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Evaluating the Efficiency of a Small Aircraft Transportation System Network Using Planning and Simulation Models

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Abstract

This paper presents an evaluation scheme to determine network efficiency parameters (level of service) for an on-demand air transportation service using NASA's Small Aircraft Transportation System. The analysis employs a large-scale transportation planning model (TSAM) and an operational Monte Carlo network simulation model (MCATS) to study supply and demand network equilibrium conditions for on-demand services. The level of service is an important factor in determining the number of travelers who would use any transportation system including on-demand air taxi services proposed in the SATS Program. In the present version of the Transportation Systems Analysis Model (TSAM) developed by the Air Transportation Systems Laboratory at Virginia Tech (Trani.et al (2003)) it is assumed that SATS services are available within a prescribed accommodation time period (typically one or two hours). This factor is modeled as a schedule delay parameter to account for network inefficiencies. It is also assumed that the cost of using SATS is fixed throughout the network. A life cycle cost model has determined the cost of on-demand services using very light jets to vary from $1.50 to $2.00 per passenger mile.

I. Introduction

The objective of the analysis is to determine the level of service and equilibrium costs of the proposed Small Aircraft Transportation System (SATS). The level of service is an important factor in determining the number of travelers who would use any transportation system including on-demand air taxi services proposed in the SATS Program. In the present version of the Transportation Systems Analysis Model (TSAM) developed by the Air Transportation Systems Laboratory at Virginia Tech (Trani.et al (2003)) it is assumed that SATS services are available within a prescribed accommodation time period (typically one or two hours) . This factor is modeled as a schedule delay parameter to account for network inefficiencies. It is also assumed that the cost of using SATS is fixed throughout the network. A life cycle cost model has determined the cost of on-demand services using very light jets to vary from $1.50 to $2.00 per passenger mile.

The first assumption is optimistic because a finite fleet size and the random nature of the demand at airports will certainly create inequities in the delay experience by passengers across the network. Variable waiting times at airports translate into schedule delays that affect the perceived level of service of the SATS mode thus reducing the demand.

This reduction in the demand in turn leads to a higher level of service. Higher levels of service induce more demand. Therefore it can be expected that the demand would oscillate and converge to a final value. Since service cost, schedule delay, rejection and fleet size are functions of the demand, these variables would follow the same trend as the demand. The behaviors of the demand and level of service parameters (service cost, schedule delay, rejection and fleet size) are included as a set of table functions into the TSAM model. The new demand prediction in the TSAM considers the fleet size and the network effects.

The relationship between the demand and level of service parameters are obtained with an air-taxi scheduling model called MCATS (Toniolo (2004)). MCATS determines the relationship between the demand and the level of service parameters by simulating the air taxi operations for the given region for a specific period of time.

In this paper the variation of the level of service parameters with respect to some causal factors (demand, fleet size) are presented. These relationships are used to model the dynamics between demand and level of service in TSAM. MCATS is run based on daily demand. A scenario was simulated multiple times and the representative values for each scenario are calculated to obtain expected values and included in this paper

During initial runs of the MCATS model the selection of the regions of analysis considers a wide possibility of SATS scenarios (present and future) and included in the TSAM model. This should ensure that users of TSAM would not have to make extrapolations of the results presented in this paper.

This paper consists of two parts: In the first part of the paper the approach employed in this analysis is discussed. The results of this analysis are generated in a tabular format. The second part of this paper explains a methodology adopted to integrate the Transportation Systems Analysis Model (TSAM) and results of MCATS analysis. In order to capture the dynamic interaction between SATS cost and SATS demand, an iterative method is suggested. The final results include SATS costs ($/seat-mile), fleet sizes, average passenger per flight, and average percentage of dead head flights for eight different regions in the U.S.

