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Design of an Inter-Regional Transportation Planning Decision Support Tool

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Abstract: The transportation sector within the U.S. comprises numerous modes of transport that service short haul routes (under 250 miles). Advances in technology such as composites, batteries, and DC motors have altered the cost and development of air transportation. Taking these advances into account, a Decision Support Tool (DST) was developed in the form of a graphical user interface, utilizing economic aviation theory to map out the various economic statistics associated with alternate city pairings. A case study was conducted analyzing the Essential Air Service (EAS), a U.S. government program enacted to guarantee small communities within the U.S maintain commercial service. Utilizing the DST, it was determined that 29%, 27%, and 25% of the 82 short haul routes were profitable when airfare sensitivity was inelastic, slightly elastic, and elastic respectively. Six routes are optimal for a 100-seat vehicle (7.3%). Once routes were optimized, 97% of routes were profitable regardless of elasticity.

Keywords: Transportation, Hybrid Vehicle, Aviation, MATLAB, Climate, Systems Engineering, Decision Support Tool

1. Context Analysis

1.1 General Transportation Statistics

Within the United States, 13% of total travel takes place on public transit, with 15% of these daily trips being taken for commuting purposes (MTI 2022). In general, 30% of travel pertains to inter-regional or short haul commute. Short haul transportation, when referenced in this project, refers to travel between an origin-destination pair where distance is less than 250 miles. Approximately 7,918,125 total trips that took place in the United States were between 100 and 250 miles. Within 50 and 100 miles, 19,117,670 traveled locally in the United States (MTI 2022).

Short haul transportation in the United States has three factors that play a major role in its overall utilization: Cost, environmental impact (CO2 Emissions), and time. Cars are optimal for extremely short distances, but as distance increases, overall efficiency decreases. Planes and trains take much less time to transport passengers as the distance begins to increase. Cars emit the most carbon per passenger, making emission from planes and trains look minimal in comparison. Per mile, cars are the cheapest, whereas the cost to travel via plane or train exponentially increases simultaneously with distance. Note that none of these three modes of transport dominate the market. In other words, each form of transportation has a tradeoff (BTS 2021).

With no mode of transportation completely dominating the United States transportation sector, new modes of transport are likely to compete with current forms as technology continues to advance. For example, lighter than air vehicles are currently being developed that are close to carbon neutral, but are less optimal for longer commutes due to their low average velocity.

1.2 Enterprise

The United States regional economy is in need of new forms of transportation due to economic, social, and regulatory forces. Transportation is the engine of the economy and increases overall quality of life. It is highly regulated to ensure public safety. Increased emphasis on climate change has shifted public opinion towards more environmentally friendly modes of transport. In order to address these various forces, technology has had to advance; more specifically, new modes of transport have been developed to take each acting force into account.

1.3 Essential Air Service

The Essential Air Service (EAS) is a U.S Government program enacted to guarantee that small communities in the U.S, which had been served by certificated airlines prior to deregulation in 1978, maintain commercial service. The EAS program allows the Department of Transportation to grant subsidies to provide service to communities that would otherwise be underserved. Smaller rural markets that do not have access to main line transportation benefit from this program. There are just over 160 EAS airports in the U.S., with around 82 routes considered short-haul. In order to be eligible for EAS, three basic requirements must be met (Essential Air Service 2017):

- The airport must have a per-passenger subsidy rate of $200 or less unless the community is more than 210 miles from the nearest medium or large hub airport.
- While in the EAS Program, the community must have an average of 10 or more enplanements per day to qualify for EAS funding
- The community must be located more than 70-highway-miles from the nearest medium or large hub airport

1.4 Economic Aviation Theory

Economic Aviation Theory is based on a complex relationship between Revenue, Cost, Profit, and Airfare depicted in Figure 1. Two assumptions must be made for the economic model: revenue is driven by demand and cost is driven by fuel price, labor, and aircraft performance.

