A SIMULATION APPROACH TO TRANSPORTATION MODAL SPLIT ANALYSIS

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Summary

This paper describes a unique simulation approach to transportation modal split analysis, which was developed and applied at The Aerospace Corporation. Modal split analysis attempts to determine the utilization of a number of alternative travel modes between specified origins and destinations. These studies have traditionally been done using regression methods. The method and associated computer program developed by the authors computes the modal split by generating simulated travelers—each having a set of pertinent attributes randomly selected from appropriate distributions. The method assigns them to travel modes on the basis of a cost function that includes time, service frequency, and traveler preferences in addition to out-of-pocket cost. A number of advantages over the traditional regression approach are offered by the method, and are discussed in the paper. Results of applying the simulation program to studies of the Portland-Seattle corridor and feeder modes for the Palmdale, California airport are presented.

I. Introduction

A unique simulation approach to transportation modal split analysis has been developed and applied at The Aerospace Corporation*. Modal split analysis attempts to determine the utilization of a number of alternative travel modes between specified origins and destinations, when the characteristics of the competing transportation modes, the characteristics of the traveler population, and traveler mode choice criteria are given. The results of modal split analysis are used by transportation system planners, designers, and analysts to determine the utilization of new travel modes, and to optimize the characteristics of new or existing modes. Modal split analysis has traditionally been done using regression methods. The method and associated computer program developed by the authors computes the modal split by generating simulated travelers. Each simulated traveler has a set of pertinent attributes randomly selected from appropriate distributions. The method assigns them to travel modes on the basis of a cost function that includes time, service frequency, and traveler preferences in addition to out-of-pocket cost.

This method offers a number of advantages over the traditional regression approach. The most significant advantage is that random samples from probability distributions rather than averages are employed for travelers' attributes. This technique results in a much more realistic population of simulated travelers. Other advantages are that the modal split procedure is easily understood and easily modified or extended. Input preparation is simple and natural. The attributes of individual travelers are identified; therefore, it is a simple matter to gather a variety of statistics from a simulation. Constraints (for example, finite mode capacities) are readily handled, correlations are explicitly represented, effects of local travel (door to origin port and destination port to door) are included, and a capability for sensitivity analyses is inherent in the procedure. Validation of the model is much more straightforward than when a regression procedure is used.

This modal split simulation model has been implemented as a Fortran program that runs on The Aerospace Corporation's CDC 6400/6600 computer complex. The program has been applied to a study of alternative ground and air travel modes (including a proposed new short-takeoff-and-landing or STOL service) in the Portland-Seattle corridor, and a study of feeder modes (again including a proposed new STOL service) for the Palmdale (California) Intercontinental Airport. The program has facilitated study of the effects of STOL fares, port locations, and service frequency on the modal split between the proposed STOL services and competing modes such as conventional aircraft (CTOL), bus, rail, and private car.

II. Simulation Approach to Modal Split Analysis

The simulation approach to modal split analysis is based upon the use of probability distributions to describe the pertinent traveler characteristics. Distributions are used to determine purpose and duration of trip, origin and destination door locations, the traveler's "time value" (a function of his income) and party size, his "preference factor" for each alternative travel mode, and his waiting times (which are functions of service frequency) for each mode. (These quantities are explained fully in the following section.) The attributes of individual simulated travelers are generated by drawing random samples from these distributions.

Once an individual traveler's attributes have been generated, his "cost function" for each travel mode is computed. This cost function reflects out-of-pocket cost, trip time, travel mode service frequency, and traveler preferences. When the cost functions for the alternative modes have been computed, the traveler is assigned, within capacity constraints, to the mode with the minimum cost function; that is, the mode which is best for him.**

The modal split is thus determined by generating many simulated travelers and assigning each traveler to his minimum-cost-function mode. The resulting apportionment of travelers is then the modal split. Time does not explicitly enter into the modal split simulation. A given simulation run is formulated to apply for a particular time interval (for example, "morning rush hour"), and all inputs are made consistent with that formulation.

A detailed description of the modal split simulation model and its operation is provided in the following section.

*Part of this work was conducted in support of the Definition Phase Study of the Western Region Short Haul Air Transportation Program. [1]

**See "New Directions for Passenger Demand Analysis and Forecasting" by G. Kraft and M. Wohl for a discussion of various aspects of behavioral demand modeling. This discussion includes the value of treating individuals rather than aggregate groups, and the importance of breaking each potential trip into cost and time components as they are perceived by an individual. [2]

III. Simulation Model

A. Arena

Figure 1 depicts the arena, or abstraction of the real world, in which the modal split simulation takes place. The origin and destination cities are each divided into a number of rectangular areas of various size. (Dividing the cities into areas provides a means of simulating the real-world heterogeneous nature of the cities — certain statistical traveler characteristics are associated with each area, as discussed in Section III-B.) Each travel mode has one or more ports in each city, some of which may be co-located (as, for example, the combined CTOL/STOL port in the figure). Car mode is also considered to have "ports," which normally represent points of access to the highway system between the two cities. Transportation service may be provided between some or all origin-destination port-pairs. Each origin-destination port-pair of each mode for which service is provided is called a service path. (By definition, service paths exist between all origin-destination pairs of car ports.) Service, when provided, is characterized by its cost, trip time, and frequency (car mode is always considered to have infinite service frequency).

