A Methodology for Assessing Business Models of Future Air Transportation in the Atlanta Regional Transportation System

Choon Giap Lim*, Jung-Ho Lewe*,
Georgia Institute of Technology, Atlanta, GA 30332-0150

Daniel A. DeLaurentis†,
Purdue University, West Lafayette, IN 47907

and

Dimitri N. Mavris‡
Georgia Institute of Technology, Atlanta, GA 30332-0150

A methodology employing physics-based and economics-based tools in conjunction with probabilistic treatment is developed to study Personal Air Vehicle business model. In the context of the paper, a business model is a mathematical representation of a service provider business operation. Vehicle concepts and hypothesized metrics such as mobility freedom and 'value of time' are embedded in the methodology. Market behavior of the complex transportation environment is captured as part of the equation through Agent-based Modeling and Monte Carlo Simulation techniques. This simulation platform for the transportation environment facilitates the case study of the Atlanta Regional Transportation System. The establishment of this model lays the foundation for creating a robust and adaptive design methodology that allows experts in fields other than aerospace engineering to contribute their expertise towards the realization of this very diverse and dynamic future air transportation system.

Acronyms

ABM	=	Agent-based Modeling
ARC	=	Atlanta Regional Commission
COAV	=	Commercial On-demand Air Vehicle
COSP	=	Cost of Services Provided
D-D	=	Doorstep-to-Destination
IRR	=	Internal Rate of Return
MARTA	=	Metropolitan Atlanta Rapid Transit Authority
MNL	=	Multinomial Logit
NPV	=	Net Present Value
PAV	=	Personal Air Vehicle
PI	=	Productivity Index
PV	=	Present Value
RoR	=	Required Rate of Return
TAF	=	Transportation Architecture Field

* Graduate Research Assistant, Aerospace Systems Design Laboratory, School of Aerospace Engineering; AIAA Student Member.
† Assistant Professor, School of Aeronautics & Astronautics Engineering; AIAA Senior Member.
‡ Director, Aerospace Systems Design Laboratory, School of Aerospace Engineering; AIAA Associate Fellow.

I. Context and Foundation: Transportation System-of-Systems

The current transportation system is approaching its natural limit, particularly in terms of meeting the fastidious mobility demands of today's travelers. A market overview survey by Teal Group in year 2000 has reported that 8% to 12% first and business class airline customers are moving from scheduled flight services to on-demand private aviation services[1]. While this number may not seem alarming, this category of airline customers generates the largest portion of the airline's total revenue. Maturity and saturation of present system's potentials along with a healthy trend of increasing interests in on-demand personal mobility led us to believe that advanced small-to-medium sized aircraft is a strong candidate for elevating human mobility to the next level. Such vehicle is called Personal Air Vehicle (PAV), owned and operated by individuals. However, there exists a gap between today's technology level and the technology level required to kick-start the "PAV phenomenon." This creates a transition period where we anticipate PAV business models to act as a catalyst that bridges this technology gap and generates momentum for the economies of scale of PAV technology (See Figure 1). In their study on identifying key barriers to the utility of general aviation, Downen and Hansman supported that "modifying the business model for owning and operating general aviation may be the best near-term strategy for lowering the expense of general aviation transportation."[2] For this paper, the concept of these PAV business models is termed Commercial On-demand Air Vehicle or COAV for short.

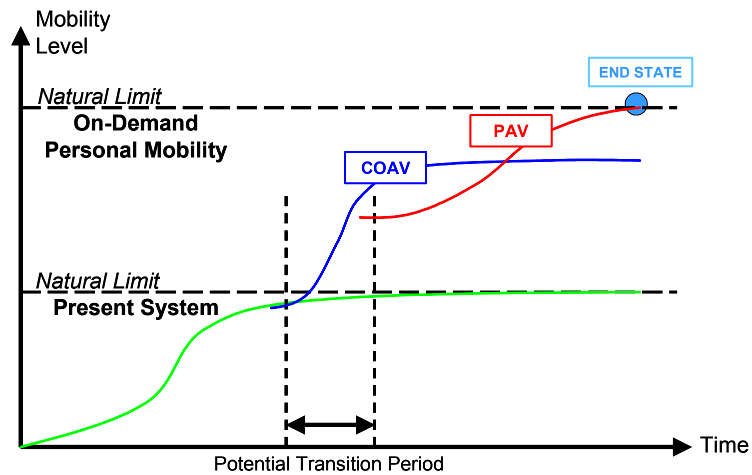


Figure 1. Evolution of Mobility Performance

The motivation of the research described in this paper is the belief that *future service provider business models play a critical role in shaping and pushing the technology envelope for developing affordable, reliable, and competitive air transportation.* Thus, the research goal is to develop a family of potential COAV that are amenable for embedding into a larger simulation system-of-systems environment such that vehicle technology requirements can be driven by the actual market forces likely to be in place. This system-of-systems thinking process is adopted with the mindset that defining boundaries of the investigated transportation system must go beyond today's existing systems and into a future without preconceived boundaries. This implies that careful measures are required to capture the effects of all possible entities and their corresponding interrelating networks. Hence, a holistic approach is adopted to abstract the transportation system-of-systems.

A. Abstraction Process

Abstraction is essential to completing a successful system-of-systems study. The purpose of the abstraction is to rise above the stovepipes that typify the current paradigm so that future architectures can be imagined without prescribed limitations[3]. The entity-centric abstraction of the transportation system shows an architecture consisting of a collection of explicit and implicit entities that are linked by networks. Explicit entities are embodied as resources such as vehicles and infrastructures and implicit entities are embodied as stakeholders (See Table 1). This depiction reveals a system where stakeholders employ particular resources organized in networks (both explicit and implicit) to achieve a transportation objective. The relationship between the resources and stakeholders is manifested in the time-variant Transportation Architecture Field (TAF) depicted in Figure 2 (See Ref. [4] for details). From the abstraction, we identified the interaction between service providers and consumers as one of the key relationships present within the stakeholder network. Hence, the focus of this paper is to understand the nature of this relationship and to explore the strength of its presence in the stakeholder network.

