Scheduling Analysis Model of Rural Commuter Air Service

Lonnie E. Haefner and J. Lee Hutchins, Jr., Civil Engineering Department, Washington University

The analysis and evaluation of a regional air transport system for urban areas of 10 000 to 50 000 people and for large metropolitan areas have quantitative and qualitative differences. Airport facilities within an intrastate air system often serve as catalysts of community development. The analysis of alternatives, therefore, is different from conventional major air system evaluation. The objective of this paper is the formation of a scheduling analysis model for air commuter systems in rural regions. The optimal transportation alternative will be selected in light of costs, subsidies, and travel demand. The format of this scheduling analysis model incorporates a Markovian decision theory approach. This analysis technique employs the formulation of the system state space, state transition probabilities, and state reward matrices. The alternatives studied reflect differences in service patterns and scheduling frequency. A test case example involving the Idaho intrastate air transportation system was used.

The objective of the example problem presented in this paper is to develop and demonstrate a scheduling analysis model for an air commuter system for rural regions. Its financial feasibility is related to optimal employment of scheduling alternatives in light of subsidies for commuter systems and to the travel demand characteristics of a sparsely populated rural region (1).

The regional case deals with commuter airports in communities or urbanized areas of 10 000 to 50 000 people oriented to interstate travel. Urban areas of this size have quantitative and qualitative life-style differences from larger metropolitan areas (2), and the airports and their impacts are significant in linking each of the communities as functional places in the rural region (3, 4). The air transportation system often serves as a catalyst for the community in attracting components of a strong economic base (business, industry, and tourism) and provides a basis to connect centers of government and finance with remote or isolated areas, allowing the entire region to operate in an integrated and functional manner.

PROBLEM INPUTS

The case study region selected for the example problem is the Idaho rural commuter air transportation system. The current system is shown in Figure 1 (5); a further breakdown of the Idaho air transportation demand areas is shown in Figure 2. This system has been discussed in detail in previous research documents (6).

ANALYSIS APPROACH

The analysis and evaluation of an air transportation system such as that described can be undertaken by a Markovian decision theory approach that involves the formulation of a state space, state transition probabilities, and reward matrices for the system under study. The system can be considered as occupying a specific state when the system is exclusively described by the values of the state variables delineating that state. The state transitions can then be viewed as a change in the value of these variables from one set describing a state to those of another set. In this example, the variable considered was a person trip and the states were the specific origin and destination points within the rural commuter study region. These state transitions can be indexed by time; that is, the system can be considered to make a state change (a new person trip demand) after some time increment t. As a result, the suitability of employing this statistical decision theory for this discrete time process turns on the development of the probabilistic nature of these state transitions. These transition probabilities were developed from current passenger demand volumes.

Associated with the state transitions are rewards that accrue to the system for such transitions. These rewards are a summation of costs and revenues for the service provided that are peculiar to the service and scheduling alternatives considered. The optimal alternative for the long-term system operation is determined by using the policy iteration method. This method employs a 2-step iterative technique: the value-determination operation (calculation of the relative values to the system of occupying any state for each alternative) and the policy improvement routine (selection of the alternative that maximizes the reward to the system for each state).

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Figure 1. Existing air service.

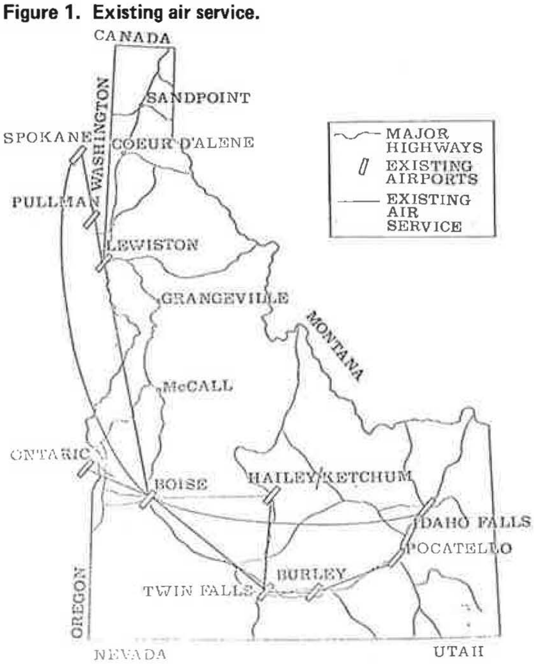

Figure 2. Demand areas.