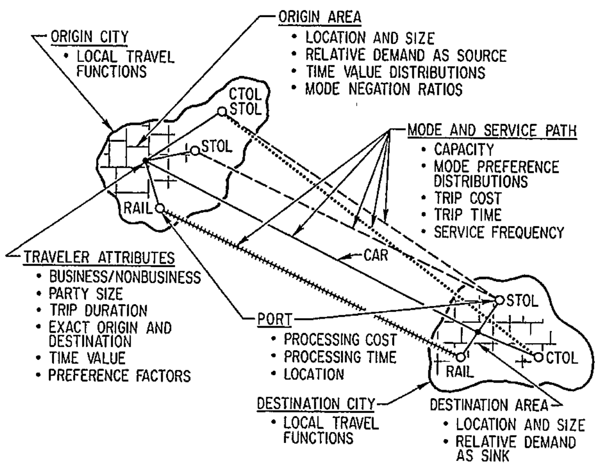

Figure 1. Typical Modal Split Simulation Model Arena

B. Inputs

Inputs to the simulation model consist of those associated with the entire arena, the origin and destination cities, the areas within each city, each travel mode, each port of each mode, and each service path. These are discussed in order in the following sections. As with all simulation models, the choice of this particular set of inputs represents a carefully-considered compromise between model fidelity, data availability, and implementation complexity.

1. Arena Inputs. Inputs associated with the entire simulation arena consist of the time interval for which the simulation applies, the number of simulated travelers to be generated, the fraction of those travelers that are business travelers, and the party size and trip duration distributions and the fraction of travelers affected by frequency of service, for both business and nonbusiness travelers.

The time interval for which the simulation applies, together with the specified service frequencies of the various modes, is used to compute the time intervals between flights or services. For those travelers who are affected by service frequency, random samples are drawn from these time intervals during simulation, and are used to compute waiting times for the various modes.

The distinction between business and nonbusiness travelers is important because many of the attributes directly affecting mode choice are dependent upon whether or not the traveler is on a business trip (for example, the traveler's time value, trip duration, and party size). Party size is important because the direct costs associated with car mode can be considered to be divided by party size, while those of other modes cannot. The party size distributions are discrete and represented in tabular form, as illustrated in Figure 2.

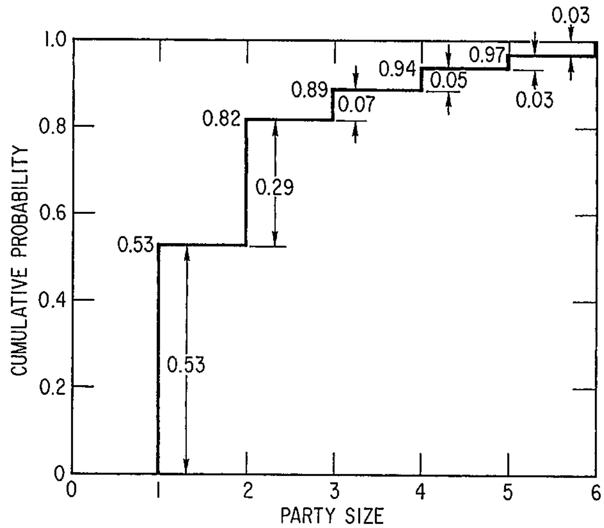

Figure 2. Example of Party Size Distribution

Trip duration is important because certain costs (for example, the parking cost at a port) are dependent upon the length of trip. The trip duration distributions were found to be inherently lognormal, and so are represented by two parameters related to the mean and standard deviation of a lognormal distribution. (Section IIIB-3 contains a further discussion of lognormal distributions.) The fraction of travelers of a given type (business or nonbusiness) affected by frequency of service represents those who have strong schedule preferences; any time spent by them waiting at either end of a flight or trip is wasted. Conversely, the fraction not affected by service frequency represents those flexible travelers who would not be appreciably inconvenienced even if a mode had only one departure during the simulation interval.

Note that with the exception of the simulated time interval and the number of travelers to be simulated, all of the input quantities discussed in this section represent distributions; as such, they are not utilized directly in subsequent computations. Rather, random samples drawn from these distributions are used to establish the attributes of individual simulated travelers.