Table 1. Stakeholders of the Transportation System

Stakeholders		Descriptions	Objectives
Public	***Consumers***	Individual travelers or shippers (for commercial goods) that are the end user for the transportation system.	min: travel time, expense, max: comfort, safety
	Society	Represents the aggregated interests of citizens, from research agencies, to communities, to the national level.	min: noise, emission, max: quality of life
Industry	***Service Providers***	Owners of resources who sell transportation services to consumers.	max: profit, market share, consumers' satisfaction
	Manufacturers	Design, produce and sell transportation resources to service providers and/or consumers.	max: profit, market share, service providers' satisfaction
	Insurance Companies	Provide protections against mishap operation of transportation resources by collecting insurance fee.	max: profit, market share, customers' satisfaction
Government (Policymakers)	Regulatory Agencies	Impose rules on the system that restrict stakeholder activity and resource characteristics.	max: safety, security
	Infrastructure Providers	Plan and approve employment and enhancement of infrastructure resources.	max: capacity, min: delay
Indirect Stakeholders	Media	Report information, forecast and plan from/to the public.	Varied, but vague
	Research Agencies	Develop and provide transportation related technologies.	Provide firm foundation for transportation development

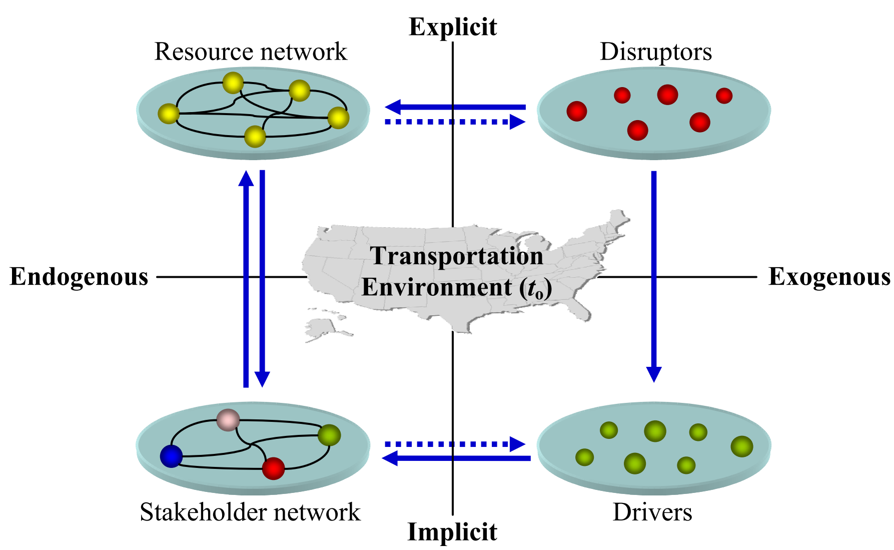


Figure 2. Transportation Architecture Field (TAF)

B. Mobility Measures of Merit

The most commonly accepted measures of merit for personal mobility are travel costs and doorstep-to-destination (D-D) time. Travel cost measures the monetary value spent for generating a particular trip with a specific transportation mode. D-D time measures the travel time starting from your origin location to your destination location, going through different portals (highway ramps, airports, transit stations, etc.) if necessary and utilizing different transport medium (roads, rails, air, sea, etc.). Clearly, a transportation mode with a lower D-D time yields a *travel time saved* relative to a baseline. This *travel time saved* can also be converted to reflect the monetary value saved by the traveler relative to one's *value of time*. The value of an individual's time is a continuously debatable issue since one's worth of time truly depends on his/her personal evaluation and character. Nevertheless, it is reasonable to impose a numerical value of time based on the individual's income per hour (ratio of annual income to 2080 paid hours a year)[5].

While travel cost and time remains to be the key metrics for assessing mobility, significance of other attributes such as safety, convenience, and comfort begin to weigh in as desirability (rather than strict necessity) becomes a larger subset of mobility demand. Alternative transportation modes not only save time and cost, but also induce unforeseen travels both in terms of frequency and purpose. The embrace of such 'mobility freedom' calls for a better measure for travel utility.

II. Technical Approach

A. Commercial On-demand Air Vehicle (COAV) Basics

COAV, i.e. PAV business models are used to represent the air service providers for this study. Three main issues plague the development of PAV; ease of use, noise, and affordability. Ease of use is undoubtedly the single most important criteria that determine public acceptance of the PAV concept. While loosely termed, 'ease of use' encompasses the combined effectiveness of a multitude of system components, ranging from high-lift devices to flight controls to ground portals accessibility. Meanwhile, environmental concerns particularly vehicle noise remains a disrupting side effect of technologies aimed at improving ease of use. Hence, technology development should be directed at deriving easy to use PAV with acceptable vehicle noise. Consequently, the cost of technology development will be reflected on the affordability of the PAV.

The assessment of PAV affordability is essentially a balance between the economic utility of the improved system attributes and the costs of making these improvements, distributed over the population of PAV users. COAV is expected to remedy the affordability concerns in three sequential ways. Firstly, commercial air services such as charters and rentals reduce the cost of PAV utilization through increased vehicle utilization and mass operations (with distributed cost recovery structure). Secondly, cheaper PAV options expand the population of PAV users and increases PAV market share in the transportation industry. Thirdly, business models generate the incentives and financial resources for technology development through expanded business opportunities and increased market shares. These three impacts are depicted in the flowchart below. To assess the impact of different business strategies on COAV development, the profitability and performance of these service provider operations must be measured.

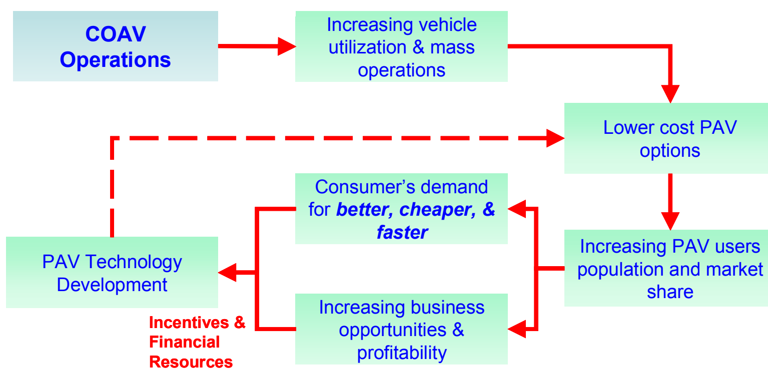


Figure 3. COAV Remedy for Affordability Concerns

For the purpose of this paper, the business models considered are COAV air charters (including air taxis) and COAV rentals. To ensure distinction from the already available air charters and rental general aviation aircrafts, these models heavily emphasize the three key benefits of PAV: Doorstep-to-Destination, On-Demand, and Flexible Itinerary. These two service providers offer mobility services in return for an hourly service fee. The only distinction between these two service providers is that COAV air charters provide piloted flights. In other words, rental COAV targets a more specific (and much smaller) market made up of licensed pilots, which is a mere 0.22% of the total population of the United States as of 2000.

This paper assesses the short and long term impact of COAV on the Atlanta Regional Transportation System through economic analysis and sensitivity studies, producing aggregated insights on the mechanics and economics behind these business models. More importantly, establishment of this model lays the foundation for creating a robust and adaptive design methodology that allows experts in fields other than aerospace engineering to contribute their expertise towards the realization of this very diverse and dynamic future air transportation system. Conveying this knowledge and information to decision makers will help guide the path of technology development of future air vehicles in the right direction and at a faster pace, taking us a step closer towards the vision of on-demand, doorstep-to-destination, personal mobility.

