNG/SimBioSys, XRaptor, Aspen, JASA, ModuleCo, SDML, Vensim, Z-Tree, EcoLab, Quicksilver, VSEit. The list was narrowed to three finalists: RePast, Swarm, and MASON. The basic functionality of all three finalists is similar, and all are free and open-source. The provided frameworks are sufficient to support and assist with the creation of agent-based models while maintaining the flexibility to develop advanced customized models. The similarity in basic functionality is perhaps due to the fact that Swarm was one of the first agent-based software toolkits, and both RePast and MASON were designed based on Swarm. Simulations within all of these toolkits are driven by a discrete event scheduler and all have the capability to log and graph results. A brief summary of the finalist software programs follows:

- 1) Swarm was created by the Santa Fe Institute and is currently maintained by the Swarm Development Group (www.swarm.org). Swarm has a large base of users, a large support base available online (including via the Swarm wikipedia and mailing list), and the largest collection of applications of all frameworks examined. An Objective C and a Java version of Swarm are available.
- 2) MASON (Multi-Agent Simulator of Neighborhoods... or Networks... or something...) was created by the Evolutionary Computation Laboratory and the Center for Social Complexity at George Mason University (cs.gmu.edu/~eclab/projects/mason/). MASON is easy to use with good support including tutorials and a searchable mailing list. However, it does not have as large a library as RePast or Swarm nor some of the more powerful tools available with RePast. MASON is implemented in Java.
- 3) 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)

Selection of the agent-based software toolkit for NESC from among the three finalists was accomplished by qualitatively evaluating development maturity, available modeling libraries and options, applicability to NESC modeling, support and documentation, the graphical user interface, future viability, and ease of installation. Each of these criteria were evaluated through independent testing and supplemented by software reviews^{5, 6}. Ultimately RePast was selected for the applicability of its available libraries, ease of use and installation, and quality of documentation. Given the three language implementations of RePast, the Java implementation (RePast J) was chosen because of the availability of Java, flexibility of the language, and familiarity to the authors.

II. Goal of the NESC Project

A. 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). 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 (duopoly, pure competition, etc.) and simulates the financial case of entities that undertake these projects. NESC is of higher fidelity than existing models, and utilizes 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). Sample future markets that NESC will simulate include sub-orbital space tourism, orbital space tourism, commercial and government spacecraft, government exploration (ISS, moon) cargo/crew services, and future resources (mining, Space Solar Power, etc.). Agent-based modeling (ABM) allows one to simulate the impact of decisions before applying them in the real world. These choices include behaviors such as end-user price changes, product differentiation, insurance charges, and vehicle cost increases. Additionally, the impact of government actions can be incorporated (price elasticity, technology investment, anchor contracts, tax credits, regulation, etc.). The current model is still in development and this paper is designed to provide clarity as to the capabilities of the NESC model. The NESC philosophy allows for a more realistic and dynamic simulation of traditional and emerging space markets.

The Nodal Economic Space Commerce (NESC) model has the following characteristics:

- 1) Demand and supply relationships based upon price and other qualities of the product (reliability, intrinsic appeal, etc.)
- 2) Autonomous decision making by agents with communication between agents
- 3) Express demand as individual customer agents or groups with unique desires and behaviors
- 4) Allow for price setting strategies
- 5) Modeling the exit and entrance of new companies into the marketplace
- 6) Model the relationship between product suppliers, operators, and eventual consumers.
- 7) Impact of the government actions (technology investment, anchor contracts, tax credits, etc.) upon commercial entities

For the government and consumers, NESC shall model their particular demand for various products and services. For modeling commercial companies, NESC shall be composed of modules that calculate important business case metrics of interest containing balance sheet, debt financing, depreciation, venture / equity toolsets, Net Present Value (NPV), Free Cash Flow (FCF), and Internal Rate of Return (IRR) calculations. NESC will be able to use inputs from other models (such as NAFCOM) for determination of these metrics. NESC will utilize existing market data where available to help generate behaviors of the various agents.

