SOLON: Interactive Method for Evaluating and Improving Transit Route Performance

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ABSTRACT

SOLON is an interactive microcomputer graphic method that addresses the problems of transit scheduling and route efficiency and productivity improvement. It has three unique characteristics: First, it provides solutions at any specified time or continuously through the life of a transport service by tracing the interactions among scheduling changes, route ridership, and service cost-effectiveness. Second, it explicitly treats time delays that hamper route performance. Third, its modules operate interactively or independently and can be modified by the user. Because it addresses transit problems at the route level, SOLON can facilitate management and funding decision making, by determining the viability of individual routes, and aid in selecting the best performance policies. Further, because it assumes no previous computer knowledge, it can substantially increase personnel training productivity. SOLON inputs include conventional socioeconomic and transportation data. Output performance indicators are provided by mode and for every time instant, subject to selected policies and exogenous fluctuations such as changes in energy cost, inflation, and unemployment.

Declining subsidies, low ridership, and rising deficits are increasingly affecting management decisions in public transit operations. Although revenues from the gas tax bill may alleviate some transit fiscal problems temporarily, structural inefficiencies remain and act to discount the added benefits. Curtailing services, a simple short-term solution, may spell the end of urban public transit in the long term. Service changes, applied selectively to individual routes, are emerging as one of the most feasible policy alternatives for improving the cost-effectiveness of public transportation operations.

Transit managers can accomplish such improvements by selecting the best options from an extensive set of policy variables (e.g., fare, service frequency, number of stops, and route length). However, traditional planning methods cannot deal effectively with this complex problem, especially because it is subject to continuously changing constraints and often requires different solutions at different stages of development. To be sure, in real-world applications, strict optimality with respect to performance measures is seldom required. On the other hand, there is a need for decision-making procedures that are systematic and that reflect trade-offs and simplifications in the policy selection process. To be effective, such methods should be interactive and time sensitive and should be able to quickly sort through a great number of policy alternatives and advise the decision maker of the most desirable choice or choices given the stated evaluation criteria. Such are the capabilities of SOLON (selection of policy options interactively), the interactive method presented here.

Although several quick-response planning methods have been developed, SOLON is the only interactive system that begins to address the time interactions between the major elements that give rise to changes in transit route performance. The method is rather straightforward and is distinguished by three unique characteristics: First, it provides solutions at any specified time or continuously through the life of a transport service by tracing the interactions between scheduling changes, route ridership, and service cost-effectiveness. Second, it explicitly treats time delays (e.g., capital procurement and ridership) that hamper route performance. Third, its modules (demand, supply, and performance) operate interactively or independently and can be modified by the user. For instance, trip purpose (work or shopping) and market segments (by automobile ownership, transit availability, and so forth) may be selected; demand specifications can be updated; and management plans on fare, frequency, and other policies may be proposed by the user or adopted from those suggested. SOLON addresses these problems at the route level, where management decisions are usually made. It, therefore, can facilitate management and funding decision making by assessing the viability of individual routes (or route sets) and aiding in the selection of the best performance policies.

Route performance evaluation and policy selection could, of course, be performed without use of an interactive graphics system. A dynamic methodology was initially developed by this author for evaluating transport systems without the benefit of interactive graphics (1-3). However, inclusion of the interactive and graphic capabilities creates substantial savings in the time required to select a better set of policies. In addition, SOLON has been implemented in a way that allows easy access by decision makers with little or no computer experience. As a result, it enables experienced policy analysts to examine expected performance improvements in greater depth by experimenting with a wide range of plans and to fine tune selected policies before implementation. Further, it can substantially improve personnel training productivity as suggested by Twin Cities transit specialists who had hands-on experience with one version of this method. Recommendations for improvements, made by these specialists, have been incorporated in the current version, which is being continually updated with data from Metropolitan Transit Commission (MTC) routes in the Twin Cities.

OVERALL MODEL STRUCTURE

The structure of SOLON can be analyzed at several levels of detail. At the most general level, it may be pictured as a simple demand-supply model (Figure 1) with the transit route performance sector acting as a link between supply and demand. For instance, a transit frequency increase in the service supply sector results in waiting time reduction in the performance sector; as level of service improves, so does travel demand. In turn, as demand for and use of transit grow along a route, cost-effectiveness measures (e.g., load factor, operating ratio) improve and call for service adjustments. Following such adjustments (e.g., frequency, fare) in the supply sector, performance measures are further modified and the interactions continue full circle.