B. Capital Budgeting Methods

Net Present Value (NPV) and Internal Rate of Return (IRR) techniques are always or almost always used by 75% of top executives to evaluate capital budgeting[6]. Hence, investments of these two COAV service provider models are primarily assessed via the projects' NPV and IRR. On top of that, Payback and Profitability Index (PI) are computed along with the sensitivity analysis of key economic attributes.

Present Value (PV) is a measure of the company's future cash flow at any point of time within the project period, discounted to a reference year (typically year zero). NPV is defined in Equation (1). For evaluating an independent project such as the COAV, a positive NPV implies that the project is expected to add value to the company and that the project should be accepted and a negative NPV implies the opposite. IRR is defined as the discount rate that causes the project's computed NPV to equal zero. It is a useful complement to NPV since its computation uses the same cash flow projections as the NPV analysis. Essentially, IRR reflects the rate of return that shareholders expect to earn on the capital invested in the project and proves to be a useful approach to project evaluation. Payback method computes the break-even year for a project given the same initial investment and cash flow projections used in NPV and IRR analysis. This approach is particularly useful in longer term investments as it gives shareholders estimations on how long it takes to recover the capital invested. On the other hand, PI measures the 'bang for the buck' of the project, given by profit to investment ratio. However, all the aforementioned capital budgeting methods requires many assumptions in terms of time value of money and cash flows projections. Hence, sensitivity analysis is used to answer the question "What if some projections computation are wrong?"

$$
\begin{aligned}
&NPV = \sum Present\,Value - Initial\,Investment \\
&IRR = Discount\,Rate\Big|_{NPV=0} \\
&Payback = Operation\,Year\Big|_{NPV=0}\ for\ given\ discount\ rate \\
&PI = \frac{NPV}{Total\,Capital\,Investment}
\end{aligned}
\tag{1}
$$

C. Business Models Overview

The business models begin with a Capital Investment process of acquiring vehicles to service the mobility demands. Here, Total Capital Expenditures is computed based on the price of each vehicle and the fleet size. Next, the Operations of the mobility services are defined. Here, a required rate of return (RoR) on service is determined to compute service pricing as a percentage markup of total operating costs, also known as Cost of Services Provided (COSP). Subsequently, Revenues of the business operations are computed as the product of service pricing and an estimated mobility demand. These information and the accompanying assumptions provided below facilitates the Cash Flow Analysis of the business models.

General Assumptions:

1. The *service corridor*[*] of these business models are dedicated to the specified locales of this study and are independent of other business activities of the service providers, if any.
2. Business assessments of these models are strictly on the service corridor of this study.
3. Investment projects span over 8 years of operations where thereafter, new evaluations are required due to changes in market behavior and technology status.
4. Corporate tax for companies with estimated taxable income between \$335,000 and \$10,000,000 is fixed at 34% [7].
5. Nominal discount rate and inflation rate is fixed at 10% and 3% for the 8 years of cash flow projection. Real discount rate is then computed as follows:

$$
Real\ Discount\ Rate = \frac{1 + Nominal\ Discount\ Rate}{1 + Inflation\ Rate} - 1 \tag{2}
$$

[*] Service corridor concept adopted for the modeling and simulation of this study is discussed in the next section.

D. Capital Investment

Assumptions:

1. Maximum vehicle operational time per day is 5 hours, limited mostly by the daily peak commuting hours rather than vehicle utilization.
2. Fleet size is determined as the number of vehicles required (plus 30% reserve) to service the projected daily trip demand estimated from percentage market share captured by each COAV mode and the total daily commute in the three locales.
3. Baseline vehicle acquisition price (including interests) is fixed at $140,000.
4. Vehicles are depreciated without salvage value under the 7-year Property Class Modified Accelerated Cost Recovery System (MACRS): 1986 Tax Reform Act. Allocated depreciation schedule is {14.29%, 24.49%, 17.49%, 12.49%, 8.93%, 8.93%, 8.93%, 4.45%}[8].

E. Operations

Annual Service Revenues for the business model is estimated as shown below:

$$\begin{aligned}&\text{Daily Trip Demand} = \text{Total Daily Trips} \times \%\ \text{Market Share Captured}\\&\text{Daily Operational Hours} = \text{Daily Trip Demand} \times \text{Mean Travel Time per Trip}\\&\text{Annual Service Receipts} = \text{Daily Operational Hours} \times \text{Annual Working Days}\end{aligned} \tag{3}$$

For a service provider company, total operating cost is also known as Cost of Services Provided (COSP) and is rated on an hourly basis. For COAV Air Charters and COAV Rentals, COSP include pilot fee and docking fee respectively. Annual COSP for the business models is defined in Equation (4). Since Revenues and COSP are projected for the following 8 years of operations, it is necessary to assign an estimated growth of revenues and costs for the business models.

$$\text{Annual Expenditures} = \text{COSP} \times \text{Daily Operational Hours} \times \text{Annual Working Days} \tag{4}$$

Other assumptions:

1. Total daily trips generated by the three locales are computed by multiplying commuter-to-population ratio and external trip-to-total trip ratio (we are neglecting internal travel) with the total population of the three locales. Total daily trips generated 'between' the three locales is assumed to be a 1/10 factor of the total daily trips generated by the three locales.
2. Daily trip demand is obtained unique for each sensitivity study since percentage market share changes when influential assumptions are varied for the sensitivity studies.
3. Baseline required rate of return is fixed at 30%.
4. Annual growth rate for revenues and costs for the next 8 years are fixed at 5% and 6% respectively.

F. Cash Flow Analysis

Accounting structure for computing corporate cash flows is as follows:

Table 2. Computing Corporate Cash Flows

Description (Annual)	**Year 0 Year 1 ... ... Year 8**
Service Revenues - Cost of Services Provided - Vehicle Depreciation	
Pretax Income - Corporate Tax Provision	
Net Income + Vehicle Depreciation	
Operating Cash Flow - Capital Expenditures	
Free Cash Flow	
Present Value for given discount rate Net Present Value for given discount rate	Free Cash Flows discounted back to Year 0 Sum of all Present Value Cash Flows minus Initial Investment

III. Modeling & Simulation

The transportation system can be characterized as a complex system due to a number of factors. Key factors include the large number of component systems, their heterogeneous nature, and the high degree of connectivity between systems that can lead to highly non-linear behavior. These factors make it extremely difficult to model or to resolve these problems analytically from a top-down reductionism approach. On the other hand, the bottom-up nature of agent-based modeling (ABM) may prove to be an ideal way to tackle the transportation system-of-systems problem. ABM allows the inherent microscopic complexity to manifest itself within the simulations and then generalize these sets of simulation data to produce aggregated outputs. Overall modeling and simulation scheme closely follows Ref. [9]. Hence, the modeling and simulation process of this project is built upon the agent-based approach, where the two main components are Agent Definition and Environment Definition.