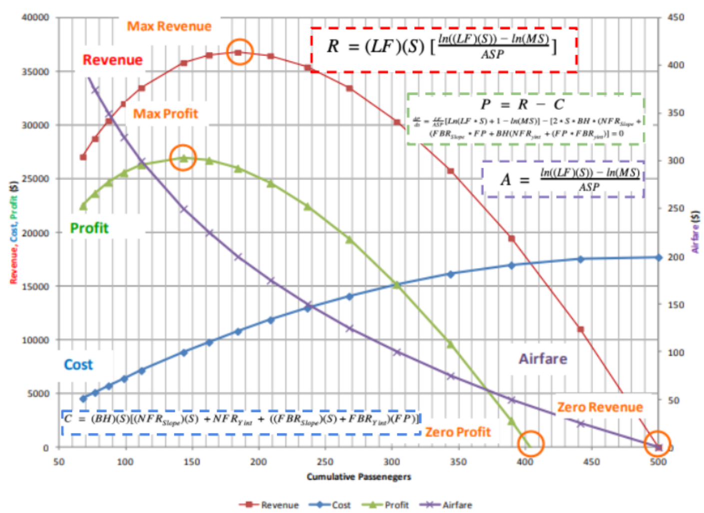

Figure 1. Complex non-linear relationship between revenue (red), based on airfare vs demand (magenta), cost (blue), and profit (green)

The equations found within this model are dependent on numerous variables such as Block Hours (BH), Non-Fuel Rate (NFR), Fuel Burn Rate (FBR), Fuel Price (FP), Market Size (MS), and Airfare Sensitivity (ASP). Airline companies are able to utilize these equations to determine the optimal number of seats for a specific air vehicle, which in turn allows them to determine maximum profit and revenue.

2. Stakeholder Analysis

Advancements in technology are dependent on the opinions and roles of different stakeholders associated with the United States transportation sector. These stakeholders are grouped into three different categories: passengers, regulators and third-party. Passengers are anyone who will be utilizing the system to travel between destinations. Third-party stakeholders are the companies and individuals that have some impact on the aviation industry (investors and suppliers). Regulators include Air Traffic Control, US Environmental Protection Agency, Department of Homeland Security, Planning Department of District, Government, Federal Aviation Administration, and Regional Jet Operators/Manufacturers. Passengers' primary concern is the safety of their ride. The primary goal of third-party stakeholders is the monetary success of the system. The goals of the regulators and government are to implement safety rules and funding to the system.

3. Performance Gap (AS-IS), Problem and Need Statement

After conducting stakeholder interviews, a performance gap was found within the Hybrid Air Vehicle Marketing process. This gap can be attributed to Hybrid Air Vehicle companies' inability to make effective marketing decisions. Current decision-making regarding hybrid air vehicle placement is based on intuition and gut feeling. Without a quantitative method to identify optimal transportation routes, companies struggle with attaining monetary support when marketing their hybrid air vehicles to regional economies.

After determining the performance gap, the problem with the Hybrid Air Vehicle Marketing process is clear; current transportation decision making models cannot account for the characteristics associated with advances in technology and changing policy. Therefore, there's a need for a new model that can account for advances in technology and changing policy related to short haul transportation planning.

4. Concept of Operations (TO-BE)

The proposed concept of operations, in the form of a desktop application, allows decision makers to view the design space linked with short haul transportation. This will further enable the improvement and variability of the transportation sector in the United States. All of the inputs of the desktop application come directly from Economic Aviation Theory discussed in section I. The only additional inputs not discussed previously are the longitude and latitude values used to calculate distance. Outputs, much like the discussed inputs, are returned by the Economic Aviation Theory equations shown in *figure 1*.