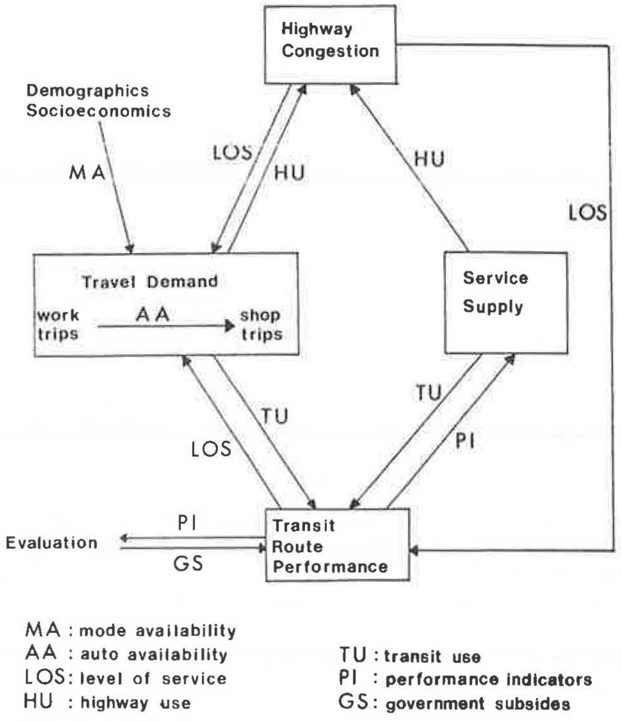


FIGURE 1 SOLON structure.

However, service as well as pricing adjustments are limited by government regulations. For example, it may be impossible to increase transit fares in order to clear the market at given levels of transit service supply. Further, many of the changes in transit route service (e.g., route length and frequency modifications), supply resources (e.g., equipment and funding acquisition), and travel patterns can be accomplished only over relatively long periods of time or at infrequent time intervals (1-3). Such substantial physical and information delays to transit supply and demand changes, together with regulatory restrictions, imply that a realistic model of transport supply-demand interactions should be able to treat the time dynamics of response to policy changes. SOLON achieves this by tracing the interactions shown in Figure 1 continuously through time.

As demand and supply continue to interact, each pass through the performance sector determines a new value for the set of efficiency, cost-effectiveness, and productivity indicators of that sector. The tables and plots of these indicators through the study period are the major products of SOLON and will be discussed in a later section. These performance records can facilitate the route evaluation process by assisting managers in assessing candidate operating policies and by advising funding agencies in making subsidy decisions on the basis of performance.

MODEL COMPONENTS

Tracing the demand-supply interactions through time is done on the basis of component equations housed within each of the four major SOLON modules shown in Figure 1. A summary of the contents of the modules (i.e., logic, empirical base, and data sources) is presented in this section. Although this exposition is necessarily constrained by space, it should nevertheless expose the strengths and limitations of the methodology. The summary should further aid the reader to identify the assumptions and, therefore, the applicability of SOLON to specific decision-making and policy evaluation situations.

Travel Demand Sector

Estimating the expected demand for a planned transit service is essential to system managers before implementation of specific service policies along a route. In SOLON the demand model should be capable of estimating ridership as a function of time and level-of-service measures based on initial route conditions only (i.e., without the need for extensive time-series data for the entire policy evaluation period). In addition, it should take into account the information delay between the time a service policy is implemented and the time residents of the service area become aware of the new service. However, most existing demand models are static (i.e., they estimate demand when the transport system is at equilibrium). Further, the static approach overlooks delayed interactions between the demand and the other transportation sectors and cannot treat transient policy impacts. Such impacts are of particular importance to decision makers during periods in which conditions exogenous to the transportation system, having created a trend, suddenly undergo major changes and force the system away from equilibrium.

Because of the limitations of the existing models, a dynamic demand equation was developed that fulfills the requirements of a time-sensitive technique such as SOLON. Assuming, for the purposes of this discussion, that the trip generation and trip distribution stages are completed, the dynamic demand equation states that P_{t+1}, the estimated probability of selecting a given mode of travel, is a function of the current probability (P_t), the estimated equilibrium probability (P_e), and an information time constant (T_p):

$$P_{t+1} = P_t + (P_e - P_t)/T_p \qquad (1)$$

The information time constant can be determined experimentally and is generally longer in rural areas (2). The equilibrium probability is estimated by a disaggregate logit specification calibrated with data from the area of application. When SOLON is implemented, the suggested parameter values, which have been validated at several rural and urban routes (2-4), can be updated with a small data sample (5). Alternatively, any steady-state demand model, such as ULOGIT (6), or a simple regression equation could replace the existing specification. It should be noted that Equation 1 is based on the assumption that transportation demand, unless otherwise driven, behaves as a first-order system. Although this assumption is based on data from several systems (4), transportation operations may exist for which higher order effects are substantial.