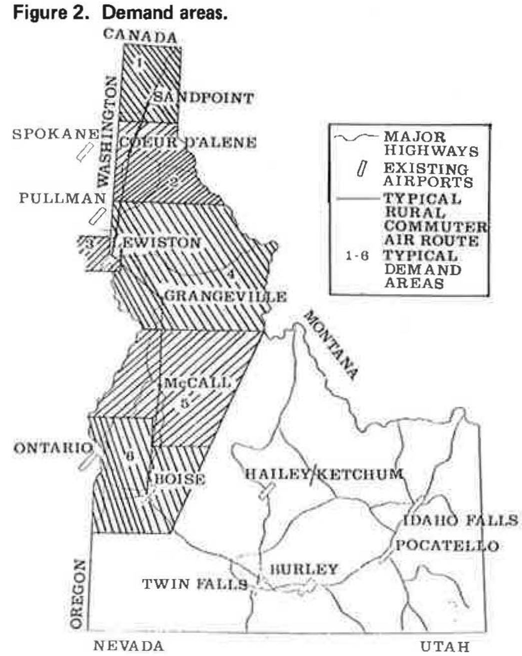

Table 1. Daily 2-way person trips by air mode in the commuter region.

	Person Trips					
Airport	Sandpoint	Coeur D'Alene	Lewiston	Grangeville	McCall	Boise
Sandpoint	—	7	7	15	4	9
Coeur D'Alene	7	—	16	35	7	17
Lewiston	7	16	—	19	10	19
Grangeville	15	35	19	—	17	27
McCall	4	7	10	17	—	48
Boise	9	17	19	27	48	—

Table 2. Remote region air travel demand.

Site	State	Estimated Daily Enplanements	Site	State	Estimated Daily Enplanements
Sandpoint hub	1		Grangeville		
Bonners Ferry	7	2	hub	4	
Priest River	8	2	Orofino	16	4
Clark Fork	9	0.5	Pierce	17	1
Coeur D'Alene	2		Kamiah	18	1
hub			McCall hub	5	
St. Maries	10	2	Riggins	19	0.5
Avery	11	0.5	Council	20	1
Kellogg	12	4	Cambridge	21	0.5
Lewiston hub	3		Cascade	22	1
Potlatch	13	1	Boise hub	6	
Elk River	14	0.5	Caldwell	23	8
Craigmont	15	1	Emmett	24	2
			Weiser	25	3

Figure 3. State space transitions.

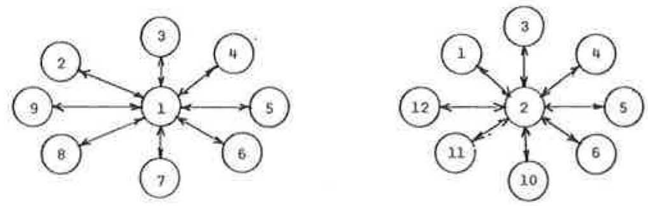

Table 3. Single-step transition probabilities.

State	1	2	3	4	5	6	7	8	9	...
1	0.135	0.118	0.118	0.255	0.068	0.153	0.068	0.068	0.017	...
2	0.074									
3	0.075									
4	0.102									
5	0.056									
6	0.042									
7	1.0									
8	1.0									
9	1.0									
⋮	⋮	...	...	...	...	...	...	...	...	...

The basic underlying concepts of Markovian decision theory are detailed by Howard (7, 8).

The decision algorithm developed in this paper makes use of Howard's policy iteration method for the determination of the steady-state probabilities method and yields an optimal scheduling alternative for commuter operation for the current travel demand status of the region. The formulation of the state space, associated transition and steady-state probabilities, alternatives, reward matrices, and iteration results will now be discussed in detail.

FORMATION OF STATE SPACE

The formulation of the system state space involved a review of the north-south travel corridor in Idaho and the classification of air transportation into 2 categories. In the first category, the commuter airports located in Sandpoint, Coeur D'Alene, Lewiston, Grangeville, McCall, and Boise were selected as candidate interstate commuter airports as shown in Figure 2. In the second category selected for analysis, airports were in a remote region and had a sufficient air travel demand and air service in various cities was 32.2 to 96.6 km (20 to 60 miles) from the commuter hubs. These remote region air service airport locations include the cities of Caldwell, Emmett, Weiser, Cambridge, Cascade, Council, Riggins, Kamiah, Pierce, Orofino, Craigmont, Elk River, Potlatch, Saint Maries, Avery, Kellogg, Clark Fork, Priest River, and Bonners Ferry.