II. Literature Review

There have been studies in literature which address the problem of scheduling air-taxi operations. Chavan (2003) employs a combined linear programming and simulation approach to schedule air taxi operations, and derives efficiency parameters (utilization, deadheads and average waiting times). Etschmaier and Mathaisel (1984) discuss the concept of dynamic scheduling, similar to Demand Driven Dispatch. Berge and Hopperstad (1993) present a Demand Driven Dispatch model for dynamic aircraft capacity assignment. More complex scenarios involving slower aircraft speeds, vehicle breakdowns and cancelled service are modeled using heuristics (Horn, 2002). Keskinocak and Tayur (1998) consider the problem of scheduling time shared aircraft. They prove that the problem is NP-complete and use a 0-1 integer programming formulation to solve small and medium sized problems. Simpson (1966) developed an algorithm for determining the frequency and the timetable for non-stop services and assigned departure times for each service for each route. Loughran (1970) presented a scheduling algorithm which he called the Timetable Building Module. This module had two parts, the initial scheduling program and the fleet reduction program. The first part takes the demand distribution for each city pair and builds a timetable which is acceptable for the passenger requesting service but not efficient for the service provider. The fleet reduction routing takes the initial timetable and changes the arrival and departure times for better and more efficient utilization of the aircraft fleet. Ronen (2000) discusses charter aircraft scheduling. He dealt with scheduling various types of aircraft using a Set Partitioning approach. This method is useful when the costs and operational rules are complicated.

Most of the methods discussed employ formal mathematical programming methods which are suitable for small and medium sized problems. The analysis presented in this paper involves scheduling an air-taxi service for the entire U.S., involving hundreds or even thousands of airports and thousands of flights in a single day. It is clear that none of the methods described above would be computationally tractable. Adding another layer of complexity, the population of the U.S. is not evenly distributed thus adopting a single cost value of service for on-demand services might not be realistic. In the analysis presented in the paper, a heuristic based simulation approach was adopted instead of a rigorous mathematical model, and separate analyses were done for each part of the country.

III. Methodology

To determine the true cost of SATS operations considering network effects, an integrated approach combining a network operational model (MCATS) and a planning demand estimation model (TSAM) is employed. The MCATS (Monte Carlo Air Transport Simulator) (see Toniolo, 2004) model is used to derive response curves for various SATS level of service parameters such as cost and rejection rate with respect to causal variables such as demand and fleet size. These response curves are then incorporated into TSAM (Transportation System Analysis Model), leading to a change in cost structure and hence a change in demand. This process is repeated until equilibrium conditions are attained. This section is divided into two parts. In the first part the methodology adopted to derive the response curves is explained. In the second part the integration of these results with the TSAM model is presented.

A. Response Curve Analysis.

The utility of a transportation mode is measured by the level of service. The level of service comprises several metrics: 1) Cost of operation per passenger; 2) Number (Percentage) of passengers accepted/denied 3) Profit margin. 4) Schedule delay 5) Load factor

1. Cost Of Operation Per Passenger

The cost is an important metric because travelers are sensitive to fares. When fares are high demand decreases.

2. Number (Percentage) Of Passengers Accepted/Denied

For a mode to be viable, it has to serve most of the requests that it receives. Since SATS competes with commercial airlines and automobile, the expectation is that the service rate of SATS must be higher than that of the airline industry. The maximum acceptable rejection rate for SATS must be no more than 2%. The analysis generated results with up to 5% rejection rates to have a wider range for study.

3. Profit Margin.

Profit margin is an important variable for determining the level of service. If the profit margin is too low due to either the cost being too high or the number of passengers being too low then it is not possible for the service provider to operate commercially.

4. Schedule Delay

Schedule delay is the difference between the desired departure time and the actual time when the service is provided. Higher schedule delay implies lower level of service. Therefore demand is affected by schedule delay.

5. Load Factor

Load factor is an indication of the level of utilization of the mode of transportation. Higher load factors mean higher utilization and consequently lower costs of operation.

The objective of this analysis was to derive response curves of the level of service variables described above to certain independent (causal) variables. The causal variables explored in the analysis are:1) Demand 2) Fleet size 3) Airport set 4) Region 5) Fleet size

1. Demand

Demand is an important variable that affects the level of serviceableness. More demand could translate into higher delays and rejections and a reduction in the level of service. The baseline demand obtained from the mode split analysis is not true and needs to be adjusted to the new values.

2. Fleet Size

Fleet size is another important variable that affects the level of service. A larger fleet size implies that there are more aircraft to service the demand. This in turn leads to higher level of service and lower rejection rates. The baseline fleet size was chosen so that the rejection rate was less than 5%. The baseline fleet size was perturbed on either side to observe the dependence of the level of service parameters on fleet size.

3. Airport Set

The size of the airport set used is the third factor that determines the level of service. More airports typically imply a greater demand. This will lead to a lower level of service for a constant fleet size. In this analysis three airport sets were considered
1) The airport set satisfying 95% of the entire SATS demand with paved runways > 915 m (3000 feet) runway length (1500 airports)
2) Airports equipped with ILS systems (688 airports), and
3) Airports with Glide Path Angle of less than 3 degrees (1916 airports).