2. City Inputs. For both the origin and destination cities, the cost and time of local transportation as functions of distance are provided in tables. Cost vs. distance and time vs. distance tables are provided for both private car and a composite local transportation mode. These tables permit the cost and time associated with the door to port (origin city) and port to door (destination city) portions of trips to be computed based on the distance to be traveled. The tables enable each simulated traveler to make a tradeoff between driving his car and parking at the port (for his trip duration) vs. taking the composite local transportation mode (which may be a weighted average of taxi, local bus, airport limousine, etc.). The tables permit realistic nonlinearities in these functions, such as the fact that for short distances local travel is accomplished at a lower average speed than for longer distances.

Tables of parking cost and transportation rental cost vs. trip duration for the destination city are also provided. These tables permit different costs to be incurred in the destination city, depending upon whether a traveler drives there (in which case he would incur the parking cost) or takes a public transportation mode (in which case he would incur the transportation rental cost). Either or both of these costs may be made zero for all values of trip duration if appropriate for a specific application.

3. Area Inputs. The inputs associated with each rectangular area of the origin city are the coordinates of the corners of the area (relative to an arbitrary origin), the relative business travel demand (the number of business travelers emanating from that area relative to other areas), the relative nonbusiness travel demand, time value distributions for business and nonbusiness travelers, and car availability factors for business and nonbusiness travelers.

Time value is the hourly rate the traveler associates with the time spent on his trip, and is generally considered to be different when he is traveling for business rather than for nonbusiness purposes. Time value is used to convert total trip time to equivalent dollar cost. Examples of typical time value distributions are provided in Figure 3. Time value distributions were found to be inherently lognormal, as illustrated by Figure 4 in which the distributions of Figure 3 are plotted with log-probability scales (a lognormal distribution will plot as a straight line with these scales). Time value distributions are therefore represented by only two parameters each (U and S in the figure, which are the mean and standard deviation, respectively, of the corresponding normal distribution). The provision for separate time value distributions for each area permits a realistic representation of the variations in affluence throughout the city.

Car availability factors are simply the fractions of business and nonbusiness travelers that have access to cars, and who can therefore trade off car mode with the public transportation modes for both the intercity and the local portions of the trip. (These factors are represented by two-valued distributions; in the simulation, a draw is made from the appropriate distribution to determine whether a particular simulated traveler has access to a car or not.)

The inputs associated with each rectangular area of the destination city are the area corner coordinates, the relative business travel demand (the number of business travelers arriving in that area relative to other areas), and the relative nonbusiness demand.