All or some elements of the demand sector can be activated by the user, depending on the nature of the application. For instance, a modal split specification for work trips should be employed for rush-hour applications. Other equations available in this sector include a joint generation/distribution/modal-split shopping specification based on concepts presented in Stephanedes (2) and Adler and Ben-Akiva (7) and specifications developed particularly for area residents without a car, with one car, with two or more cars, and with or without transit access. Although the choice of specification or specifications is made by the user, each equation takes into account the results from other sector elements as appropriate; for example, the shopping trips equation is a function of automobile availability, which is estimated by the work trip equation.

The data needs of the demand specifications include conventional demographic, socioeconomic, and trip information traditionally required by logit models (e.g., household income, automobiles per household, workers per household, trip distance, travel time, waiting time, and cost). Most of the data are entered when the method is initialized. At that time, the user has the option of entering additional data or elementary formulas generating such data for the simulation period; however, such information is not necessary. For example, forecasts of the price of gasoline and inflation and unemployment rates can be entered for each month of the study period if these are expected to change; further, formulas that forecast such changes for the evaluation period could be directly incorporated in SOLON. The second kind of data needed by the demand sector is created internally in the highway and transit route performance sectors at every time instant of the simulation.

Transit Route Performance Sector

Efficiency, effectiveness, productivity, and quality indicators describing the route performance are needed by the supply and demand sectors for estimating service and ridership decisions, respectively, during simulation. The time records of these indicators for the study period are also needed for policy evaluation and funding decisions as mentioned earlier. Although there exist a large number of indicators that could be calculated with information from the demand and supply sectors, only a set of reasonable size is initially available to the user. The indicators included in this set have been selected on the basis of earlier work by Fielding and others (2,8-11) who sought to identify the measures that can best be employed to evaluate transit performance. To be sure, the user can easily create additional indicators using the components generated by SOLON (for a set selected by a typical urban user in the Twin Cities, see Table 1). Similarly, the user can work with a smaller set that is generated automatically at the end of an evaluation and never turn to the SOLON library for additional information; such a small set could, for instance, be adequate for performing a preliminary evaluation of a rural transit route.

TABLE 1 Selected SOLON Library Performance Indicators

Condition To Be Measured	Indicator	Type
Absolute Measurements		
Demand		
Absolute ridership	Ridership	Output
Absolute demand	Demand per time period	Impact
Survivability of system	Years in operation	Effectiveness
Quality of services		
Frequency	Average headway and on-time arrival	Quality
Travel time	Average speed	Quality
Supply of services (quantity of service)	Vehicle-miles and route-miles	Output
Comparative Measurements		
Demand (relative)	Passenger trip modal split	Effectiveness
	Passenger trips/capita/time period	Effectiveness
	Passenger trips/capita/time period after service improvement compared to before	Impact
Survivability of system	Operating ratio	Cost-effectiveness
Quality of services		
Level of service	Trip time compared to automobile	Quality
Cost of service	Fare compared to automobile out-of-pocket cost	Quality
	Fare/mile	Quality
Comfort	Seat-miles/passenger-mile	Quality
Supply of services	Frequency compared to desired frequency	Output
Vehicle utilization	Vehicle-miles/vehicle	Efficiency
	Vehicle-hours/vehicle	Efficiency
	Vehicle-hours/vehicle/service-hour	Efficiency
Cost per produced unit	Cost/vehicle-mile	Efficiency
	Cost/vehicle-hour	Efficiency
Utilization of service	Passengers/vehicle-hour	Cost-effectiveness
	Passengers/vehicle-mile	Cost-effectiveness
	Passengers/seat-mile	Cost-effectiveness
	Passenger-miles/vehicle-mile	Cost-effectiveness
Cost per consumed output unit	Cost/passenger-trip	Cost-effectiveness
	Cost/passenger-mile	Cost-effictiveness
Subsidy	Subsidy	
	Per passenger trip	Cost-effectiveness
	Per vehicle-mile	Cost-effectiveness
	Per vehicle-hour	Cost-effectiveness
Diversion from other modes	Percentage of trips diverted from other modes	Impact

Performance indicators are determined on the basis of identities, assumptions, and simple algebraic equations calibrated in the area of application. For instance, headway in minutes is estimated from frequency in vehicles per hour on the basis of the identity:

$$\text{HEAD} = 60/\text{FREQ} \tag{2}$$

As another example, bus highway time along a route is determined by adding the stop time per transit trip (STIME) to the automobile highway time. In turn, STIME is a function of DAT, deceleration and acceleration time; STOP, the average number of stops experienced by a typical rider; DIST, the average trip length of a typical rider; STPR, stop time per rider getting on or off; and RPBM, rider per bus mile:

$$\text{STIME} = (\text{DAT})\ (\text{STOP}) + (\text{DIST})\ (2 \cdot \text{STPR})\ (\text{RPBM}) \tag{3}$$

The values for the parameters of Equation 3 are recommended by SOLON from previous urban and rural measurements and are supplemented with information entered by the user. "Riders per bus mile" is determined internally at every time instant of the evaluation period from values generated by the demand and supply sectors.