4. Region

The analysis conducted is also region-specific since different regions of the U.S. have different airport densities. Three regional specifications are considered in the analysis using airport density as classification attribute: low, medium and high airport density regions. For example the fleet required to service Montana would not be the same as the fleet required to service California. In this analysis the U.S. is divided into seven regions based on the Woods and Poole database (11). The regions along with their geographic and demand characteristics are given in Table 1.

TABLE 1. Airport Densities and Demand Densities for Various U.S Regions Based on Woods-Poole Definition.

Woods and Poole regions	Airports	Area (sq.mile)	Demand (passengers /day)	Airport Density (airports/1000 Sq.mi)	Demand Density (passengers/day/ 1000 sq.mi)	States in the Region
1 (H)	464	426,391	28,933	1.088	67.85	CT,DC,DE ,IN,IL,MA, MD,ME,MI ,NH,NJ,NY ,OH,PA,RI, VT,WI
2 (L)	49	518,145	5,778	0.094	11.13	IA,KS,MN ,MO, ND,NE,SD
3 (M)	370	304,725	6,401	1.214	21.00	AL,AR,KY ,LA,MS TN,WV
4 (M)	223	234,179	11,132	0.952	47.53	FL,GA,NC,SC ,VA
5 (M)	111	569,909	8,419	0.194	14.77	AZ,NM,OK, TX
6 (L)	82	517,365	2,772	0.158	5.35	CO,ID,MT,UT ,WY
7 (M)	137	432,810	9,554	0.316	22.07	CA,OR,NV ,WA

The three regions used in the analysis are 1) a high density region (Region 1) consisting of Delaware, Washington DC, Maryland, New Jersey, New York and Pennsylvania. 2) a medium density region (Region 7) consisting of California, Nevada, Oregon and Washington and 3) a low density region (Region 6) consisting of Colorado, Idaho, Montana, Utah and Wyoming.

5. Fleet Mix

The level of service is affected by the fleet mix since different aircraft have dissimilar range capabilities, cruise velocities and cost functions. The analysis presented in this report applies to only one type of vehicle, a very light jet with operational, economical and performance characteristics similar to that of the Eclipse 500. MCATS was executed on subsets of the three regions above to validate the analysis. During the execution of MCATS several issues were uncovered. These issues are reported in the next section along with the remedial actions.

FIGURE 1. Regions Used for the MCATS Analysis.

B. Issues in the Response Curve Analysis

1. Rejection Rate Insensitivity to Fleet Size

The first apparent inconsistency observed is the insensitivity of the rejection rate to the fleet size for a low density region (ND, SD, MT and NE). (Area = 372,582 mi^2). This is summarized in Table 2.

As can be seen from Table 2, the rejection rate is practically constant with fleet size, which means that the extra fleet is not being used. This is supported by the fact that aircraft idle times show a significant increase with fleet size.

TABLE 2. Rejection Rate for the Low Density Region as a Function of Fleet Size.

		Demand (passengers /day)		
		407	**814**	**1221**
Fleet Size	**459**	8.68%	7.95%	10.57%
	522	8.64%	7.86%	9.57%
	602	8.61%	7.83%	8.91%

2. Rejections Composed of Disproportionately High Number of Advanced Reservation Passengers.

MCATS has a certain random percentage of passengers, which make advanced reservations. These passengers are given higher priority over the so-called "walk-in" passengers (with no advanced reservations). However the rejection rate consisted of an overwhelming number of advanced reservation passengers, which was inconsistent with the passenger dispatch rule in the model. This could indicate an error or inconsistency in the dispatching rule in MCATS.

3. Insensitivity of Load Factor to the Accommodation Time

In MCATS the day is split into "accommodation intervals". For example if the passenger requests service at 8:45 am and the accommodation time interval is 2 hours then the passenger can be serviced up to 10 am, on the other hand if the accommodation time is 1 hour then the passenger can leave at 9 am. Clearly the greater the accommodation time, the greater is the chance that two passengers can be pooled together in the same aircraft, thus increasing the load factor. A cursory glance at the results indicated a very high load factor which was insensitive to the accommodation time.

C. Reasons for the Anomalous behavior of MCATS

1.Rejection Rate is Insensitive to the Fleet Size for Low Density Region

Clearly the extra Aircraft fleet has little or no effect on the rejection rate and the extra Aircraft fleet is lying idle and not being used. Several factors in the model were tweaked to explain this result.