A. Agent Definition

The fundamental building blocks of ABM are the individual components at the microscopic level of the system, namely the agents. Travelers are defined as adaptive agents who apply a set of preprogrammed behavioral rules to select the best travel mode based on the attributes and changes in the simulation environment. The choice mechanism that agents adopt to make travel decisions are implemented with utility theory and multinomial logit (MNL) model. Utility theory postulates that an individual chooses the alternative that offers the highest utility. The outcome of this utility function is a numerical representation of favorability or attractiveness of each transportation mode choice to the traveler, which ultimately reflects the traveler's decision making behavior. Synonymously, we can model the traveler's decision making behavior by computing the 'disutility function', since it is easier to capture the negative entities (cost and time spent) rather than the positive entities (cost and time saved) of the trip. In other words, the traveler assigns a disutility of each mode choice by considering the cost and travel time as well as his/her value of time spent on traveling, which is defined in Equation (5).

$$Disutility\,(time, cost) = -Utility\,(time, cost) = Travel\ Cost + Value\ of\ Time \times D\text{-}D\ Time \tag{5}$$

With this disutility function, the probability of selecting each transportation mode choice is obtained using the MNL model given by Equation (6). These probabilities are interpreted as the likelihood of selecting one mode choice over the remaining choices and are mutually exclusive. The value α in the MNL model equation is a constant for selection logic calibration. For this study, α is fixed at 0.0001 and there are four mode choices (n=4): automobile, transit (service available only between two of the three locales), COAV Air Charters, and COAV Rentals.

$$P(mode_i) = \frac{e^{\alpha U(mode_i)}}{\sum_{j=1}^{n} e^{\alpha U(mode_j)}}, \tag{6}$$

General assumptions:

Other assumptions made for the defining the fundamental behavioral rules of the agents are provided below. Attributes labeled with (Sim) refers to Simulation Variables, a set of assumptions that are varied based on predefined distributions in the Environment Simulation. Commuters are the only market target for this study and secondary ground vehicle (transit bus or automobile) is required to transport commuter to and from portals. Commuters travel twice per day, five days per week, and a conservative 40 weeks per year to arrive at a total annual commuting trip of 400.

Table 3. Assumptions for General Attributes

Attributes	Assumed Values
Annual Commuting Trip per Commuter	400 trips*
Automobile average speed	55 mph
Transit average block speed	20 mph
Secondary ground vehicle average speed	35 mph
Percentage of licensed pilot	0.5%† of commuter population

* Traveler commutes 5 times a week, 2 trips per commute, and 40 weeks per year.

† This value is estimated higher than the national value of 0.22% per entire population since commuter population is a smaller portion of the entire population.

Travel Distance:

1. Distance from origin/destination to portals varies asymmetrically (Sim), where distance from origin to portals (residence) is twice the distance from portals to destination (workplace). This is due to the fact that portals are usually located closer to workplace than to residence.
2. Radius of residence from center of origin varies (Sim).
3. Radius of workplace from center of destination varies (Sim).
4. Commuting trip distance between two locales is the sum of the two radii above and the actual trip distance.

Travel Time:

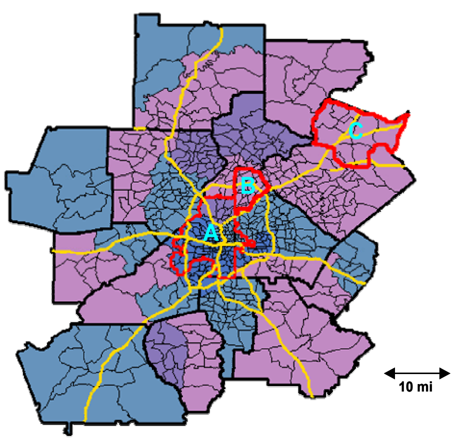
1. Any physical travel time of the commuter is the travel distance divided by the average travel speed.
2. Time delay at portals varies (Sim) for all transportation mode except automobile.
3. Traffic travel (congestion) is experienced only by automobiles and varies (Sim).

Travel Cost:

1. Automobile direct operating cost is $0.10 per mile.
2. Automobile has an annual fixed ownership cost that varies, which accounts for purchase, insurance, and maintenance (Sim).
3. Automobile has a traffic delay cost of $12.85 per hour of delay, which includes monetary losses of time and fuel spent during congestion.[10]
4. Secondary ground vehicle total operating cost is $0.35 per mile.
5. Transit fixed cost per trip is $1.75 based on Metropolitan Atlanta Rapid Transit Authority (MARTA) fee.
6. Time delay at portals for transit is doubly-weighted in terms of value of time spent because studies have shown that individual's value of time increases significantly over the displeasure of having to wait. This adjustment is part of a stipulation patch to embed the mental model of intangibles into the mechanics of the utility theory.
7. COAV service pricing is the result of a markup over the total operating cost of the vehicle per hour (Sim).
8. For commuters without pilot license, cost of acquiring pilot license is $10,000 ($100/flight hour x 100 required hours) plus 100 hours x Value of Time (value of time spent to acquire pilot license). This adjustment is part of a stipulation patch to embed the mental model of intangibles into the mechanics of the utility theory.
9. Total annual cost is the sum of annual commuting cost plus other annual fixed transport cost (automobile ownership cost and licensing cost).

B. Environment Definition

Environment simulation involves the creation of a virtual environment that mimics the locale characteristics of a real geographic location. This simulation model is constructed from a set of locales and their corresponding mobility demand, transportation resources, and other socioeconomic factors such as personal income. For this study, this geographic location is the Atlanta Regional and three locales are selected. These locales are selected specifically to represent three distinct city categories: downtown, satellite town, and suburban as shown in the map below.



Location	City Category	Locale Radius
City of Atlanta (A)	Downtown	6.5 miles
Superdistrict 23: Chamblee (B)	Satellite Town	4.0 miles
Superdistrict 52: North Gwinnett (C)	Suburban	6.5 miles

Figure 4. Locale Selection for the Atlanta Regional Modeling & Simulation

On the other hand, travel environment model is an aggregate model that uses Agent Based approach to populate a predefined study location (comprised of a set of locales) with unique individual travelers based on the aforementioned traveler's decision making behavior. The study location for this paper is the Atlanta Regional, where three locales are defined by actual geographic locations to create the service corridor for the COAV business models. The market target of these business models are assumed to be strictly commuters who travel to their workplace to and from any of these three locales.