The selection criteria were based on the availability of travel demand data for further analysis; the common criterion was that all sites enveloped only 1 competing mode of transportation—a state highway within the study region shown in Figure 2. The travel patterns assumed a 50-50 directional split. Such projected rural commuter air travel is given in Table 1. Table 2 gives the estimated daily enplanements for the remote region service areas. The transition state space (9) can be schematically represented for state 1 as shown in Figure 3. State 1 represents Sandpoint; states 2 through 6 (commuter hubs) refer to Coeur D'Alene, Lewiston, Grangeville, McCall, and Boise respectively. States 7 through 9 represent Bonners Ferry, Priest River, and Clark Fork respectively and constitute the remote region serviced by the airport in Sandpoint. By a similar delineation, a state space sample is developed, numbered, and shown schematically in Figure 3 for state 2 also. This process can be repeated for each state of the rural commuter air service region that represents a terminal location. In effect, the Idaho air transportation system can be modeled as a multiple Markov chain. A traveler in the system may move from a location in a remote region only to the corresponding commuter hub, thus incurring a transition in location state. The sequence of successive state transitions is viewed from the perspective of a passenger within the system selecting a destination j given his or her origin at some state i. The transition probabilities are therefore $P(T_{ij}) = P_{ij}$ where $P(T_{ij})$ = probability of a trip with a destination being state j given the fact that the passenger is now originating in state i. The values of the probabilities P_{ij} reflect the volume of trips from locational state i to locational state j relative to the total number of trips from state i to all states j within the system. Mathematically,

$$P(T_{ij}) = \frac{T_{ij}}{\sum_{j=1}^{m} T_{ij}} \tag{1}$$

where

$P(T_{ij})$ = probability of a trip from state i to state j,
T_{ij} = total number of trips from state i to state j, and
m = number of destination states from i.

Typical transition probabilities are given in Table 3.

SCHEDULING AND OPERATION ALTERNATIVES

The formulation of the alternatives reflects options in alteration of service patterns and operations given the demand levels of the system (10, 11). Alternative 1 includes 8 round trips/day between Boise and Coeur D'Alene. Four of these trips per day will continue to Sandpoint. In the remote service region, service would be on a demand-responsive basis. Alternative 2 constitutes the same commuter hub service but with a different pattern in the remote service region. Table 4 gives this pattern. Alternative 3 has 8 round-trip flights/day from Boise to Sandpoint and a demand-responsive service to the remote region. Alternative 4 has 8 round-trip flights also but with the scheduled remote region service given in Table 4 for alternative 2. Demand-responsive service here means service for passengers at the requested location within a period of time that fits into the air commuter's overlying basic schedule for hub operation.

DEVELOPMENT OF REWARD MATRICES

The reward matrices for the system state transitions reflect the air fares, direct and indirect operating costs, and potential of available subsidies from any source (12). The air fares were calculated as a function of stage length as shown in Figure 4, and a sample is given in Table 5. Direct operating costs reflect crew pay, purchase cost of aircraft, insurance, fuel, and maintenance costs. Indirect operating costs were calculated as a function of stage length as shown in Figure 5. The total of these costs for the various transportation scheduling alternatives was used, and sample values are given in Tables 6 through 9. These calculations assume an interest rate of 12 percent and project life of 20 years in calculating annual cash flows (13), and a value of time of $10.00/h in determining time penalties for different service patterns. The r_{ij}^k value is the monetary reward per enplanement accruing to the system operation for the passenger trip from state i to state j while the commuter

Table 4. Pattern of service for remote regions, alternative 2.

Hub	Remote Service Region	Type of Service
1. Sandpoint	7. Bonners Ferry	Morning, evening
	8. Priest River	Morning, evening
	9. Clark Fork	Demand responsive
2. Coeur D'Alene	10. St. Maries	Morning, evening
	11. Avery	Demand responsive
	12. Kellogg	Morning, noon, evening
3. Lewiston	13. Potlatch	Demand responsive
	14. Elk River	Demand responsive
	15. Craigmont	Demand responsive
4. Grangeville	16. Orofino	Morning, noon, evening
	17. Pierce	Morning
	18. Kamiah	Morning
5. McCall	19. Riggins	Demand responsive
	20. Council	Demand responsive
	21. Cambridge	Demand responsive
	22. Cascade	Demand responsive
6. Boise	23. Caldwell	4 flights daily
	24. Emmett	Morning, evening
	25. Weiser	Morning, noon, evening

Figure 4. Air taxi fares, including taxes.