5. Requirements

The Project Requirements are split up into mission and design requirements. A selected sample of these requirements are listed below:

5.1 Mission Requirements

- **MR.1** The system shall output an analysis of economic feasibility for modes of transportation
- **MR 5.4.7** The interface page shall output a 3D graph with the x, y, and z axis representing market size, airfare sensitivity, and the user's selection (profit, revenue, cost, seats) respectively

5.2 Design Requirements

- **DR.1** The system shall output a distance using the haversine function corresponding to two inputted longitude and latitude values with 99% accuracy
- **DR.2** The system shall utilize the following values: block hours, seats, non-fuel rate, fuel burn, and fuel price in order to calculate and graph Cost per trip with 95% accuracy

6. Prototype/Implementation

The prototype, in the form of a Graphical User Interface, was developed in MATLAB, a software tailored towards data collection and visualization. The Application consists of 8 pages, each providing the user with functionality which supports the marketing of a specified hybrid air vehicle.

Figure 2 displays the interconnection of each page found within the tool. Note that two packages are used: MATLAB App Designer and MATLAB Geoaxis. Excel is used to transport and store data.

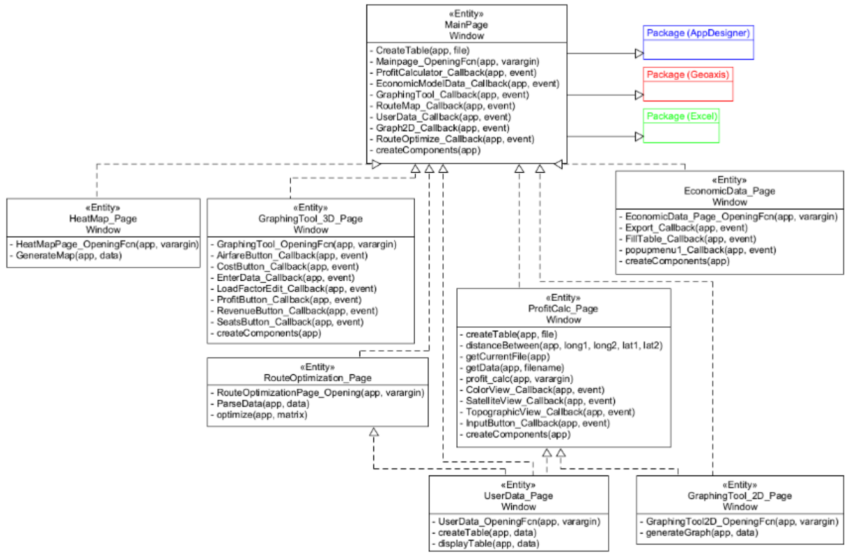

Figure 2. Basic class diagram depicting the relationships between pages of the application

The tool itself will allow decision makers to complete three tasks to assist in both their transportation planning and route selection. For task 1, users input Origin-Destination (O-D) pairings and the tool will provide them with profit, revenue, cost, and airfare data. This will drive the other pages of the application, as creating files full of O-D pair data will ensure the other tasks are properly completed. The functionality supported in the Economic Model Calculator, User Data, and 2D graphing tool page are tailored for this task.

Task 2 should be used when the decision maker may have more freedom as to the characteristics of their hybrid vehicle (initial conception), or may want to revise and optimize the vehicle to ensure its continued usage in the transportation market (Post Development). The tool works well in both cases, as it can provide decision makers ways to view the design space associated with Short Haul transport. Users can input ranges of seat values and the tool will output generic route variables. Rather than inputting data for a predetermined route pairing, a user can find an O-D pair that matches the data generated. The 3D graphing and Economic Model data page both assist in completing this task.

The final task is about optimizing data inputted and collected by the tool. By inputting already generated data, users are able to create optimized reports, while simultaneously viewing which routes are profitable. The Route optimization and Route Map page allow for the creation and viewing of these optimized route pairings.

7. Case Study: Essential Air Service

A case study was conducted focusing on the Essential Air Service (EAS), a U.S. government program enacted to guarantee that small communities within the United States maintain commercial service. The EAS provides aviation transport to 160 different locations across the country, with 82 being considered “Short Haul” routes. Using the Bureau of Transportation Statistics (BTS), these routes were mapped out and inputted into the developed decision support tool. BTS had data associated with the number of passengers per flight, the distance between each flight, and the frequency of each flight. In the case of EAS routes, flight frequency was always 1, which intuitively speaking makes sense considering these aren't profitable routes. Using flight frequency and total number of passengers per day, daily market size was determined for each route.