Phase I of NESC development entails research into such agent-based development, acquisition of an agent-based modeling framework, development of NESC for various future space markets, and analysis using NESC of those space markets. For this Phase the models will be run deterministically. The final NESC model (with all associated modules) shall:

- 1) Provide a market model that reflects the interaction of competitors and new pricing schemes based upon relevant and available market models such as those from Teal Group, Futron Corporation, FAA COMSTAC, NASA, DoD, etc.

- 2) Be able to accurately reflect the impact of government activities upon the private development of space activities, namely the impact of separate government pricing, government cost sharing, technology risk reduction, tax credits, loan guarantees, tax holidays, etc. upon the valuation to private companies of large scale capital projects
- 3) Calculate not just Net Present Value (NPV) based upon a qualitatively derived discount rate as in current models, but actually apply Weighted Average Cost of Capital (WACC) measurements to determine a discount rate
- 4) Use more elaborate financing models than those currently employed in space transportation and architectures models, namely apply venture / mezzanine financing toolsets with calculation of warrants / stock valuations for commercial entities
- 5) Have the breadth and depth to model the economics of both space transportation and infrastructure using inputs from cost, operations, safety, and market models; the model can simulate one commercial entity as the provider of the entire space service chain (i.e. in the case of Space Solar Power, one company provides both the ETO and in-space transportation service as well as develops the orbital infrastructure and Solar Power Satellites) or model the interaction of many companies each providing a different service (i.e. in the case of Space Solar Power, three companies interact to provide ETO transportation, in-space transportation, and orbital infrastructure while charging different prices to each other)
- 6) Have heuristic based acquisition / manufacturing logic using inputs of life, reusability, turn-around time, etc.
- 7) Be integrated within the Phoenix Integration's ModelCenter© collaborative design environment framework.

III. 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).

A. 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.

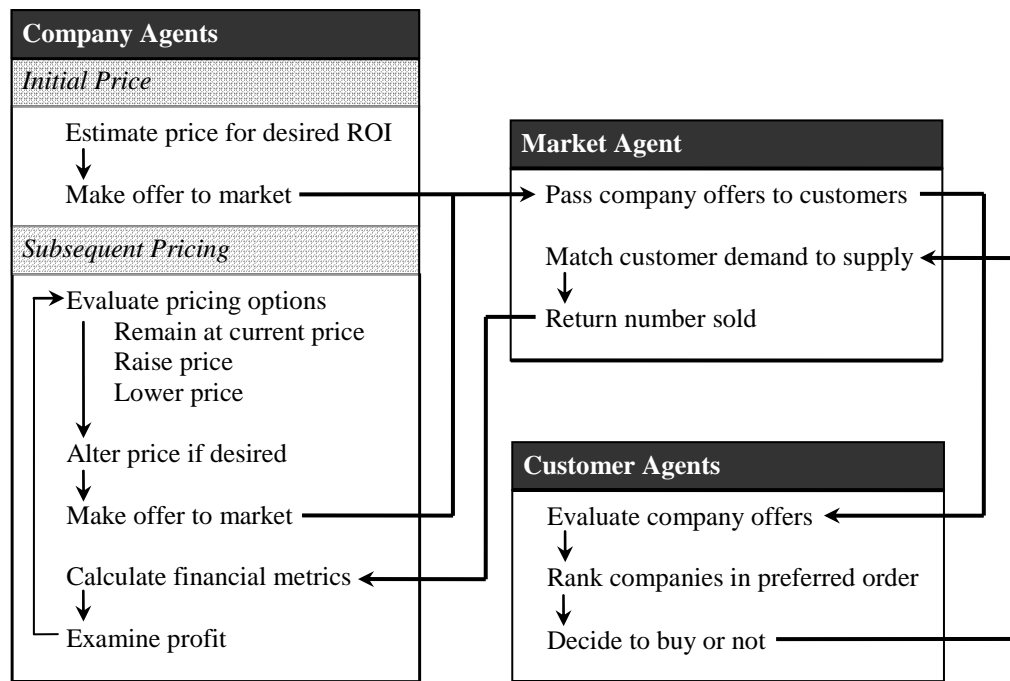


Figure 1. NES Case A Formulation (Suborbital Space Tourism Market Simulation)

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.