As a third example, the operating ratio is defined as fare revenue, determined from ridership estimates in the demand sector, divided by operating cost. Previous experience with SOLON and its predecessor, TRANSIT (12), has indicated that most systems break the operating cost down to a variable and a fixed unit cost component, b_1 and b_2, respectively:

$$\mathrm{OCOST} = b_1\ (\mathrm{FREQ}) + b_2 \qquad (4)$$

where b_1 is in dollars per round trip times hours per week and b_2 is in dollars per week; a third variable component, based on the number of route buses, can be added in Equation 4 if necessary. Route values for the b_1 and b_2 parameters are usually available from transit operations or can be determined from routinely recorded information on gas, oil, garaging, maintenance, wages, insurance, and other cost components.

Service Supply Sector

Using information from the route performance sector regarding key performance indicators such as load factor, operating ratio, and net revenue, the service supply sector determines the transit frequency that is necessary to keep the route within certain performance guidelines. These guidelines are declared by the SOLON user during initialization and are essential to the policy evaluation and decision-making process.

The guidelines reflect management's objectives and constraints and are usually expressed in terms of performance measures. For instance, most transit managers would not make a frequency change while the load factor remained within a range they consider acceptable. Further, frequency changes cannot be implemented unless the route performance fulfills certain constraints. A set of basic guidelines that depend on the load factor, operating ratio, and available capital has been designed with data from conversations with experienced managers (2-4) and is included in SOLON. The user can then indicate the specific threshold values of the performance constraints as well as the desired frequency modification at those values. Alternatively, the user can override the proposed guidelines and enter others that are more appropriate to the application at hand.

The service sector employs the information on the current state of the route available from the performance sector to determine the estimated frequency (FREQ_{t+1}) as a function of current frequency (FREQ_t), a management time (T_f), and the frequency control coefficient U:

$$\mathrm{FREQ}_{t+1} = \mathrm{FREQ}_t + (U)\ (\mathrm{FREQ}_t)/T_F \qquad (5)$$

where U reflects the performance guidelines discussed previously and is usually a function of the load factor, the operating ratio, and the available capital; namely, revenue, employees, and rolling stock (see Figure 2 for an illustration of U from a suburban route in the Twin Cities). The new frequency value is then fed back to the route performance sector where it is employed in the estimation of the performance measures and level of service, which, in turn, determine the demand estimate at the next time instant.

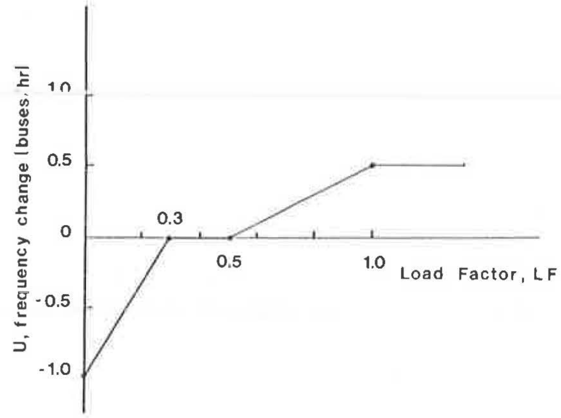


FIGURE 2 Sample SOLON policy input.

Highway Congestion Sector

Transit travel time and demand for transit are influenced by the level of service supplied by the highway sector. This influence is substantially stronger in urban areas, where congestion effects are more likely. In addition, the differential effect of congestion on mode choice may be considerable where bus preferential treatment allows buses to avoid congestion areas.

In SOLON the effects of congestion are treated by estimating the highway travel time for varying highway characteristics via simple delay curves that can be updated by the user. In large urban areas, delay curves can be prepared off-line using simulation [e.g., the freeway priority entry control model FREQ6 (13)]. In simple corridor applications the same information can be prepared with limited field traffic measurements. In rural areas, where congestion is often not a problem, constant highway times can be used at different times of day and, therefore, this sector is not needed.

APPLICATION: POLICY EVALUATION AND SELECTION

The basic process for evaluating and selecting route performance policies using SOLON is now illustrated through application of the dynamic method to peak-period work trips on bus Route 35, Burnsville-Minneapolis, a radial route along a corridor south of the Minneapolis central business district. This route is characterized by local stops at the two ends of the trip and virtually no stops in the middle portion, which makes use of freeway I-35W. Census data on Burnsville and traffic information on I-35W were readily available to the project team in the course of the study.