Once the routes were compiled and market size was calculated, 7 assumptions had to be made before the decision support tool could be used. Fuel Price, non-fuel rate, fuel burn rate, speed, load factor, airfare sensitivity, and seat size were assumed to be 3 $/gallon, 5 $/seat-hour, 2 gallons/seat-hour, 65 MPH, 0.8 passengers per seats, -0.004, and 100 seats respectively. A less negative value for airfare sensitivity means people are more likely to buy a ticket regardless of price. To account for this, the case study was split into three segments. Each section accounts for analyzing data with either Inelastic (-0.004), Slightly Elastic (-0.007), or Elastic (-0.01) ASP.

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Using the tool, or more specifically the economic calculator page, it was determined that of the routes selected, 29%, 27%, and 25% were considered profitable when airfare sensitivity was Inelastic, Slightly Elastic, and Elastic respectively. As elasticity of demand increased, there was a slight decrease in the number of profitable routes, however, the average profit per flight decreased substantially. Regardless of elasticity of demand, the potential gain was enough to pursue each route listed to be profitable. Whether a route was profitable or not did not necessarily depend on the time of travel, but rather, the market size of the route in question. Revenue, Airfare, and Profit followed a logarithmic function as Market size increased.

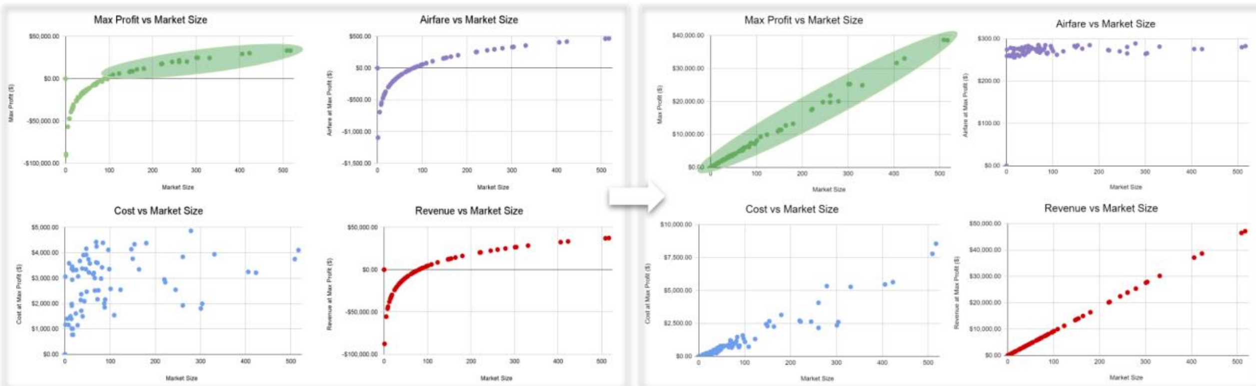

Figure 3. Non optimized vs Optimized data for Profit, Airfare, Cost, and Revenue vs Market Size

Figure 3 depicts eight graphs, each one plotting the EAS route data for inelastic demand. Market size represents the x value and profit, airfare, cost, and revenue represent the y value respectively. The graphs on the left side are non-optimized, whereas values on the right are optimized by the tool. The graphs for Max Profit, Airfare, and Revenue displayed on the left side of *figure 3* follow a logarithmic function when viewed against market size. The function for Cost does not follow any particular trend. The graphs help depict how for less desirable routes and the assumptions previously made, roughly 70% of the routes are concentrated in the negative y axis, meaning the routes are not profitable.

By utilizing route optimization functionality provided by the DST, the graphs on the right side of Figure 3 no longer follow a logarithmic function, but rather, follow a linear function. Roughly 97% of routes become profitable, a 70% increase from the non-optimized data. As Market Size increases, the maximum profit of a specific route increases. Airfare does not vary much for the optimal route pairings. Table 1 displays four sample routes and their corresponding statistics before and after optimization.