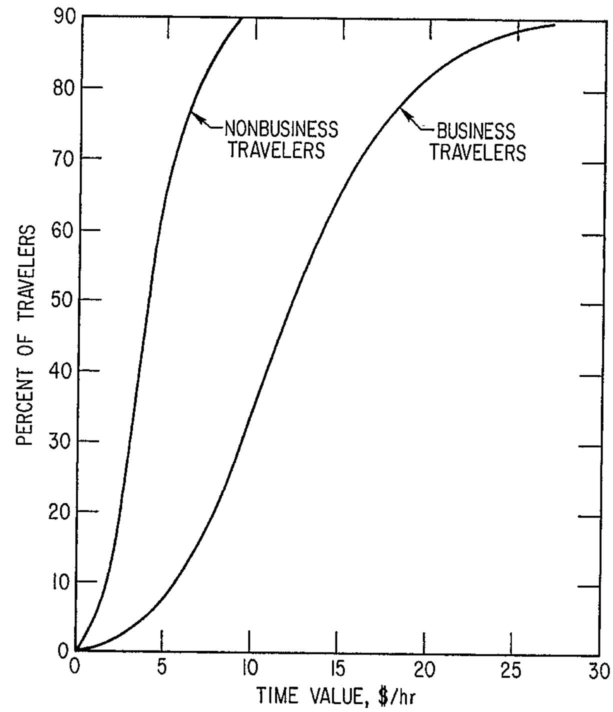

Figure 3. Example of Time Value Distributions

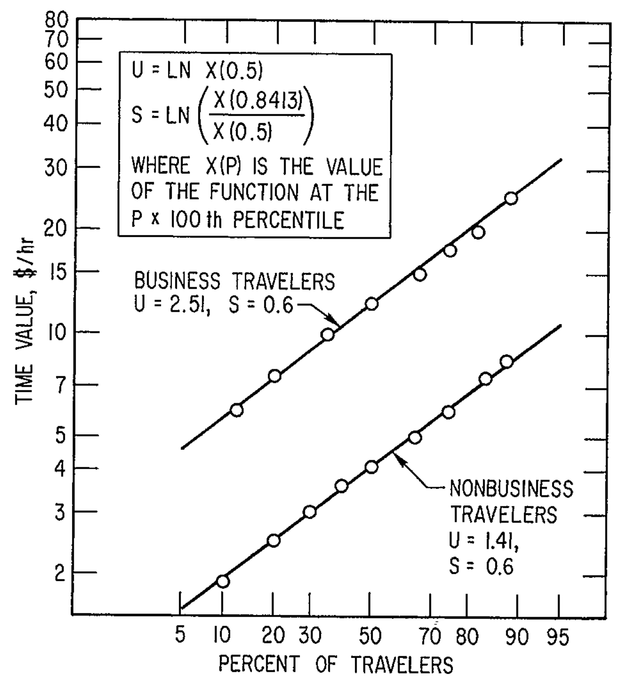

Figure 4. Example of Time Value Distributions, Log Probability Scales

4. Mode Inputs. Each travel mode is described in terms of its unit capacity and "negation" and "preference" factors for both business and nonbusiness travelers. The product of unit capacity and service frequency (discussed in Section III-C) is the total capacity available via a given service path during the simulation time interval. The negation factors for a

given mode represent the fractions of business and nonbusiness travelers who will not, under any circumstances, use that mode (for example, "12 percent of nonbusiness travelers will not fly on a helicopter" corresponds to a nonbusiness negation factor of 0.12 for helicopter mode).

The preference factors for the various modes are intended to represent all of the noneconomic factors affecting mode choice; that is, all of the factors which cannot be expressed in units of cost or time. Since they represent the intangibles, the preference factors are the calibration parameters of the simulation model. They are the quantities that are adjusted to achieve consistency between model predictions and actual mode-use surveys in arenas for which survey data exists. In the simulation, the intercity portion of a traveler's cost function for each mode is multiplied by his preference factor for that mode (as drawn from the appropriate distribution). Thus a preference factor greater than 1 for a given mode indicates that the traveler views that mode with disfavor, whereas a factor less than 1 indicates a preference for the mode. Preference factors, therefore, represent the degree to which a traveler will go against pure economics in choosing a travel mode. To avoid the possibility of negative cost multipliers, the preference factor distributions were taken to be lognormal, rather than normal.

5. Port Inputs. Each travel mode may have one or more ports in each city. Ports are uniquely associated with specific modes. For example, a combined CTOL/STOL port is simulated by locating a CTOL port and a STOL port at the same point. Each port is characterized by its location, processing cost, processing time, parking time, and a table of parking cost vs. trip duration (the length of time in days that the traveler will be away from the origin city). The port processing cost is simply any cost incidental to the use of that port, such as a baggage handling charge. The processing time is the time spent from arrival at the entrance to the port until the intercity portion of the trip begins. The parking time is the additional time required to park a car and walk from the parking lot to the port entrance. This time is added if the traveler elects to drive his car to the port and park it for the trip duration. The parking cost table is used to establish the cost he incurs.

6. Service Path Inputs. The inputs associated with each service path are those required to describe the service provided between that pair of ports: out-of-pocket cost, trip time, and service frequency. For public transportation modes, the out-of-pocket cost is the fare, the trip time is the scheduled time (which may include an increment for predictable or usual delay), and the service frequency is the number of trips made during the simulation time interval. For car mode, cost and time are the values that apply to that service path, and service frequency is not input since it is automatically considered to be infinite (a traveler's own car, if available, is not constrained by a finite "service frequency").

C. Generation of Traveler Attributes

The attributes of each simulated traveler are generated by random draws from the input probability distributions described in the preceding section. Correlations between attributes are explicitly represented in that the determination of a given attribute may define the distributions from which other attributes are drawn.

The sequence used to generate a complete set of attributes for a simulated traveler is as follows: first, a draw is made based on the specified fraction of travelers that are business travelers to determine the traveler's trip purpose. Based on the outcome, draws are made from the appropriate distributions to determine the traveler's origin city area, trip duration, party size, negation and preference factors for each of the alternative modes, and destination city area. From distributions associated with the traveler's origin area, his car availability factor, time value, and origin door coordinates are drawn (door coordinates are drawn uniformly from within the area). A determination of whether or not the traveler is affected by service frequency is made by drawing from the appropriate two-valued distribution representing the fraction of business or nonbusiness travelers affected. If he is found to be affected, his waiting times for all the alternative service paths are computed by drawing from uniform distributions over the intervals between trips. For example, if the interval between trips on a particular service path is 30 min, the waiting time for that path will be determined by drawing from a uniform distribution of 0 to 30 min. Finally, the traveler's destination door coordinates are drawn from a uniform distribution over the destination area.