Passenger Comfort Time. This is a factor that takes into account the fact that small aircraft are in general have limited range. In MCATS the time is 3 hours, giving a maximum flying distance of about 1150 statue miles. In case the flying time is more than the passenger comfort time, a penalty of 5 minutes (30 miles flying distance) is added to the flying time. This could affect the rejection rate, since some O-D pairs are outside the comfort zone. The extra penalty could lead to more rejections. However in this case the furthest O-D pair was within the passenger comfort zone, making this factor irrelevant.

Accommodation Time. This could also affect the rejection rate. If the accommodation time interval is low, a passenger would be rejected if the aircraft can not reach his departure airport in time. However increasing the accommodation time from 2 hours (default value) to 4 hours did not have any effect on the rejection rate.

Fuel Capacity (Maximum Range of the Aircraft). The last variable that was tweaked to explain the first issue was the fuel capacity (maximum range) of the aircraft. Table 3 gives the rejection rates as a function of fleet size, for two aircraft ranges.

TABLE 3. Rejection Rate for the Low Density Region as a Function of Fleet Size.

Demand (814 passengers/day)		
Fleet Size	Rejection rate with 1400 nautical mile range	Rejection rate with 3300 nautical mile range
469	7.43%	0.54%
522	7.13%	0.07%
1400	7.06%	0.06%

To further validate the hypothesis that rejection rate is dependent on the range capacity of the aircraft, the analysis was run for the state of Nebraska alone.

TABLE 4. Rejection Rate for the Low Density Region as a Function of Fleet Size for Nebraska.

Demand (814 passengers/day)	
Fleet Size	Rejection rate with 1400 nautical mile range
57	6.29%
90	0.34%
203	0%

This would indicate that the range is a critical factor for the rejection rate. If the passenger requesting service wants to fly any distance greater than the maximum range capability of the aircraft, then his request would be denied. However the maximum O-D distance was less than 1400 nautical mile range limit of the aircraft, which would mean that one could theoretically serve all passengers. However upon reading the manual it was found that the model has a 45 minute reserve fuel capacity and 30 minute hold time.

TABLE 5.Calculation of the Effective Range of the Very Light Jet Used in the Analysis.

Fuel tank capacity of the Very Light Jet (aircraft under consideration)	230 gallons
Safety factor (hold time + reserve)	1.25 hours
Corresponding safety factor distance	375 (cruise speed) * 1.25 = 470 nautical miles
Specific air Range of the Very Light Jet	5.5 Nm/gallon
Range capability of the Very Light Jet	230*5.5 = 1265 nautical miles
Net range capacity of the aircraft	1265-470 ~ 800 nautical miles

The above analysis, indicates that the reason for the rejection of passengers are O-D pairs that are too far away for the aircraft to fly between them given limited by the fuel tank capacity of the Very Light Jet aircraft. Increasing the capacity of the fuel tank or decreasing the area of interest results in reduced rejection rates.

2 .Rejections Composed of Disproportionately High Number of Advanced Reservation Passengers.

Upon closer examination it was found that since the proportion of advanced reservations is unknown (random) it is possible that a large percentage of the passengers make advanced reservations and thus making up the bulk of the rejected passengers. To test this assumption the advanced reservation percentage was fixed at 20% and the model rerun. It was seen that the majority of rejected passengers were the “walk in” passengers, since they formed the bulk of the passengers.

D. Integration of the TSAM and the MCATS Results

The main motivation for integrating TSAM and MCATS models is to consider the interaction of the two models: 1) the mode choice model, and 2) the SATS cost model. Until now, the mode choice model estimates total SATS demand assuming cost is estimated outside the TSAM model. For instance, a 1.50 ($/seat-mile) has been used as a typical cost per seat-mile for on demand SATS services using a Very Light Jet (VLJ) aircraft. However it should be noted that estimating an appropriate SATS cost requires some knowledge of the SATS demand. In other words, the cost model requires demand
and demand changes cost. This happens in many economic problems where supply and demand are interacting. This issue is resolved by integrating TSAM with MCATS. Figure 2 illustrates the framework of the two interacting models.
The method is designed for the following sets of input data: 1) an initial SATS cost, 2) a rejection rate at which a SATS service provider desires to operate, and an airport set from where SATS operations will be conducted. Currently in the second part of the model, we consider only a single airport set, the airport set satisfying 95% of the total SATS demand (1500 airports).