Table 1. Non optimized and Optimized data for Profit, Airfare, Cost, and Revenue vs Market Size

Market Size (Monthly)	Market Size (Daily)	Revenue For Max Profit	Cost at Max Profit	Airfare	Max Profit	Seats (Optimal)	Revenue For Max Profit	Cost at Max Profit	Airfare	Max Profit	Block Hours
3680	123	$8,603.15	$2,541.00	$107.54	$6,057.91	52	$11,276.86	$1,324.99	$270.33	$9,951.88	2.31
1990	66	-$3,847.44	$3,003.00	-$48.09	-$6,855.03	28	$6,043.72	$827.91	$274.02	$5,215.81	2.73
750	25	-$23,263.02	$3,322.00	-$290.79	-$26,582.37	10	$2,287.14	$343.39	$276.58	$1,943.75	3.02
2215	74	-$1,559.23	$2,519.00	-$19.49	-$4,074.46	31	$6,784.81	$790.80	$270.15	$5,994.01	2.29
3040	101	$4,661.88	$2,574.00	$58.27	$2,085.29	43	$9,259.12	$1,100.96	$270.59	$8,158.16	2.34

The total number of routes that followed a specific seat size range were heavily concentrated towards ranges below 40 seats. 33 routes fell in between 0 - 19 seats, whereas 21 routes fell in between 20 - 39 seats. The distribution of seat size range is depicted in Figure 4.

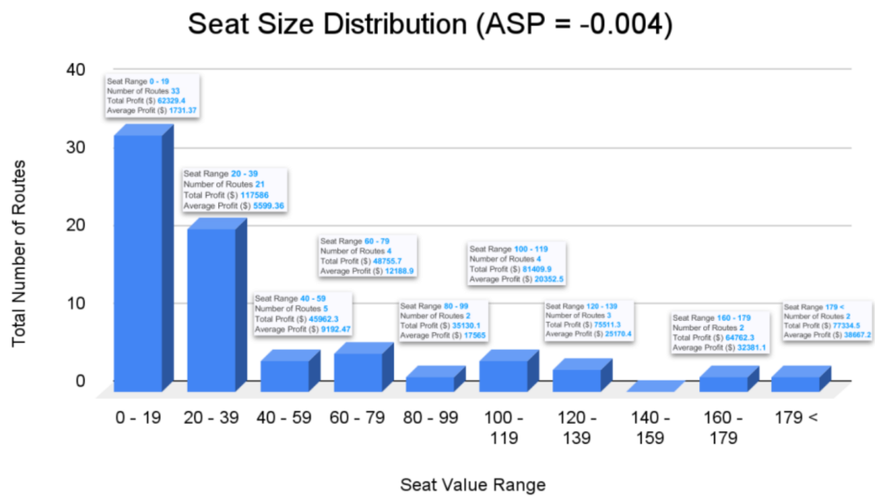

Figure 4. Bar graph of optimal route seat size ranges

8. Conclusion

With the original assumptions, less than 30% of the routes for all levels of elasticity were profitable. Looking at future improvements, smaller aircrafts may provide a hybrid vehicle with the same assumed characteristics, a better chance of competing in the transportation sector. If a company were to have already developed an aircraft with these characteristics, it would be in their best interest to look at a more favorable group of routes. If that is not an option, the average profit per route within 100-119 seats is roughly $20,352, with four optimized routes falling within this range.

For the Essential Air Service routes, a 40 seat lighter than air vehicle, with the specifications used for this analysis, could service 54 of the 82 routes (from figure 15). By reducing overall seat size, more cargo could be shipped out on this aircraft, increasing the calculated profit substantially, while also reducing the total number of passengers required to fill up the aircraft. If the ship is unable to reduce the total number of seats, only 7 of the routes would be beneficial for a 100-seat ship.

It is extremely important to note that this case study looks at a very specific vehicle. When utilizing the tool, vehicles may have completely different fuel burn and non-fuel rates, or they may be much faster than the one analyzed. The possible variation of vehicles is why this tool can be extremely beneficial to the transportation sector as a whole.

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