D. Cost Function Computations

Once the attributes of a simulated traveler have been generated, his cost function for every service path is computed. The cost function for a given service path consists of three components—the door to origin port portion of the trip, the port to port portion, and the destination port to door portion. For each component, the pertinent costs and times are summed separately, and the total time is converted to equivalent cost by multiplying it by the traveler's time value. The port to port portion of the cost function (cost plus time multiplied by time value) is multiplied by the traveler's preference factor for the mode under consideration. All costs associated with the use of a private car (either for the entire trip, or to drive to a port and park) are divided by the traveler's party size. For public intercity modes, a tradeoff is made between driving to the origin port and parking for the trip duration vs. taking the composite local transportation mode to the port; the traveler is presumed to follow the course of action with the minimum cost function. Local travel (door to port and port to door) is presumed to take place along orthogonal north-south and east-west lines (or any other designated orthogonal compass directions for that matter), and local travel distances are computed accordingly. Costs and times are determined from these distances using the input tables discussed in Section IIB-2. The assumption that local travel takes place along orthogonal lines represents a first-order model of a city street network, while it avoids the necessity of representing such a network explicitly.

E. Outputs

The outputs of the modal split simulation program consist of optional output during simulation, and a standard set of outputs at the conclusion of a simulation. During simulation, "traveler's records" may be printed for every nth traveler (where n is specified). A traveler's record consists of all of the known facts about a given traveler — all of his attributes, his assignment to a particular mode and service path, and the cost function components (all the costs and times) associated with that assignment. Traveler's records are useful for verifying that a simulation case is specified correctly, and for gaining insight into why travelers are making certain mode choices.

At the conclusion of a simulation, the modal split is provided in three different ways: the number of travelers assigned to each service path of each travel mode is provided, along with totals by origin and destination ports, and travel mode. Traveler assignments expressed as fractions of total demand — the fractional modal split— are also provided with the same totals. Finally, traveler assignments expressed as fractions of capacity for each service path — carrier load factors— are provided, also with totals by ports and modes.

F. Implementation

The modal split simulation model is implemented as a CDC Fortran IV program, which runs on The Aerospace Corporation's CDC 6400/6600 computers. The basic program requires 23,000 words of core storage, which permits arenas of up to 100 areas in each city, 5 travel modes, and 10 ports per mode in each city. Larger arenas can be readily handled with more storage.

A very flexible scheme for providing input data to the simulation model was devised to minimize drudgery and errors. The various data card types are identified by alphanumeric labels, and the order of the input cards is immaterial. All references to travel modes and ports are made by alphanumeric identifiers. Many cases can be simulated in one computer run. A complete set of input data must be provided for the first case, but only the data that are changed need be input for subsequent cases. Comprehensive input data diagnostic checks are performed before running each case to verify completeness and consistency of the input data.

Fortran was chosen rather than one of the special-purpose simulation languages (for example, GPSS or Simscript) for several reasons. Time is not explicitly represented in the simulation, hence, the automatic timing routines provided in simulation languages were not needed. Similarly, sets and queueing were not required. Random variable generators were needed, but an excellent collection of Fortran generators were already available in The Aerospace Corporation's subroutine library (both table-based generators for arbitrary distributions and mathematical generators for textbook distributions such as the Gaussian and the lognormal). Finally, the CDC Fortran compiler (Run 2.3) generates relatively efficient code, which minimizes program running time. The only reasonable alternative to Fortran for The Aerospace Corporation's computation facility for simulation programs is CDC Simscript I.5, but for the reasons above it was not considered to be a preferable one.

Model development was begun in the early fall of 1969, and the basic program became operational in February 1970. Modeling and programming consumed approximately one-half man-year. Effort is continuing on model enhancement and applications.

IV. Applications

A. Characteristics

The modal split simulation has been successfully applied to a variety of transportation arenas.[3] Two significantly different applications will be discussed in some detail to highlight the ability of the model to accommodate a wide variation in input data content and detail.

The first application was a feeder service between the Los Angeles metropolitan area and the proposed new Palmdale Intercontinental Airport. The Palmdale airport is to be located about 45 air mi from the Los Angeles Central Business District (CBD) and about 70 air mi from some of the outlying metropolitan communities. However, because of the San Gabriel Mountain barrier between Los Angeles and Palmdale, typical surface mode distances are increased by 20 or 30 mi relative to air miles because the surface routes utilize circuitous mountain passes.

The Palmdale airport is expected to carry the bulk of Los Angeles area long-haul air traffic in the future. Therefore rapid and convenient access from the metropolitan area will be required. The purpose of the Palmdale study was to determine the viability of introducing STOL service between a series of metropolitan area STOL ports (including the CBD) and the Palmdale airport. The airport is also expected to be served by rail and bus lines as well as the freeway system.