Using the given SATS cost, the mode choice model estimates yearly SATS travel demand at the airport level. One of the outputs from this procedure is a SATS trip demand matrix [1500 x 1500]. The yearly SATS trip table is then converted into a daily trip table applying seasonal variations that are obtained by analyzing the American Travel Survey (ATS) data at the state level.

The next step is to decide the SATS cost along with the fleet size that is appropriate to serve the daily SATS demand at the rejection rate pre-specified by the user. For this purpose, **two assumptions** are made: 1) there are eight SATS service providers covering all U.S. and each provider serves only one single region that is defined by the Bureau of Economic Analysis (BEA, 2000) 2) As many aircraft can be supplied as possible to meet the provider’s requirement to satisfy demand at the given level of service. This means that there are no limits in aircraft production. It should be noted that the second assumption can be removed if a SATS aircraft production model is available.

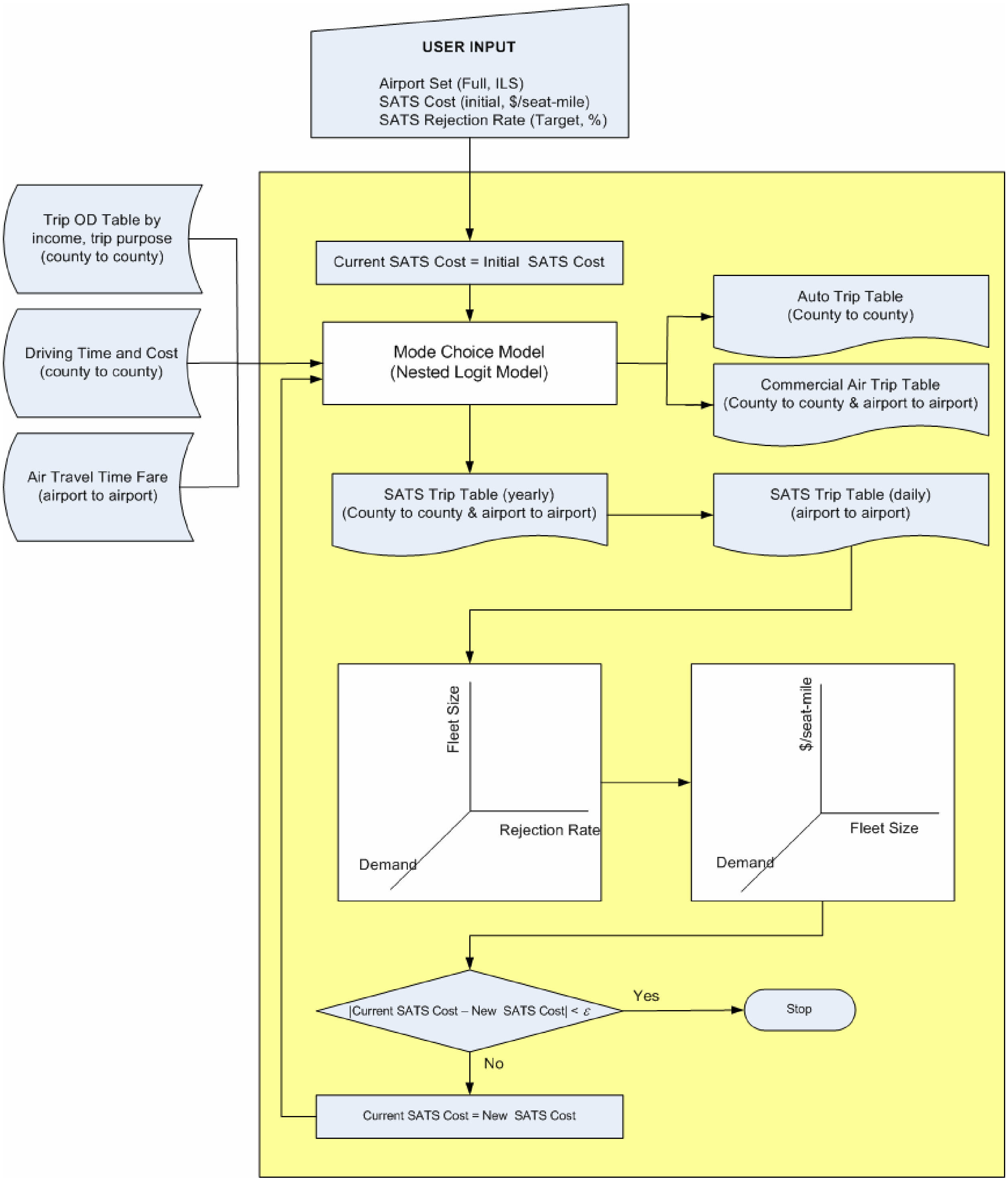

FIGURE 2. Integration of TSAM and MCATS (flowchart).