Data initialization is the first step in applying the policy selection method. The data requirements include conventional demographic, socioeconomic, and trip information, readily available to transport planners. Most of these data are required by the logit specifications that are built in SOLON. [The statistical properties and data needs of logit are well documented (5,14-17) and not restated here.] Additional data, associated with the dynamic nature of the method, include T_p and T_F, the information and management time constants, respectively, and the initial values of ridership and frequency. A summary of data initialization, with values from the Burnsville application, is shown in Figure 3.

Performance guidelines, indicating how transit service should be modified in response to performance changes, must next be declared by the user. In this application, for instance, the Metropolitan Transit Commission (MTC) of the Twin Cities follows a policy that states that there should be no frequency change for round-trip load factors in the 0.3

```
SOLON here!

For some of the input values that follow hit RETURN
if [DEFAULT] value is desired, else enter the desired value.

U1...Round-trip transit fare, cents - - - - - - - - - - - - - - [200]
U2...Round-trip drive cost , cents  - - - - - - - - - - - - - - [225]
A1...Management implementation delay, wks - - - - - - - - - - - [3.0]
A2...Ridership information delay, wks - - - - - - - - - - - - - [3.0]

Are you happy with this input - - - - - - - - - - - - - - - - - (y/n)
n
Please enter the correct values now -

U1...Round-trip transit fare, cents - - - - - - - - - - - - - - [200]
U2...Round-trip drive cost, cents - - - - - - - - - - - - - - - [225] 425
A1...Management implementation delay, wks - - - - - - - - - - - [3.0]
A2...Ridership information delay, wks - - - - - - - - - - - - - [3.0] 4.0

Are you happy with this input - - - - - - - - - - - - - - - - - (y/n)
y

X1INIT...Initial value of ridership,  rtrips/wk - - - - - - - - [1000]
X2INIT...Initial value of frequency, bus/h- - - - - - - - - - - [1.0]
MINF.....Minimum value of frequency allowed, bus/h- - - - - - - [0]
DT1......Management conference interval, wks- - - - - - - - - - [5.0]
DT.......Value of time step for computing, wks- - - - - - - - - [0.1]
DTP......Value of time step for printing, wks - - - - - - - - - [5.0]
LEN......Time length of simulation period, wks- - - - - - - - - [60]

Are you happy with this input - - - - - - - - - - - - - - - - - (y/n)
y

You have an option to enter the input to the logit equation
or else default values will be assumed.

WPOP...Total origin work population - - - - - - - - - - - - - - [13600]
SERM...Fraction of origin served by transit - - - - - - - - - - [0.16]
PPH....Origin people per household- - - - - - - - - - - - - - - [4.12]
AALD...Autos available per licensed driver- - - - - - - - - - - [0.64]

DAYS...Days/wk system operates- - - - - - - - - - - - - - - - - [5.0]
DIST...One-way trip length, mi- - - - - - - - - - - - - - - - - [15]
NSTOP..# Stops experiencedin aver. 1-way trip - - - - - - - - - [15]
TWLKT..Transit round-trip walk time, min- - - - - - - - - - - - [12]
ADVTT..Auto out-of-veh rtrip travel time, min - - - - - - - - - [10]

Are you happy with this input - - - - - - - - - - - - - - - - - (y/n)
y
```

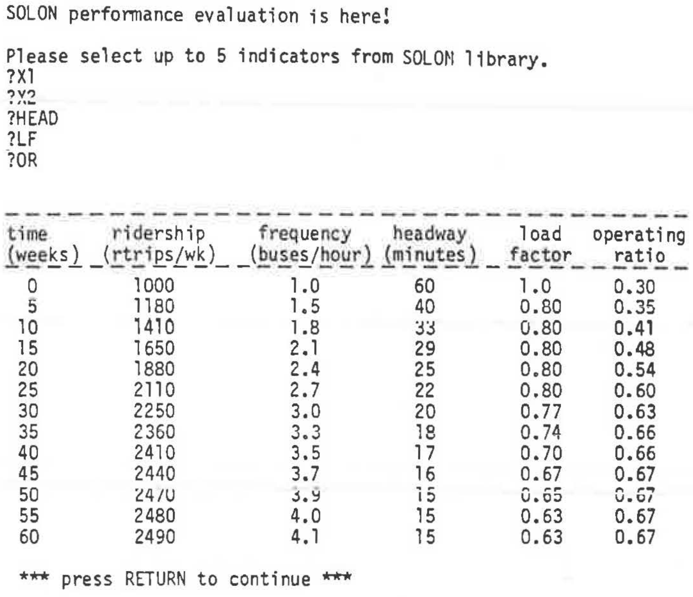
FIGURE 3 Sample SOLON data initialization.

to 0.5 range; below this range, frequency should decrease whereas above it (i.e., when there are standees), it should increase. To be sure, there exist an infinite number of candidate policies to deal with similar situations; see Stephanedes et al. (4) for a more detailed discussion. A visual display and hard copies of the policy are produced at this stage and can be used to facilitate communication among decision makers. The SOLON user can update this policy, if desired, at a later stage after the performance evaluation results have been reviewed. The management policy from the Burnsville application is shown in Figure 4. An illustration of this policy, which corresponds to control U of Equation 5, is shown in Figure 2.