The second application was the Portland-Seattle corridor. Portland and Seattle are currently served by bus, rail and CTOL services as well as being connected by freeway. The CBDs are 145 mi apart. CTOL service is provided between their respective international airports at very regular intervals (about 40 departures per day), but both airports are located 10-15 mi from their respective CBDs. The purpose of the Portland-Seattle study was to determine the viability of introducing STOL service between the CBDs as well as between each city's CBD and the CTOL port in the other city, for a total of three new service paths.

While both studies involve the viability of STOL service relative to established modes, there were drastic differences in the characteristics of the simulation. The Palmdale application was a feeder service study; that is, all of the travelers were going to Palmdale airport to take an airplane trip to another city. In other words they were all air travelers who for the purpose of this simulation had a point destination—the Palmdale airport. The Portland-Seattle application was a general service study; that is, all types of travelers were represented and as a class their destination was an entire city, rather than a point as in the Palmdale application.

For a feeder service such as in the Palmdale application, car, rail, bus, and STOL became secondary rather than primary modes in that these modes only serve to get to the airport. Therefore, intermode scheduling between primary and secondary modes was a factor for all travelers taking the public modes of rail, bus, and STOL, and all such travelers were affected by frequency of service. Of course, car travelers were not affected by frequency of service, but for a feeder service they must pay parking for the duration of the trip (while parked at the Palmdale airport). This is to be contrasted with the general service in the Portland-Seattle application. Intermode scheduling requirements did not exist there and car travelers drove all the way to their destination; hence, they did not pay parking fees for the duration of the intercity trip.

Because of the vastness and density of the Los Angeles freeway network, which results in a multiplicity of possible routes, as well as its proximity to Palmdale, it was decided to explicitly model the freeway network. A total of 69 on-ramps were utilized to represent car "ports" and these were explicitly modeled. Thus the local car travel cost vs. distance and time vs. distance functions were primarily utilized to implicitly model the local street network for getting from the traveler's door to a freeway on-ramp. In Portland-Seattle only one car "port" was explicitly modeled in each city (where the Portland-Seattle highway leaves each metropolitan area at the point closest to the other city). Then the local car travel time vs. distance function was formed to model not only the local street traffic conditions but also to model implicitly the freeway system as it exists in the metropolitan areas.

Two other characteristics can be used to contrast these two applications: the number of origin/destination areas and the number of service paths. Of course, as a feeder service study the Palmdale application had only one destination area, the airport, which was modeled as a point. The Los Angeles metropolitan area was divided into 59 rectangular areas, representing 41 distinct statistical districts each having its own income, occupancy, and occupational statistics. Much less detailed information was available for Portland and Seattle. Only three statistical districts were available as input data for each city. These were divided into 10 areas for Portland, and eight for Seattle.

The Palmdale application, in addition to the 69 freeway on-ramps, also had 15 bus, 12 STOL and 5 rail ports in the Los Angeles metropolitan area for a total of 101 ports. With four ports at Palmdale (one for each mode) the system had 105 ports and 101 service paths. For the Portland-Seattle application each city had six ports (two STOL ports and a car, rail, bus and CTOL port) with seven service paths.

The final major difference between these applications was the availability of mode survey data. For Portland-Seattle a 1967 traffic survey was available which allowed calibration of preference factors for existing travel modes. Such a data base did not exist for the Palmdale application so a pure economic trade-off simulation without preference factors was conducted.

B. Data Base Sources and Values

Most data base values used to describe business ratio, party size, and trip duration were based on the 1967 Census of Transportation[4]. This census is broken down by purpose of trip, mode, and geographical area. With some interpolation, extrapolation, and interpretation, it was possible to obtain the detail required for the simulation. The values used in the two applications are presented in Table I.

	Los Angeles - Palmdale		Portland-Seattle	
Business Ratio	0.513		0.167	
Party Size	Business	Nonbusiness	Business	Nonbusiness
1	0.77	0.53	0.665	0.176
2	0.19'	0.29	0.213	0.283
3	0.018	0.072	0.049	0.194
4	0.012	0.048	0.033	0.129
5	0.004	0.024	0.016	0.087
6 or more	0.006	0.036	0.024	0.131
Median Trip Duration (Days)	2.75	3.75	1.25	1.68

Table I. Business Ratio, Party Size, and Trip Duration Data

A significant difference exists in the values used in the two applications. In particular, note the effect that demand consisting of air travelers only had on the Los Angeles-Palmdale data base with its high business ratio, small party size structure, and longer trip duration. Also of interest is the difference in both applications between business and nonbusiness party size structures and trip durations.