B. 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 NES Case A.

Cost and vehicle variables are fixed in NES 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.

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

C. 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.⁸ 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.

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.

D. 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.

E. 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 2 is a screen capture of NESC Case A on a PC desktop showing the RePast toolbar, NESC display, and major output windows.

IV. Sample Results

NESC Case A can be used to examine the impact of different company/product types and impact of business

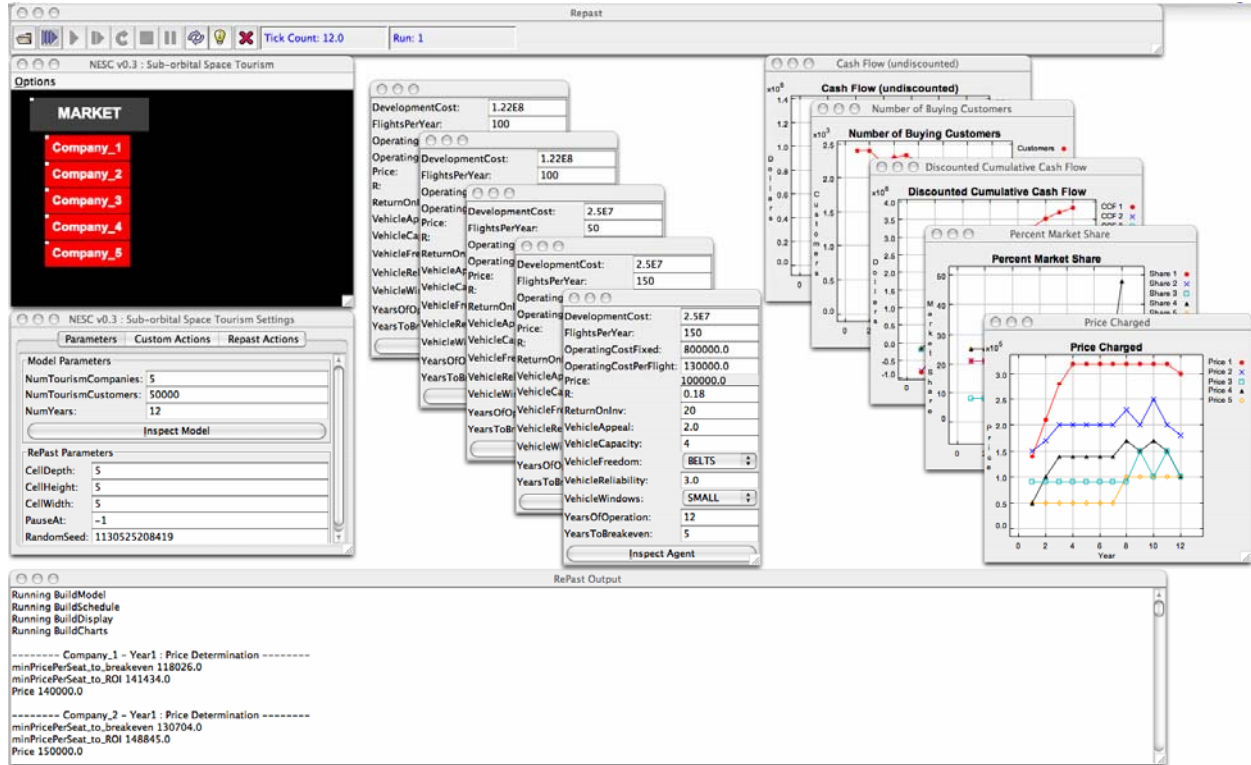


Figure 2. NESC Case A (Sub-orbital space tourism market) in RePast Framework on PC Desktop

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 3 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).