Mobility Demand:

These three locales are transformed from the map depiction in Figure 4 to a service corridor model shown in. This service corridor model is a linear representation of the three linked locales that focuses on the travel flow from one locale to another. There are 6 possible combinations of travel routes between the three locales. Distance for each route is estimated by mapping cities in the center of each locale to one another via MapQuest (Atlanta, Doraville, and Buford for City of Atlanta, Chamblee, and North Gwinnett respectively).

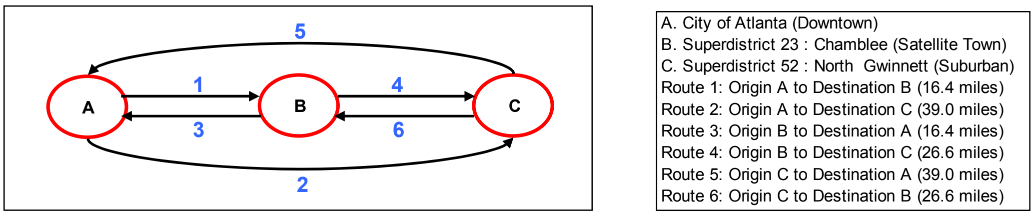


Figure 5. COAV Service Corridor Model

Origin-destination matrix (O-D matrix) is an N x N matrix that shows the travel flow from N origins to N destinations including internal flows and it is a commonly used method to define travel flow in transportation research. The ideal O-D matrix for the Atlanta Regional case study would be actual historical travel data recorded by transportation authorities such as the Georgia Department of Transportation (GDOT) and the Atlanta Regional Commission (ARC). Unfortunately, data acquisition with these two main sources came short since O-D matrix information was only available for larger compositions of locales such as at the county-level. Hence, the travel flow model for this study was switched from an empirical-based model to a hypothetical-based model using the gravity model. The gravity model is a modification of Newton's Law of Gravitation that is widely used by social scientists to predict movement of people, information, and commodities between different locations[11]. This model takes into account the population size and the distance between two places, relying on the idea that larger places have greater attractions than smaller places. The relative strength of a bond between two places is determined by the product of the two population sizes divided by the squared distance between the two places. A constant is typically multiplied to this value as a calibration or conversion factor identical to the universal gravitational constant G.

The target travelers for this study are commuters. Intuitively, higher total employment at the destination location (E_D) directly implies a greater attraction to commute to the destination location, while higher population size at the origin location (P_O) indicates a greater urge for locals to job search outside the origin locale due to competition and limiting employment. Note that internal flows are neglected as they are not significant for the purpose of this study. Hence, if the gravity model is to be used to predict travel flow of commuters, it is reasonable to compute travel flow as P_O multiplied by E_D divided by the distance between the two locations squared. Fortunately, P_O and E_D data are easily available. Hence, a hypothetical O-D matrix is generated a shown in Figure 6. The proportion of each route can be interpreted as the likelihood of generating each route in the simulation.

O-D Matrix	Atlanta (A)	Chamblee (B)	North Gwinnett (C)
(A)	N/A	7,011	422
(B)	10,347	N/A	281
(C)	1,542	696	N/A

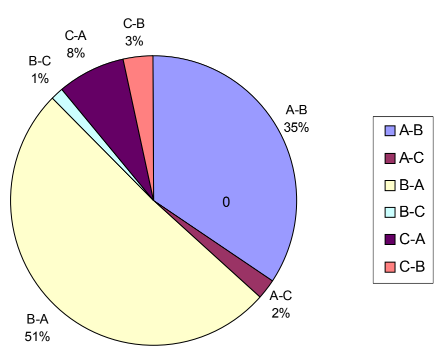


Figure 6. Estimated Travel Flow based on Hypothetical O-D Matrix Model

Transportation Resources:

The transportation resources available to all three locales are automobiles, COAV Air Charters, and COAV Rentals. There are two key assumptions in terms of COAV services. First, vehicle performance level is assumed adequate for the operations of COAV service providers. Second, infrastructure readiness in each locale is assumed adequate for the operations of COAV service providers. Metropolitan Atlanta Rapid Transit Authority (MARTA) is the local transit provider that services the entire City of Atlanta limits within the I-285 perimeter. For this study, MARTA services the locales of City of Atlanta and Chamblee (Doraville NE10) but not North Gwinnett. Clearly, it is impossible to choose MARTA for routes 2, 4 and 6 and it makes little sense to choose MARTA for routes 5 although it is theoretically possible by first commuting to the nearest MARTA portal in Chamblee before proceeding to City of Atlanta. To include these set of logic into the agents' set of rules, residents of North Gwinnett who insist to commute to the other two locales via MARTA will pay a huge premium in the form of the distance from origin to portal being equal to the distance from North Gwinnett to the nearest MARTA portal (Chamblee), a premium that will clearly yield a high disutility for the mode choice.

Personal Income:

Personal income information is the only socioeconomic data used for this study since it is a critical attribute for computing value of time. Raw income data in percentile formats are acquired from the Atlanta Census 2000, a collaborative effort between the ARC and the Fiscal Research Program of the Andrew Young School of Policy Studies at Georgia State University[12]. A non-linear regression fit of the percentile data is required. Income data can be regarded to mimic the behavior of a classical growth method. The most frequently used and most generalized growth model is the Richards growth curve[13] defined by:

$$Y = \{1 - \beta_1 exp(-\beta_2 \kappa)\}^{\frac{1}{1-\beta_3}} \tag{7}$$

Here, κ is set to be Income. Using commercially available statistical software (JMP), a non-linear regression is fitted for the income percentile data and values for the remaining three fitting parameters (β_1, β_2, and β_3) are obtained for each locale. Solution for income is analytically solved as follows:

$$Income = \frac{1}{\beta_2} ln\left\{ \frac{1}{\beta_1}\left[1 - \left(\frac{Y}{\beta_1} \right)^{1-\beta_3} \right] \right\} \tag{8}$$

where Y is a random number generated over a normal distribution. Fitting parameters and the root mean square errors (RMSE) are provided in the Appendix section.