The data used to determine relative demand and time values for the various origin and destination areas were significantly different for the two applications. For Portland-Seattle, Bureau of Census data were utilized. Based on population density and area classification, i.e., CBD, within the Standard Metropolitan Statistical Area (SMSA) or outside the SMSA, relative demand was determined for each area. Time values for this application were based solely on income, with business travelers having a time value of 1.5 times income and nonbusiness travelers having a time value of 0.5 times income. These ratios are typically used in travel analysis studies.[5]

In the Palmdale application a much broader and more detailed data base was available for determining relative demand and time value. Based on studies by the Lockheed-California Company[6] and Landrum and Brown,[7] it was possible to base relative demand (for air travel) not only on population in each area, but also occupation, multiple dwelling, and income statistics for that area. A regression fit had been utilized to weight the impact of each of these factors on air travel demand. For the Palmdale application, time value was based not only on area income directly but also included an air travel propensity factor. This factor considered that air travelers from a given area have a higher median income than the median income of the whole area.

As stated earlier, a survey to establish traveler preference factors did not exist for the Palmdale airport application, so unity preference factors were used for all modes. For the Portland-Seattle application the simulation was first conducted using only the existing travel modes and unity preference factors. The modal split results were then compared with the 1967 Portland-Seattle travel survey. A new set of preference factors was selected so as to cause the modal split results to agree with the survey. (Arbitrarily, in all cases, the preference factor for car was selected as unity to serve as a baseline.) After a few iterations the modal split results matched the survey data for the following preference factors (remember that these are cost multipliers): Car = 1, CTOL = 1.05, Rail = 1.4, and Bus = 1.6. While these preference factors appear intuitively reasonable, notice that they may be peculiar to Portland-Seattle in that they reflect the service quality and other qualitative attributes of these modes in that arena. The CTOL preference factor of 1.05 was then assigned to the proposed STOL service since STOL service will most closely resemble CTOL. With the model thus calibrated for that arena the simulation was then conducted using both current modes and the proposed STOL mode.

C. Typical Modal Split Results

The typical approach to utilizing the simulation has been to fix the characteristics of each of the current modes and vary the parameters of the proposed new service. For the Palmdale study, STOL fare and service frequency were varied. STOL system results as a function of fare and frequency are presented in nomogram form in Figure 5.

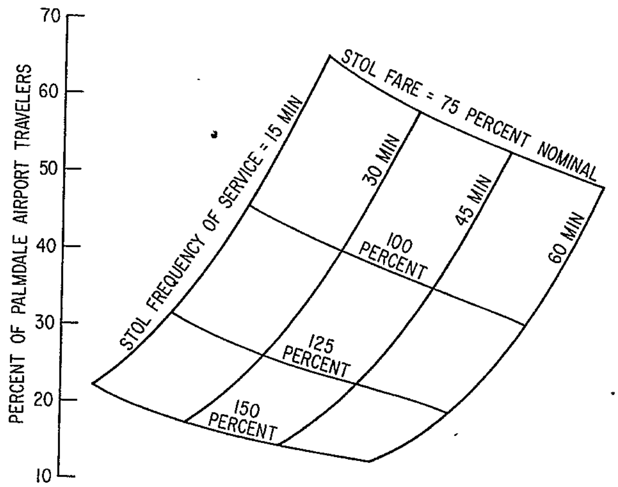

Figure 5. Percent of Palmdale Airport Travelers Using STOL Feeder

Since the system simulated had 12 STOL ports at varying distances from Palmdale, a differential fare structure was utilized. Thus the system fares are depicted relative to a nominal baseline, where 100 percent corresponds to a fare of 13-18¢ per mile, depending on port location. As expected, patronage goes up with decreased fare and increased service, but in a nonlinear manner. This is a system summary. Similar results for each of the service paths are also available. They are used to determine appropriate vehicle capacity, fleet size, schedules, fares, revenue, and other economic or service parameters.

For the Portland-Seattle study, STOL vehicle cruise speed was varied in addition to fare and service frequency. Cruise speed variations were used to reflect different vehicle types. Some typical results, selected to highlight parameter sensitivities and the effects on other modes, are presented in Table II.

The STOL fare of $17.85 was the prevailing Portland-Seattle CTOL fare. Most of the travelers still go by car, and as STOL parameters are varied, most of STOL modal split gain or loss comes from car. The first case of Table II is a baseline condition of nominal speed, fare, and service frequency. Cases 2, 3, and 4 feature differential increases in service frequency, fare, and cruise speed, respectively, relative to Case 1. Case 5 indicates the combined opposing effects of increased speed and increased fare. This might reflect an operational situation where utilization of a faster plane requires charging a higher fare. In all cases, STOL gets a significantly greater share of the market than does CTOL. This is attributed not so much to STOL's having more service paths, but rather to most candidates for an air mode preferring to travel between the CBDs instead of the international airports. Indeed, the STOL CBD-CBD route generated about 70 percent of the STOL traffic when all three STOL routes had equal service frequencies.