IV. Results

A. Response Curve Analysis

The MCATS model gives out three relevant metrics. 1) the percentage of passengers rejected 2) the cost per seat mile 3) the number of passengers per flight (load factor) 4) The schedule delay. In addition the model also gives the percentage of deadhead flights (flights with no passengers). The results for the high density region are given in Tables 6, 7, 8, 9 and in Figure 3.

TABLE 6.Variation of the Rejection Rate with Fleet Size and Demand for the High Density Region.

Demand (passengers/ day)									
		491	**1,965**	**3,931**	**5,896**	**7,862**	**11,793**	**23,587**	**31,450**
Fleet Size	**100**	20.06	64.54	78.13	83.70	86.90	90.31	94.07	95.24
	350	1.91	19.71	42.16	53.81	61.29	70.41	81.54	85.13
	700	1.54	2.44	16.11	28.60	37.84	49.71	67.02	72.97
	1000	1.48	1.59	5.53	15.47	24.06	36.94	56.59	63.77
	2000	1.41	1.39	1.60	1.83	3.64	11.54	32.04	40.83
	3000	1.41	1.35	1.52	1.61	1.70	2.80	16.57	25.26
	5500	1.41	1.35	1.47	1.51	1.56	1.59	2.47	5.88
	7000	1.41	1.33	1.47	1.50	1.54	1.55	1.61	2.41
	9000	1.41	1.33	1.46	1.50	1.52	1.54	1.58	1.62

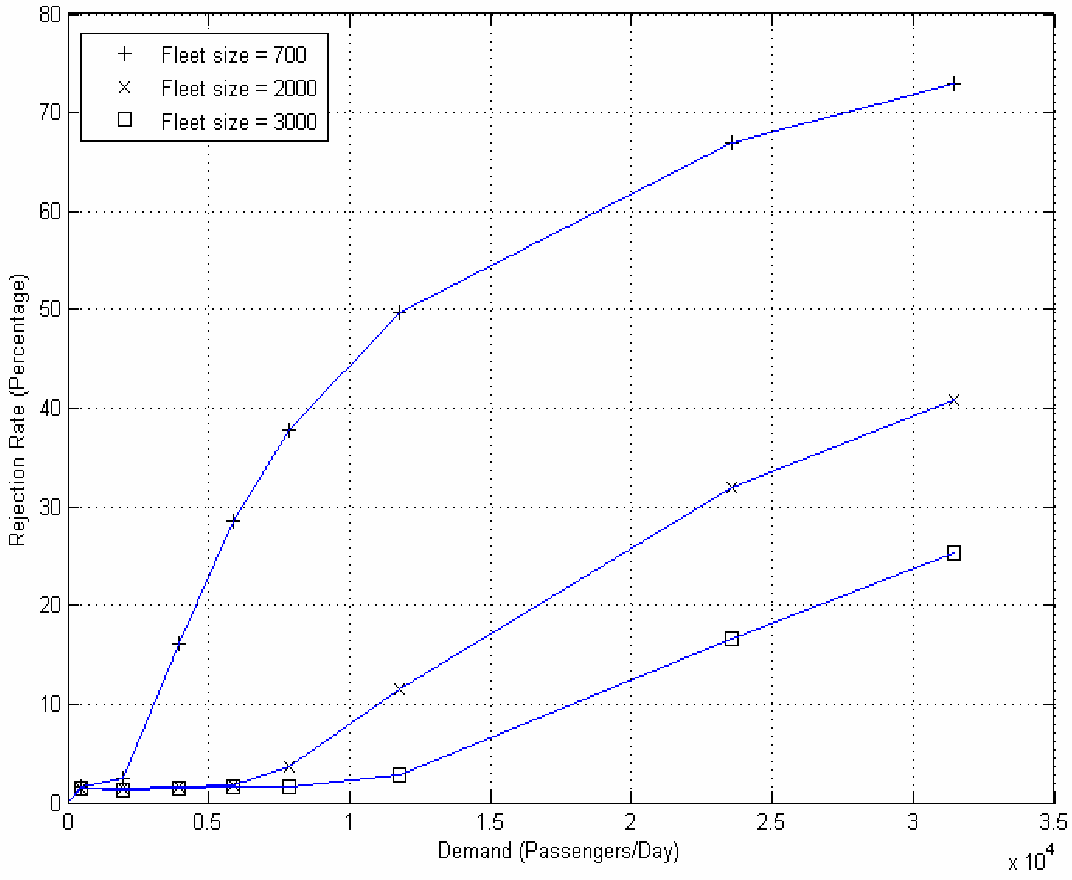

FIGURE 3. Variation of the Rejection Rate (Percentage) with Demand in the High Density Region.