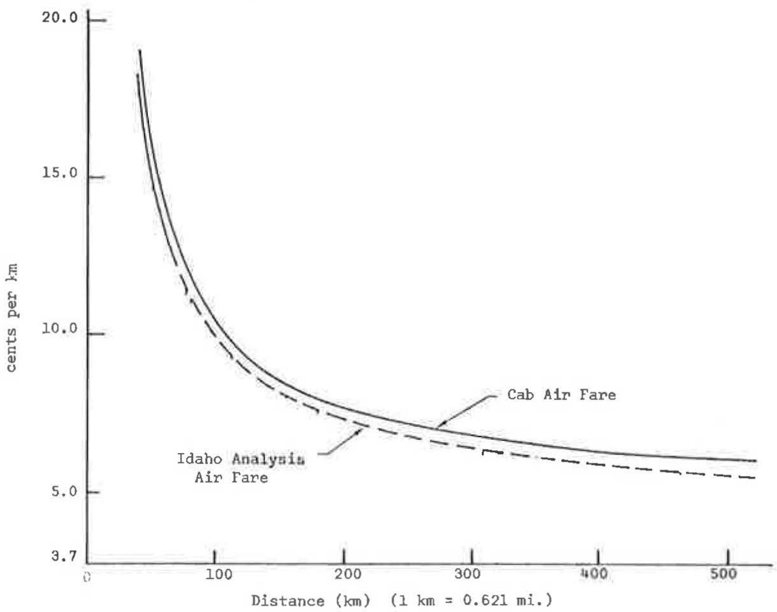

Table 5. Actual 1-way air fares.

State	1	2	3	4	5	6	7	8	9	...
1	0	8.95	17.85	21.00	26.70	34.50	8.35	6.00	6.60	...
2	8.95									
3	17.85									
4	21.00									
5	26.70									
6	34.50									
7	8.35									
8	6.00									
9	6.60									
⋮	⋮	...	...	...	...	...	...	...	...	

Figure 5. Indirect operating costs.

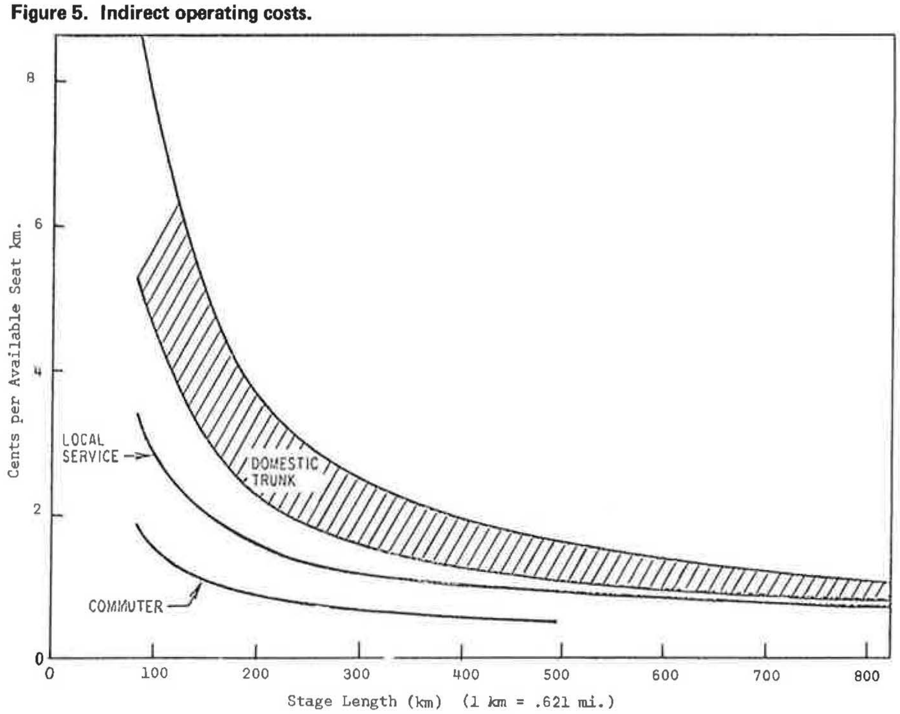

Table 6. Reward matrix, alternative 1.

State	1	2	3	4	5	6	7	8	9	...
1	0	2.22	9.69	11.68	15.95	22.49	-1.94	-2.75	-2.41	...
2	2.37									⋮
3	9.80									⋮
4	11.87									⋮
5	16.37									⋮
6	22.68									⋮
7	-2.14									⋮
8	-2.95									⋮
9	-11.56									⋮
⋮	⋮	...	...	...	...	...	...	...	...	⋮

Table 7. Reward matrix, alternative 2.

State	1	2	3	4	5	6	7	8	9	...
1	0	2.22	9.69	11.68	15.95	22.47	-11.62	-12.55	-12.19	...
2	2.37									⋮
3	9.80									⋮
4	11.87									⋮
5	16.37									⋮
6	22.68									⋮
7	-11.82									⋮
8	-12.75									⋮
9	-21.34									⋮
⋮	⋮	...	...	...	...	...	...	...	...	⋮

Table 8. Reward matrix, alternative 3.