Simulation & Sensitivity Studies:

Simulations using this agent-based model involve a careful selection of two types of variables/assumptions: uncertainty variables and/or agent defining variables. These variables are then assigned distributions or known probability of occurrence such that the sampling data mimics the mental model anticipated by the analyst. Commercially available Monte Carlo Simulation software (Crystal Ball) is used to perform the simulation studies. Simulation variables/assumptions are listed as follows:

Table 4. Simulation Variables/Assumptions

Variables/Assumptions	Symbol	Distribution	Description*
Route selection	Route	Discrete probability	Based on O-D matrix probability
Annual income	income	Equation (8)	$
Value of time	vot	-	$ Annual Income / 2080 hours
% of licensed pilot	license	Discrete probability	0.5% licensed. Remaining unlicensed
Origin to portal distance_transit	D1 Gen Marta	Triangular distribution	(0, 2.5, 5) miles. Similar for MARTA and COAV.
Dest to port distance_transit	D3 Gen Marta	Triangular distribution	(0, 2.5, 5) miles. Similar for MARTA and COAV.
Origin radius_route	radiusOroute	Uniform distribution	(1, 6.5) miles. Similar for route 1 thru 6.
Destination radius_route	radiusDroute	Uniform distribution	(0, 2.5) miles. Similar for route 1 thru 6.
Origin portal time delay	OPortalDelay	Triangular distribution	(0, 0.25, 0.5) hour. Similar for MARTA and COAV.
Destination portal time delay	DPortalDelay	Triangular distribution	(0, 0.25, 0.5) hour. Similar for MARTA and COAV.
Congestion delay_auto	Congestion delay	Triangular distribution	(0.2, 0.3, 0.5) hours. Negatively skewed.
Ownership annual cost_auto	Owncost	Triangular distribution	(2000, 3500, 5000) $.

* For uniform distributions, (X, Y) implies (min, max). For triangular distributions, (X, Y, Z) implies (min, most likely, max)

Simulation forecasts are listed as follows:

Table 5. Simulation Outputs/Forecasts

Forecasts	Symbol	Units
Total travel distance	distance	Mile
Total travel time	travel time	Hour
Probability of auto selected	Prob_auto	%
Probability of MARTA selected	Prob_marta	%
Probability of COAV charters selected	Prob_charters	%
Probability of COAV rentals selected	Prob_rentals	%
Mode choice selection_auto	N_auto	Counts
Mode choice selection _MARTA	N_Marta	Counts
Mode choice selection _charters	N_charters	Counts
Mode choice selection _rentals	N_rentals	Counts
Average net income	Net Income	$
NPV for given r%_charters	NPV_charters	$
NPV for given r%_rentals	NPV_rentals	$
Calculated IRR_charters	IRR_charters	%
Calculated IRR_rentals	IRR_rentals	%
Break even year_charters	Break Even Charters	Year
Break even year_rentals	Break Even Rentals	Year

Since sensitivity analysis is performed, we want to ensure the same runs are maintained for each of the 10,000 cases. Hence, the sequence of random numbers is generated using an identical initial seed value. The key output of the ABM simulation is percentage market share captured by each mode choice. This output is used to estimate the daily trip demand of COAV services for business models evaluation and sensitivity study. Other outputs of the ABM simulation are mean travel time, mean annual trip cost, and mean selection probability for each mode choice.

In the sensitivity study, each variable is perturbed around a baseline value such that the impact of those perturbations can be assessed on the travel and business forecasts generated by the ABM. There are two categories of variables. *Simulation-sensitive variables* are variables that affect the ABM simulation outcome when perturbed. *Simulation-insensitive variables* are variables that do not affect the ABM simulation outcome when perturbed. The ABM simulation is rerun every time a simulation-sensitive variable is perturbed since the percentage market shares captured by COAV as well as other simulation output have changed. Table 6 shows the sensitivity variables that are being investigated. When average vehicle cruise speed is varied, actual travel time via COAV modes changes. This alters agents' perspective of COAV utilities in the simulation model. When total operating cost and required rate of return are varied, COAV service pricing is also varied. Subsequently, COAV services are offered at a varying price to the customers in the simulation model, which also alter agent's perspective of COAV utilities. Hence, these three variables are simulation-sensitive variables. Besides altering the percentage market captured by COAV modes, variations of these three variables modify other trip-related outputs. One particularly important output is the mean travel time per trip, computed as the mean trip distance divided by the mean block speed of samples collected ONLY when COAV modes are selected. This output is important in capturing the dual-effects of increasing vehicle speed; reduction in travel time or increase in travel distance. When computed for COAV Charters and COAV Rentals specifically, mean travel time per trip is used to predict the number of vehicles required by the service provider to cater the estimated daily trip demand, thus, affecting the entire business forecasts. Meanwhile, vehicle acquisition cost, nominal discount rate, and corporate tax rate are strictly business-related variables that do not affect the outcome of simulation models. At the end of each sensitivity analysis, a macro script is executed to iteratively solve for the IRR using MS Solver function.

Table 6. Sensitivity Variables for Project Evaluation of COAV Models

Variables	Units	Min	Baseline	Max
Average vehicle cruise speed	Mph	150	200	250
Total operating cost (price?)	$/hour	50	100	150
Required rate of return	%	10%	30%	50%
Vehicle acquisition cost	$	80,000	140,000	200,000
Nominal discount rate	%	7	10	13
Corporate tax rate	%	14	34	34

IV. Results & Discussions

Forecasts such as mode choice selection count, selection probability, travel time, trip cost, and business models forecasts are extracted for the baseline case study as shown below:

Table 7. ABM Simulation Mode Choice Selection Count for Baseline Case

Mode Choice	Selection Count	% Market Share
Automobile	7,192	71.92%
MARTA	2,622	26.22%
COAV Air Charters	154	1.54%
COAV Rentals	32	0.32%
Total counts	*10,000*	*100%*

Table 8. Business Forecasts for Baseline Case

Business Forecasts	COAV Air Charters	COAV Rentals
Average Net Income	$1,406,938	$300,151
NPV for given discount rate	$6,426,005	$1,404,255
IRR	27.93%	29.69%
Breakeven year	4	4
Total capital investment	$8,540,000	$1,680,000
Profitability Index	0.75	0.84
Percentage market share captured	1.54%	0.32%
Fleet size (Number of aircraft acquired)	61	12

Perturbations of COAV average vehicle speed can be interpreted as a translation of technology benefits into the travel behavior and business performance of COAV service provider. Table 9 shows the output recorded when average vehicle speed is varied for 150 mph and 250 mph (baseline = 200 mph). The first observation made is that percentage market share captured by both COAV modes decreased when speed is decreased. Unexpectedly, for the scenario with lower vehicle speed, the number of COAV Air Charters vehicles required to cater the lower daily trip demand increased from 61 to 72. Slower vehicles increases the mean travel time per trip for the scenario, which appears to be more dominant than the reduction in daily trip demand, causing the business model to acquire more (but slower) vehicles. Realistically, slower vehicles should be less expensive than faster vehicles if all else remains equal, producing a possible self-correcting mechanism for this scenario. Future expansion of this model will attempt to capture these implicit factors.