Following initialization, SOLON begins operation by computing the initial values of the route performance indicators. Load factor, operating ratio, and net revenue are key indicators in this application because they determine the service frequency modifications. If the load factor (LF) exceeds the maximum value (LF_{max}) allowed by the size of the transit vehicles, then $LF = LF_{max}$ and SOLON signals the need for more service. If LF is below LF_{min}, the minimum value allowed by the operating ratio constraints, SOLON signals that present service conditions should be reevaluated. Fulfillment of additional performance criteria, critical to service change decisions, may also be similarly determined.

```
**** MANAGEMENT POLICY                                        ****


***  This is the transit management policy which           ***
***  determines frequency changes in terms of changes      ***
***  in the load factor, assuming maximum net              ***
***  cost per passenger trip = $1.50.  The policy          ***
***  is summarized as a graph of                           ***
***  frequency change vs. load factor                      ***


***  You must determine four points on this graph.        ***


1.  When buses are empty ...
    Frequency should change by (buses/hr) - - - - - - [-1.0]

2.  When buses are (% full) - - - - - - - - - - - - - [30]
    Frequency should change by (buses/hr) - - - - - - [0]

3.  When buses are (% full) - - - - - - - - - - - - - [50]
    Frequency should change by (buses/hr) - - - - - - [0]

4.  When buses are (% full) - - - - - - - - - - - - - [100]
    Frequency should change by (buses/hr) - - - - - - [0.5]

Are you happy with this input - - - - - - - - - - - - (y/n)
y
A plot of your management policy is being prepared.
```

FIGURE 4 Transit route service policy input.



```
SOLON performance evaluation is here!

Please select up to 5 indicators from SOLON library.
?X1
?X2
?HEAD
?LF
?OR

-----------------------------------------------------------------
time      ridership     frequency     headway    load    operating
(weeks)  (rtrips/wk)  (buses/hour)  (minutes)  factor    ratio
-----------------------------------------------------------------
  0        1000          1.0          60        1.0      0.30
  5        1180          1.5          40        0.80     0.35
 10        1410          1.8          33        0.80     0.41
 15        1650          2.1          29        0.80     0.48
 20        1880          2.4          25        0.80     0.54
 25        2110          2.7          22        0.80     0.60
 30        2250          3.0          20        0.77     0.63
 35        2360          3.3          18        0.74     0.66
 40        2410          3.5          17        0.70     0.66
 45        2440          3.7          16        0.67     0.67
 50        2470          3.9          15        0.65     0.67
 55        2480          4.0          15        0.63     0.67
 60        2490          4.1          15        0.63     0.67

  *** press RETURN to continue ***
```

FIGURE 5 Sample route performance printout.

The next step is activated only at regular time intervals (DT1), the length of which is controlled by the user (Figure 3). DT1 indicates the points in time when transit management makes service change decisions. If current resources are adequate, frequency change is initiated on the basis of the state of the performance indicators determined previously. Owing to implementation time delays, the frequency change initiated in this step can only be implemented after a period of time. This is necessary as a result of regulations or because of needed adjustments in the rolling stock and the number of available drivers. In extreme cases, when the available transit vehicles are not sufficient for satisfying the needed service improvements, additional capital (R^d) is desired; in this case vehicles may be ordered or drivers may be hired, or both. In such an event, order and acquisition delays intervene and service change decisions may be implemented more than a year after the process is initiated. At the same time, depreciating vehicles are retired and create the need for additional equipment orders.

If additional capital is needed, orders (R^o) are placed according to the following plan:

$$R^o_{t+1} = R^d_t - R_t - \sum_{m=1}^{p} R^o_{t-m} \tag{6}$$

As Equation 6 suggests, the orders are determined by desired capital (R^d) but take into account existing capital (R); that is, existing number of buses and all previous orders that have not yet arrived because of the capital arrival delay (p). Meanwhile,

$$R_{t+1} = R^o_{t-p} + R_t\ (1 - 1/L) \tag{7}$$

An account of existing capital is kept, where R is estimated as the sum of R_t, current capital, and R^o_{t-p}, the capital ordered p weeks earlier and arriving now. Further, assuming a capital lifetime of L weeks, the appropriate amount of capital (R_t/L) is depreciated from this sum.