TABLE 7.Variation of the Cost per Seat Mile with Fleet Size and Demand for the High Density Region.

Demand (passengers/ day)									
		491	**1,965**	**3,931**	**5,896**	**7,862**	**11,793**	**23,587**	**31,450**
Fleet Size	**100**	2.94	2.34	1.97	1.78	1.67	1.50	1.23	1.14
	350	4.43	2.48	2.08	1.88	1.74	1.57	1.29	1.21
	700	7.25	2.89	2.24	1.99	1.83	1.65	1.36	1.27
	1000	9.66	3.45	2.42	2.10	1.92	1.71	1.41	1.30
	2000	17.68	5.52	3.33	2.60	2.24	1.91	1.52	1.40
	3000	25.71	7.55	4.39	3.26	2.70	2.15	1.63	1.48
	5500	45.76	12.61	6.95	5.02	4.01	2.97	1.93	1.68
	7000	57.79	15.63	8.47	6.04	4.80	3.50	2.16	1.83
	9000	73.83	19.67	10.50	7.39	5.82	4.21	2.50	2.07

TABLE 8. Variation of the Passengers per Flight with Fleet Size and Demand for the High Density Region.

Demand (passengers/day)									
		491	**1,965**	**3,931**	**5,896**	**7,862**	**11,793**	**23,587**	**31,450**
Fleet Size	**100**	0.68	0.83	1.03	1.18	1.29	1.46	1.85	2.00
	350	0.81	0.85	1.00	1.11	1.21	1.37	1.74	1.88
	700	0.94	0.90	1.00	1.09	1.19	1.31	1.62	1.78
	1000	0.99	0.98	1.01	1.09	1.17	1.29	1.57	1.71
	2000	1.03	1.08	1.11	1.13	1.17	1.27	1.51	1.62
	3000	1.04	1.11	1.17	1.20	1.23	1.27	1.48	1.59
	5500	1.04	1.12	1.20	1.26	1.30	1.36	1.47	1.56
	7000	1.04	1.12	1.20	1.26	1.31	1.38	1.50	1.57
	9000	1.04	1.12	1.20	1.27	1.32	1.40	1.54	1.60

TABLE 9.Variation of the Schedule Delay with Fleet Size and Demand for the High Density Region.

Demand (passengers/ day)									
		491	**1,965**	**3,931**	**5,896**	**7,862**	**11,793**	**23,587**	**31,450**
Fleet Size	**100**	0.46	0.67	0.70	0.71	0.72	0.70	0.72	0.75
	350	0.39	0.47	0.52	0.58	0.61	0.66	0.69	0.70
	700	0.40	0.41	0.44	0.48	0.50	0.55	0.65	0.68
	1000	0.40	0.41	0.41	0.44	0.46	0.50	0.59	0.63
	2000	0.39	0.41	0.40	0.40	0.40	0.43	0.49	0.52
	3000	0.39	0.41	0.40	0.40	0.39	0.40	0.44	0.47
	5500	0.39	0.41	0.40	0.40	0.39	0.39	0.40	0.42
	7000	0.39	0.41	0.40	0.40	0.39	0.39	0.40	0.40
	9000	0.39	0.41	0.40	0.40	0.39	0.39	0.40	0.40

B. Results of the Integration of MCATS and TSAM

Table 11 illustrates the trend of total SATS travel demand over various iterations. The rejection rate used for the analysis is 2%. It can be seen that the cost per seat mile for the various regions converge after oscillating between an upper and lower bound. The iteration was stopped when the change between successive demand values was less than 5%. From Table 11, it can be observed that the total SATS demand, for the continental United States reaches near equilibrium condition in five iterations for most regions. Initial SATS cost was assumed as $1.75 per seat-mile for each region.

TABLE 10. SATS Cost Per Region for Each Iteration.