Table 9. Forecast Comparisons for Changes in COAV Average Vehicle Speed

	Forecast Attributes	Speed = 150	Baseline(200mph)	Speed = 250
COAV Charters	Average Net Income	$1,655,699	$1,406,938	$2,099,256
	NPV for given discount rate	$7,555,128	$6,426,005	$9,621,536
	IRR	27.87%	27.93%	28.17%
	Breakeven year	4	4	4
	Total capital investment	$10,080,000	$8,540,000	$12,600,000
	Profitability Index	0.75	0.75	0.76
	Percentage market share captured	1.31%	1.54%	1.76%
	Fleet size (Number of aircraft acquired)	72	61	90
COAV Rentals	Average Net Income	$260,127	$300,151	$423,586
	NPV for given discount rate	$1,164,343	$1,404,255	$1,815,049
	IRR	26.66%	29.69%	24.39%
	Breakeven year	5	4	5
	Total capital investment	$1,680,000	$1,680,000	$3,080,000
	Profitability Index	0.69	0.84	0.59
	Percentage market share captured	0.21%	0.32%	0.38%
	Fleet size (Number of aircraft acquired)	12	12	22

Percentage market share captured by both COAV modes increased dramatically as COSP is lowered to $50 per hour. This calls for more vehicles to serve the daily trip demand, generating higher Average Net Income than the other two scenarios. Despite the much higher NPV when COSP is low, the risk versus reward accountability is not justifiable since PI and IRR are also much lower. This situation is because service pricing (which dictates revenues) is a marked-up value of COSP by RoR (fixed at 30%) for this analysis. When COSP is sufficiently low and RoR is fixed, recovery of the $37.1 million in capital investment of COAV Charters becomes challenging. The inference from this sensitivity study is that capturing all demands of the marketplace may not necessarily be the optimal business solution if the revenues generated from the investment are not worth the risks involved.

Table 10. Forecast Comparisons for Changes in COAV Cost of Services Provided

	Forecast Attributes	COSP = $50/hr	Baseline($100/hr)	COSP = $150/hr
COAV Charters	Average Net Income	$2,617,697	$1,406,938	$627,414
	NPV for given discount rate	$6,969,714	$6,426,005	$3,168,500
	IRR	14.95%	27.93%	38.21%
	Breakeven year	7	4	3
	Total capital investment	$37,100,000	$8,540,000	$2,520,000
	Profitability Index	0.19	0.75	1.26
	Percentage market share captured	6.73%	1.54%	0.44%
	Fleet size (Number of aircraft acquired)	265	61	18
COAV Rentals	Average Net Income	$695,177	$300,151	$52,838
	NPV for given discount rate	$2,060,766	$1,404,255	$250,902
	IRR	16.00%	29.69%	30.95%
	Breakeven year	6	4	4
	Total capital investment	$8,960,000	$1,680,000	$280,000
	Profitability Index	0.23	0.84	0.90
	Percentage market share captured	1.70%	0.32%	0.04%
	Fleet size (Number of aircraft acquired)	64	12	2

Required rate of return (RoR) or hurdle rate is commonly used by corporations to intuitively investigate how much profit margin is needed on products or services sold in order to generate net income. Clearly, a higher profit margin indicates higher cash flows (i.e. higher NPV and Net Income), as seen in Table 11. For this sensitivity study, RoR of 10% appears to be too low for the business models to turn profits over investment despite the increase in percentage market share captured. This situation can be viewed as a classical price slash tactic to capture greater market shares in the expense of revenue loss. However, a price mechanism that dynamically adjusts itself towards equilibrium while appreciable market share is acquired needs to be present, one that does not exist for this model.

Table 11. Forecast Comparisons for Changes in COAV Required Rate of Return

	Forecast Attributes	RoR = 10%	Baseline(30%)	RoR = 50%
COAV Charters	Average Net Income	-$358,308	$1,406,938	$1,791,414
	NPV for given discount rate	-$5,610,527	$6,426,005	$9,447,934
	IRR	-2.15%	27.93%	47.97%
	Breakeven year	-1	4	3
	Total capital investment	$15,680,000	$8,540,000	$5,180,000
	Profitability Index	(0.36)	0.75	1.82
	Percentage market share captured	2.83%	1.54%	0.92%
	Fleet size (Number of aircraft acquired)	112	61	37
COAV Rentals	Average Net Income	-$75,566	$300,151	$292,455
	NPV for given discount rate	-$1,254,990	$1,404,255	$1,543,755
	IRR	-1.66%	29.69%	48.21%
	Breakeven year	-1	4	3
	Total capital investment	$3,640,000	$1,680,000	$840,000
	Profitability Index	(0.34)	0.84	1.84
	Percentage market share captured	0.68%	0.32%	0.15%
	Fleet size (Number of aircraft acquired)	26	12	6

The next sensitivity studies involve perturbation of key business assumptions such as vehicle acquisition cost, nominal discount rate, and corporate tax, as shown in. Impact of these perturbations will influence business model performance forecasts but will not affect aggregated agents' behavior at large, as discussed earlier. However, these key assumptions significantly affect the business forecasts and these sensitivity studies prove to be pertinent in investigating the business performance of the COAV service provider models. Discussions of these analyses are provided below and the results are attached in the Appendix.

When vehicle acquisition cost is reduced, NPV for the project increases as anticipated. The greater finding of this study is that IRR is extremely sensitive to the change in initial capital expenditure due to the urgency to break even before the project period expires. Hence, if vehicle manufacturers and service providers can affiliate to lower the acquisition cost, the investment proposal would appear much more appealing particularly to creditors and shareholders because of the highly optimistic IRR or high PI value.

There exist intangible elements such as risks and volatility that are being considered in the expression of nominal interest rate. Here, we are assuming a commonly used value of 3% for inflation rate while varying nominal discount rate from 7% to 13%. Table 14 shows that a 3% variation of the discount rate causes up to 22% variation in the NPV. The generalized observation from this study is that it is pivotal to consider all elements, tangible or not, in the projection of the nominal interest rate because of the sensitivity of NPV. Essentially, the worth of a project can be significantly overvalued or undervalued because of a small error in the nominal discount rate prediction.

Realistically, development of disruptive technologies such as PAV requires tremendous efforts from all parties. The U.S. government has always been allocating incentives and tax credits to the R&D expenditures for certain industry. Disregarding the actual complication of tax breaks and credits, we assume a 20% reduction in corporate taxes for the first 8 years of COAV service provider operations. The business forecasts are shown in Table 15.

V. Conclusion

A methodology to assess business models as part of a hypothesized future air transportation system has been introduced. This methodology employs a system-of-systems design technique starting with the abstraction of the transportation system and ending at the sensitivity analysis of key design parameters. The primary goal of this paper that is to model and assess a family of PAV business models has been achieved. Along the way, the agent-based approach adopted for the implementation of this simulation platform has opened many doors to research questions pertaining to modeling complex systems and behaviors. Simulation studies of the Atlanta Regional Transportation System reveal insights on the market entries of PAV service providers into an existing transportation system. Key attributes that define the success of COAV are also discussed through sensitivity studies. One of the main findings is that capturing all demands of the marketplace may not necessarily be the optimal business solution if the revenues generated from the investment are not worth the risks involved.