Following the change in transit service, the route performance measures (and highway levels of service if needed) are determined and the demand is estimated. A record of the ridership, frequency, and

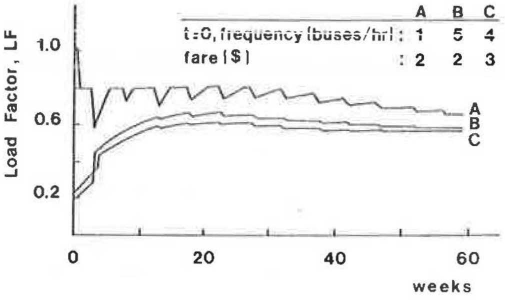


FIGURE 6 Load factor versus time for three different policies.

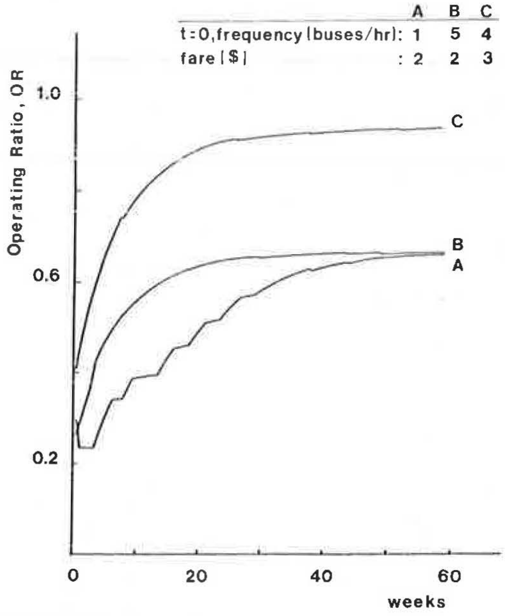


FIGURE 7 Operating ratio versus time for three different policies.

other performance indicators is kept in the form of tables and plots. These are then available to the user interactively beginning with time zero (i.e., the time SOLON is initialized) and ending with the end of the time horizon or any other instant specified by the user. In this application, the route performance is summarized in the printout sample (Figure 5) and in the plots shown by Line A in Figures 6 and 7, which illustrate the progress of load factor and operating ratio, respectively. The printout and the plots labeled "base case" represent the route performance under the policies initially proposed by the user.

Having inspected the selected printouts and plots of route performance indicators for the base policy, the user can indicate policy modifications and compare the resulting route performance against the base case. To illustrate this option, two such policy modifications have been included in Figures 6 and 7 along with the base case results. In this example, policy C succeeds in increasing the operating ratio so that it enters the desired region (i.e., becomes greater than 0.9) while the load factor remains within acceptable levels. The overplotting can continue and the user can evaluate additional policies until he is confident that one or more of the policies are superior and should be selected. A typical SOLON session in the Twin Cities application lasted 10 to 20 min before the user could make such a selection. This time length may, of course, vary depending on the complexity of the scenarios to be evaluated.

As a final step of the SOLON process, time contours are presented that indicate the time required for the route being evaluated to reach the desired performance conditions, for any combination of initial conditions. For instance, the user can determine how long it will take for a specific route to reach and remain within a set of performance constraints. This evaluation option is available for any policy selected at the end of overplotting in the previous stage. An illustration of this option with respect to the "base case" policy and policies B and C is shown in Figure 8. In that figure, the initial values of the base policy (A) are, load factor (at t = 0) = 1.0 and operating ratio (at t = 0) = 0.30 as previously computed and shown in Figures 5; 6, Line A; and 7, Line A. Similarly, the initial values of load factor and operating ratio for the other two policies were shown in Figures 6, Lines B and C, and 7, Lines B and C, respectively. As the data in Figure 8 indicate, the base policy (A) cannot guide the route to the desired conditions (i.e., to load factor ≥0.4 and operating ratio ≥0.9). Policy B, selected by the user after gaining some insights with SOLON, would also fail although it is substantially better than the initial "naive" policy. The third policy, selected after the user had some additional practice, is effective and is expected to lead the system to the desired region in approximately 25 weeks, in agreement with Figure 7, Line C.

From this application it can be seen that the number of policies that could be evaluated at once with respect to a pair of indicators, such as load factor and operating ratio, using Figure 8 covers the whole two-dimensional space and is, therefore, infinite. Thus, this figure can result in substantial time savings if the user only seeks to ascertain the degree of success (or failure) expected from a wide range of policies. Together, Figures 5-8 provide information that can substantially facilitate the policy selection process.

SOLON USES AND LIMITATIONS

SOLON has been applied to several transit routes in the Twin Cities (a validation example with Burnsville data is shown in Figure 9) and has confirmed the benefits expected to be derived from the use of systematic interactive planning methods. Further, users of the software experimental versions have made a number of helpful recommendations for improvements; incorporation of these in the current system has made it more responsive to the complex problems of the transportation practitioner.