State	1	2	3	4	5	6	7	8	9	...
1	0	-1.54	6.03	8.02	12.28	18.82	-1.94	-2.75	-2.41	...
2	-1.29									⋮
3	6.14									⋮
4	8.20									⋮
5	12.41									⋮
6	19.02									⋮
7	-2.14									⋮
8	-2.95									⋮
9	-11.56									⋮
⋮	⋮	...	...	...	...	...	...	...	...	⋮

Table 9. Reward matrix, alternative 4.

State	1	2	3	4	5	6	7	8	9	...
1	0	-1.54	6.03	8.02	12.28	18.82	-11.62	-12.55	-12.19	...
2	-1.29									⋮
3	6.14									⋮
4	8.20									⋮
5	12.41									⋮
6	19.02									⋮
7	-11.82									⋮
8	-12.75									⋮
9	-21.34									⋮
⋮	⋮	...	...	...	...	...	...	...	...	⋮

Table 10. Steady-state probabilities.

State	π_i	State	π_i	State	π_i
1	0.0688	10	0.0053	18	0.0027
2	0.1594	11	0.0014	19	0.0015
3	0.1196	12	0.0104	20	0.0028
4	0.2104	13	0.0025	21	0.0015
5	0.1228	14	0.0013	22	0.0028
6	0.2259	15	0.0025	23	0.0171
7	0.0047	16	0.0116	24	0.0043
8	0.0047	17	0.0027	25	0.0121
9	0.0012				

Table 11. Long-term system gain with subsidy.

Subsidy Level (¢)	Gain ($/enplanement)			
	Alternative 1	Alternative 2	Alternative 3	Alternative 4
0	-5.0820	-5.5347	-4.8353	-5.2599
10	-3.3296	-3.6262	-2.9756	-3.3814
20	-1.5811	-1.7220	-1.1625	-1.5021
26.3	—	—	0	—
28.0	—	—	—	0
28.6	0	—	—	—
29.0	—	0	—	—

system is employing scheduling alternative k.

ANALYSIS

Markovian decision analysis is an iterative solution process based on an efficient algorithmic investigation of long-term gains to the system under study. The solution is arrived at by the policy iteration method outlined by Howard (7, 8), which yields an optimal alternative for each state of the system. The compendium of these state-specific optimal alternatives is termed the policy vector. In this specific example, however, each state is a location of origin or destination, and a transition from i to j denotes a completed person trip from location i to location j. As such, solution requires the specification of an alternative that maximizes the gain to the system over the long-term demand characteristics of the entire set of locations. This gain g is defined as

$$g^{k*} = \max_{k} \sum_{i=1}^{N} \pi_i(Q_i^k) \qquad (2)$$

where π_i is the vector of steady-state probabilities (Table 10). g is computed as demonstrated by Howard. This is the long-term average fraction of total system person trip origins that emanate from location i at any time t. Q_i^k is the expected immediate reward as denoted by Howard (7, 8). This long-term gain g can be operationally defined as the reward to the system operation in dollars per enplanement.

CONCLUSIONS

The values of g for the various alternatives are as follows:

Alternative	Gain	Alternative	Gain
1	-5.0820	3	-4.8353
2	-5.5347	4	-5.2599

In terms of the system description and problem inputs herein, the system obtains a loss over all scheduling alternatives reviewed. In light of this, rather than review and develop other alternatives, the research team decided to investigate the subsidy issue by applying a sensitivity analysis to the losses over a range of subsidies in terms of lump-sum percentage of total capital and operating cost required to be subsidized to yield a break-even point in operations. This subsidy may come from any source such as an additional statewide sales tax, a federal subsidy, or local community support.

As can be seen by the data given in Table 11, alternative 3 requires the minimum subsidy level for operation with 26 percent of its system costs being assignable to subsidy sources. This is the scheduling alternative with 8 round trips/day from Boise to Sandpoint and a demand-responsive service in the remote region.

It should again be noted that the advantage of using a technique such as that described here lies in the capability to perform meaningful sensitivity analysis. In this case, the subsidy required was tested against different alternatives. In another option, the algorithm could have been employed to detail other radically different scheduling or curtailment of service alternatives to test the resulting system gain. The issues of subsidy and curtailment of service and resultant regional impact have certain philosophical overtones and must be dealt with by the corresponding governing and regulating agencies from the federal to the state and local levels. Options that are open to consideration and review include scheduling and service patterns and subsidies.

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