In addition to conducting the basic set of simulations described above, the model was also used to study the effect of moving or eliminating certain ports, and to determine how best to divide a fixed fleet size among a set of routes.

V. Simulation Performance Characteristics

A. Sample Size

As in any Monte Carlo simulation the desire for a large sample had to be traded off against the associated sampling cost. It was determined that 2500 travelers would be an adequate sample for these applications. For a given mode this results in a standard deviation of $\sqrt{2500\, p(1-p)}$ travelers, where p is the probability of a traveler taking that mode. The worst case value of this standard deviation (for p = 0.5) is 25 travelers. On a sample base of 2500, therefore, the worst case modal split standard deviation is 1 percent. This was deemed adequate for the economic studies for which these simulations results were utilized. Thus with a sample size of 2500, each traveler represents 0.04 percent of the total demand,

Case Number	STOL Cruise Speed (mph)	STOL One-Way Fare ($)	STOL Trips Per Day Per Route	Percent of Total Travel Demand Using Various Modes				
				STOL	CTOL	Car	Rail	Bus
1	270	17.85	16	12.8	5.4	75.5	2.0	4.2
2	270	17.85	24	14.4	5.0	74.5	2.0	4.1
3	270	20.00	16	9.5	6.4	77.6	2.2	4.3
4	402	17.85	16	16.1	4.5	73.4	2.0	4.0
5	402	20.00	16	12.2	5.4	76.0	2.1	4.3

Table II. Sample Portland-Seattle Modal Split Results and therefore a shift of a single traveler between modes does not significantly impact the resulting modal split. If conditions warrant, a larger number of travelers can easily be run.

B. Running Time

Running time for the simulation is very application-dependent even for a fixed number of travelers. Some first order effects on running time are the number of service paths, since each must be processed, and the number of traveler's records printed. During production runs only a minimal number of traveler's records is printed since their primary purpose is for checkout. To a lesser extent the simulation run time is affected by the number of modes, the number of origin and destination areas, the lengths of input tables such as the local travel distance vs. time, and whether waiting time computations need to be performed.

Typical values for the Palmdale and Portland-Seattle applications were 28 milliseconds (ms) and 6 ms of central processor (CP) time per traveler, respectively, on the CDC 6600. For 2500 travelers per case, the CP times were about 70 sec for Palmdale and 15 sec for Portland-Seattle. Thus, modal split simulation results, particularly when calculated on a port-pair basis, were very cost effective.

VI. Future Efforts

A. Modeling

Several improvements in the model are under consideration. In many cities, line and area barriers to local travel exist, such as rivers, mountains, and man-made restrictions. These barriers limit direct and efficient surface travel. Techniques for determining when and how to represent such barriers are being explored. More explicit freeway modeling, perhaps as a system of lines rather than on-ramp points, also appears worthwhile; particularly if it can effectively be incorporated in local door-to-port tradeoffs for modes other than car. Another modeling improvement would be the implementation of explicit door-to-port modes, possibly based on traveler attributes such as car ownership and origin area. For certain arenas where intercity distances are small, the implementation of car rider (where a traveler is driven to his destination and the car and driver return) as well as car driver mode may be warranted. This was not the case for the Palmdale application, but might quite likely be true of other feeder services in a smaller arena.

B. Simulation Scope

Currently the model only addresses the question of modal split; that is, what percent of the travelers will take the various modes. There are other related questions of interest such as who takes the various modes and what effect a new mode has on overall demand.

A report generator is currently being planned which will enable various statistical reports to be generated from traveler record data to determine the attributes of travelers using specific modes, the choices of travelers from specific areas, or other mode, port, or traveler specific statistics. This information will suggest ways in which the effectiveness of a community's travel services can be improved.

When an attractive new mode is introduced, it not only gets a substantial modal split share but it also increases the total demand. When adequate models for this demand enhancement process evolve, they will be incorporated since it is expected that many of the parameters required for such a model are already utilized in the simulation.

C. Other Applications

A related application for which a model is currently being developed is intra-urban travel modal split. While the scale of the arena forces a somewhat different approach to be used in developing the model, there are many fundamental similarities to the intercity model. Indeed, when it is completed much of it might be incorporated in the intercity model for applications where a high fidelity door-to-port model is needed.

The concept of drawing attributes for simulated entities which dictate alternative courses of action is, of course, the cornerstone of discrete event simulation. The concept of drawing attributes for a simulated person and determining his choice among alternatives based on those attributes is believed to be relatively novel. This concept has broader applications than transportation modal split analysis. It is the potential foundation for many behavioral model simulations where the tradeoffs can be reasonably quantified.

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