The hypothetical travel demand model is used to project travel flows for this Atlanta Regional modeling and simulation study, implying that the model remains more hypothetical than it is empirical. While numerical findings of this study are plentiful, they are relative rather than absolute. Nonetheless, this does not dishearten the fact that the model captures a great amount of details on the market behavior in respond to business assumptions. The cyclical links between simulation-sensitive variables and simulation output are not fully utilized since these studies are performed at a single timeframe. A time-series ABM simulation would be capable of investigating the system behaviors within a time-variant transportation environment, such as pricing-mechanisms, competition/game theories, and market-driven technology development schemes.

Future work on this research track includes modeling other transportation environments that are more appropriate for the intentions of investigating personal mobility solutions such as intercity models. Future models would attempt to link more vehicle and infrastructural attributes to the simulation environment in order to perform more technology-oriented sensitivity studies. Treatment of intangible factors and time variance will also be addressed. In summary, the developed model contribute towards the foundation for creating a robust and adaptive design methodology that allows experts in fields other than aerospace engineering to contribute their expertise towards the realization of this very diverse and dynamic future air transportation system. Conveying this knowledge and information to decision makers will help guide the path of technology development of future air vehicles in the right direction and at a faster pace, taking us a step closer towards the vision of on-demand, doorstep-to-destination, personal mobility.

Acknowledgments

The authors would like to thank Mr. Mark Moore at NASA Langley Research Center for his guidance and sponsor for this research under grant (NAS3-00179/L-70884-D).

Appendix

Table 12. Richards Growth Curve Non-linear Regression Fitting Parameters and RMSE

Parameters	City of Atlanta (A)	Chamblee (B)	North Gwinnett (C)
β_1	1.045556	0.991667	-0.115511
β_2	0.000019	0.000020	0.000029
β_3	-0.118026	0.453496	1.023723
RMSE	0.006964	0.008254	0.006328

Table 13. Forecast Comparisons for Changes in COAV Vehicle Acquisition Cost

	Forecast Attributes	Acq Cost = $80K	Baseline ($140K)	Acq Cost = $200K
COAV Charters	Average Net Income	$1,708,888	$1,406,938	$1,104,988
	NPV for given discount rate	$9,096,384	$6,426,005	$3,755,627
	IRR	49.69%	27.93%	17.90%
	Breakeven year	3	4	6
	Total capital investment	$4,880,000	$8,540,000	$12,200,000
	Profitability Index	1.86	0.75	0.31
COAV Rentals	Average Net Income	$359,551	$300,151	$240,751
	NPV for given discount rate	$1,929,576	$1,404,255	$878,935
	IRR	52.37%	29.69%	19.30%
	Breakeven year	3	4	6
	Total capital investment	$960,000	$1,680,000	$2,400,000
	Profitability Index	2.01	0.84	0.37

Table 14. Forecast Comparisons for Changes in Nominal Discount Rate

	Forecast Attributes	R = 7%	Baseline (10%)	R = 13%
COAV Charters	Average Net Income	$1,406,938	$1,406,938	$1,406,938
	NPV for given discount rate	$8,248,314	$6,426,005	$4,892,840
	IRR	27.93%	27.93%	27.93%
	Breakeven year	4	4	5
	Total capital investment	$8,540,000	$8,540,000	$8,540,000
	Profitability Index	0.97	0.75	0.57
COAV Rentals	Average Net Income	$300,151	$300,151	$300,151
	NPV for given discount rate	$1,780,392	$1,404,255	$1,087,847
	IRR	29.69%	29.69%	29.69%
	Breakeven year	4	4	5
	Total capital investment	$1,680,000	$1,680,000	$1,680,000
	Profitability Index	1.06	0.84	0.65

Table 15. Forecast Comparisons for Changes in Corporate Tax Rate

COAV Charters Forecasts	Tax = 14%	Baseline (34%)
Average Net Income	$1,833,283	$1,406,938
NPV for given discount rate	$8,903,123	$6,426,005
IRR	33.45%	27.93%
Breakeven year	4	4
Total capital investment	$8,540,000	$8,540,000
Profitability Index	1.04	0.75
COAV Rentals Forecasts		
Average Net Income	$391,106	$300,151
NPV for given discount rate	$1,934,019	$1,404,255
IRR	35.60%	29.69%
Breakeven year	4	4
Total capital investment	$1,680,000	$1,680,000
Profitability Index	1.15	0.84

References

[1] "Business Jet Market Overview," Teal Group Market Survey, www.AVbuyer.com, August 2004.

[2] Downen, T.D., Hansman, R.J., "Identification and Analysis of Key Barriers to the Utility of General Aviation," *Journal of Aircraft*, March-April 2003.

[3] Lewe, J.-H., DeLaurentis, D.A., Mavris, D.N., "Foundation for Study of Future Transportation Systems through Agent-Based Simulation," *24th ICAS Congress*, Yokohama, Japan, August 29- September 3, 2004.

[4] DeLaurentis, D.A., Lewe, J.-H., Schrage, D.P., "Abstraction and Modeling Hypothesis for Future Transportation Architectures," AIAA paper 2003-2514.

[5] DeLaurentis, D.A., Lim, C., Kang, T., "An Approach to Modeling of Mobility Architectures and Characterization of Solution Spaces for Conceptual Air Vehicles," *Journal of Aircraft*, January-February 2004.

[6] Graham, J., Harvey, C., "How do CFOs Make Capital Budgeting and Capital Structures Decisions?" *Journal of Applied Corporate Finance,* pp. 8, Volume 15, Number 1, Spring 2002.

[7] "Corporate and Individual Tax Rates," http://www.smbiz.com/sbrl001.html#ci, August 2004.

[8] "Publication 946 (2003), How to Depreciate Property", http://www.irs.gov/publications/p946/index.html, August 2004.

[9] Lewe, J.-H., Upton, E.G., Mavris, D.N., Schrage, D.P., "An Agent-based Framework for Evaluating Future Transportation Architectures," AIAA paper 2003-6769.

[10] "The Cost of Traffic Congestion in the Atlanta Region: The Region's 20 Worst Traffic Jams and the Steps Needed to Relieve Traffic Congestion," The Road Information Program (TRIP), Washington, DC, May 2003.

[11] Rosenberg, M.T., "Gravity Model: Predict the Movement of People and Ideas between Two Places," http://geography.about.com/library/weekly/aa031601a.htm, August 2004.

[12] ATLANTACENSUS2000, http://atlantacensus2000.gsu.edu/sur.htm, August 2004.

[13] Gille, U., "Analysis of Growth", http://www.uni-leipzig.de/~vetana/growthe.htm, August 2004.