Region							
Iteration	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	2.00	2.36	1.97	2.41	1.80	2.07	1.80
2	1.98	2.00	1.96	2.65	1.85	2.24	1.85
3	1.97	2.61	1.95	2.88	1.89	2.29	1.88
4	1.96	2.13	1.94	3.09	1.94	2.32	1.91
5	1.95	2.54	1.93	3.25	2.00	2.35	1.92
6	1.94	2.10	1.93	3.37	2.07	2.37	1.93
7	1.94	2.59	1.93	3.45	2.15	2.38	1.94
8	1.94	2.12	1.93	3.50	2.24	2.40	1.95
9	1.94	2.56	1.93	3.53	2.32	2.40	1.95
10	1.94	2.11	1.93	3.55	2.39	2.41	1.95
11	1.94	2.58	1.93	3.55	2.45	2.42	1.95
12	1.94	2.12	1.93	3.55	2.48	2.42	1.95

TABLE 11. SATS Demand per Region for Each Iteration.

	Region						
Iteration	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	24,560	4,816	5,457	10,116	7,568	2,482	8,537
2	19,605	2,740	4,421	5,921	7,184	1,876	8,128
3	19,881	3,755	4,467	5,039	6,904	1,634	7,819
4	20,104	2,244	4,506	4,393	6,640	1,576	7,593
5	20,276	3,321	4,541	3,901	6,361	1,535	7,436
6	20,391	2,369	4,566	3,593	6,,052	1,504	7,333
7	20,470	3,429	4,569	3,382	5,708	1,481	7,267
8	20,512	2,279	4,568	3,247	5,341	1,465	7,226
9	20,542	3,351	4,568	3,125	4,983	1,444	7,188
10	20,554	2,338	4,568	3,125	4,678	1,444	7,188
11	20,566	3,401	4,568	3,103	4,453	1,437	7,179
12	20,567	2,297	4,568	3,092	4,275	1,432	7,174

From Tables 9 and 10, it can be seen that most of the regions except Region 2 (Low Density region consisting of CO, ID, MT, UT and WY) which oscillates. This could be due to the fact that the demand for Region 2 is too low for SATS to be commercially viable. This problem could be solved by taking a different initial cost per region. A high initial cost could be assigned to the high density region to avoid large swings in the cost and avoid oscillations between iterations.

V. Conclusions

In this analysis, a relationship between the level of service (rejection rate, cost per seat mile) and some relevant causal factors (demand, fleet size, airport set) has been derived. The results are produced and depicted in Table 6, Table 7, Table 8 and Figure 3 .It can be seen that the rejection rate for the high density increases from 1.5% for a demand of 491 passengers per day to 50% for a demand of 5900 passengers per day. At the same time, cost per seat mile decreases from $4.44 to $1.29. These results prove that there is a strong correlation between the rejection rate, cost per seat mile and demand. It can also be inferred that the relationship is non-linear. On the other hand, from Table 7 it can be seen that the variation of passengers per flight is non-monotonic with fleet size and demand. It can be inferred that the fuel capacity (range capability) of the aircraft limits the level of service in regions with a large area and sparse demand. To achieve an acceptable service rate requires a large fleet size, especially in regions with high demand or with large distances in between airports. Therefore, it may not be possible to achieve a satisfactory level of service, during the first year of operation of SATS. This will in turn reduce SATS demand during the first year of operation. Demand will increase during the subsequent years, as the fleet size increases and service approaches the equilibrium level of service. To realistically model SATS operations during its initial period of operation, the results obtained with MCATS have to be linked to an aircraft and pilot production model.

VI. Recommendations and Directions for Future Work

MCATS provides a good initial solution to some of the questions faced by SATS operators and analysts. However the model suffers some limitations which are discussed below

1) The MCATS model assumes that there is no demand for SATS below 125 nautical miles. This is a severe restriction because we expect some trips below 125 nautical miles while running the TSAM. It is recommended that this number could be user-defined rather than pre-defined.

2) The model assigns a 5-minute penalty if the flying time exceeds the passenger comfort time. This time is a low value, if the passengers want to land. It is recommended that the comfort time should be in the range of 20-30 minutes to account for climb and descent times.

3) In the cases when the flying distance between two O-D pairs exceeds the maximum range of the aircraft, the model assumes that the trip can never be made. In reality, aircraft would refuel and execute the trip. It is recommended that the range restriction be relaxed to realistically model the flight operations.

4) It is recommended that MCATS be run along with an aircraft and pilot production model, in order to realistically model SATS operations, for the first few years.

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