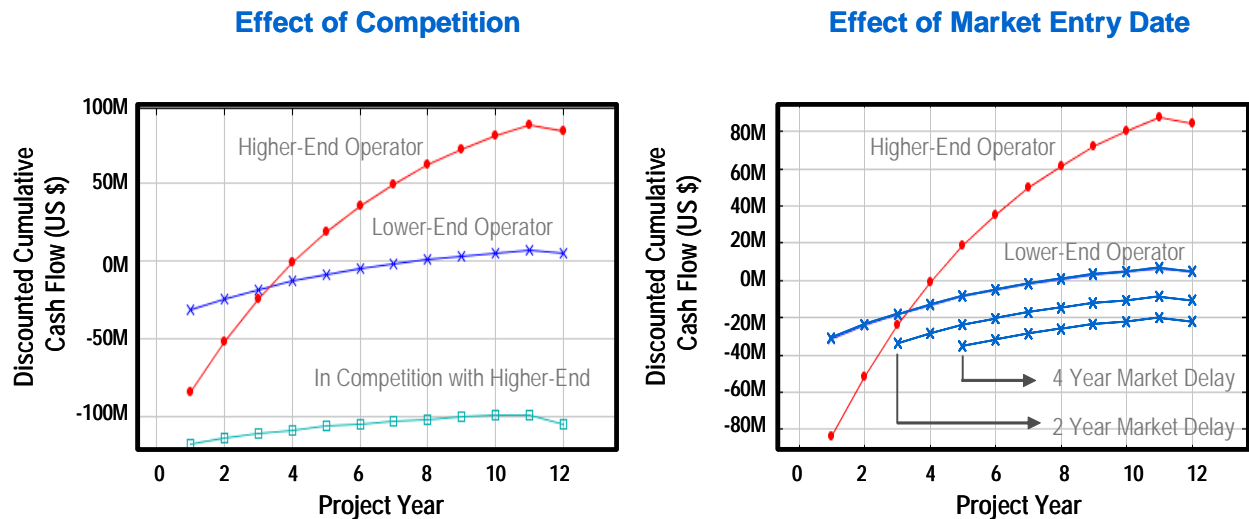


Figure 3. Sample Simulation Results: Sub-orbital Public Space Flight Market

V. Future Development

After the initial space tourism market, the next major case that was examined was the ISS cargo/crew re-supply with agents representing demand (NASA, commercial space) and supply (NASA CEV, European ATV, Japanese H-II, Soyuz, Progress, emerging alternate U.S. providers). This market has been chosen because of recent government policy to allow commercial companies to provide ISS re-supply services in anticipation of a reduction in Space Shuttle availability. This version of NESC, referred to as NESC Case C, has major upgrades in terms of company behaviors that will be incorporated into NESC Case A.

VI. 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.

Acknowledgments

Sponsorship and financial support major portions of this project was provided by NASA's Exploration Systems Mission Directorate (ESMD) Exploration Systems Research and Technology (ESR&T) office at NASA Headquarters under NASA contract no. GS-10F-0455M. The authors would also like to thank the Contract Officer's Technical Representative (COTR) for the project Mr. Dennis Petley of NASA Langley Research Center, program element manager Mr. Doug Craig of NASA Headquarters, acting program element manager Mr. Austin Evans of NASA Headquarters, and contracting officer Ms. Sharon DeBerry of NASA Langley Research Center.

References

- ¹Bonabeau, 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.
- ²Reynolds, C., "Individual-Based Models," *red3d.com* [online article], October 1999, URL: <http://www.red3d.com/cwr/ibm.html> [cited 8 August 2005].
- ³Port, 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].
- ⁴Byrne, J. A., "Flight Simulators for Management: Computer models may give execs previews of how decisions pan out," *businessweek.com* [online article], September 1998, URL: <http://www.businessweek.com/1998/38/b3596135.htm> [cited 8 August 2005].
- ⁵Gilbert, 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
- ⁶Tobias, 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.
- ⁷Dugdale, "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].
- ⁸Beard, S., Starzyk, J., "Space Tourism Market Study: Orbital Space Travel & Destinations with Suborbital Space Travel," Futron Corporation, Bethesda MD, October 2002.