Several potential applications of the interactive method have been suggested. For the transit route manager, being able to anticipate ridership and other performance indicators in response to selected service policies before policy implementation is a most valuable asset. This was especially appreciated in cases involving long implementation delays such

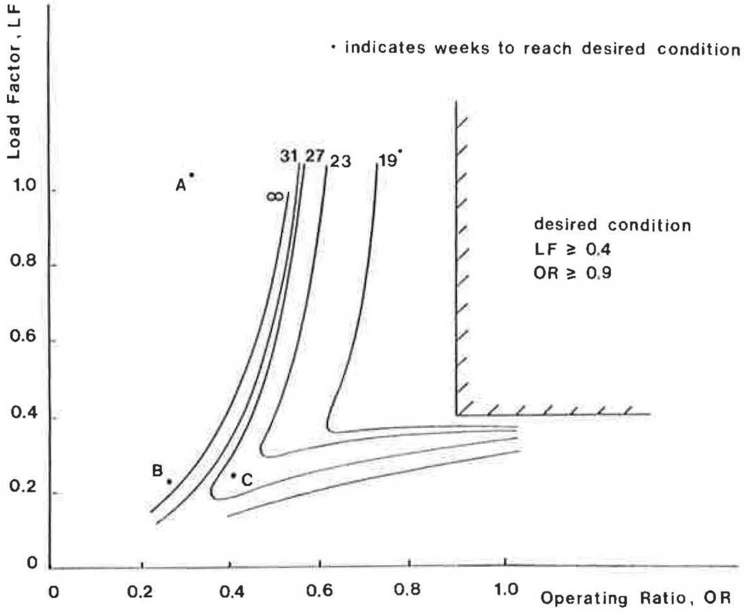


FIGURE 8 Performance time contours.

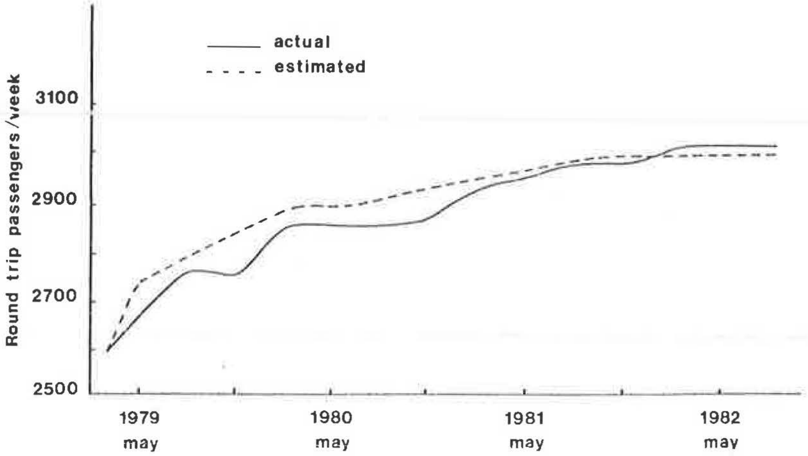


FIGURE 9 Weekly ridership in urban system.

as discontinuing service and laying off personnel. A recent movement of city suburbs toward opting out of the metropolitan transit system and beginning their own services has presented a different kind of application in which decentralized route service replaces the old provider. In this case SOLON can be employed to determine the benefits, if any, of the contemplated change and to estimate the viability and expected performance of the proposed service. Meanwhile, all questions dealing with financing transit deficits are of special interest to the transit administrators of the local department of transportation. Such issues are especially relevant in light of the recent discussions on the possibility of reducing, restructuring, or discontinuing service on selected routes on the basis of performance. Answers to such problems can be provided through use of SOLON as a performance monitoring and evaluation tool.

When implementing the performance evaluation strategies and the method developed in this work, it should be clear that the dynamic analysis described here has addressed a particular set of questions on a particular type of transport service. The questions addressed relate to ongoing policy making, and the type of service implied is one that may change in response to the strategies being implemented. The chosen application was commuter service in a metropolitan area that sought to improve the route operating ratio under a load factor constraint; fare and frequency were the major controls available to management. However, other SOLON versions can address different types of service, objectives, constraints, and controls, in urban or rural areas, in a similar fashion. For instance, a simple version that is designed to assist transit plans for rural routes is now being implemented in a small town in northwestern Minnesota. New versions, which will also relax certain simplifying assumptions currently made by the method (e.g., assumptions on carpool occupancy and route transfers), are under development. All current versions are being implemented in microcomputer PASCAL, APPLE-II, or IBM-PC and operate with 8-64K RAM.

CONCLUSIONS

SOLON is an interactive microcomputer graphic method that addresses the problems of transit scheduling and route efficiency and productivity improvement. It has three unique characteristics: First, it provides solutions at any specified time or continuously through the life of a transport service by tracing the interactions between scheduling changes, route ridership, and service cost-effectiveness. Second, it explicitly treats time delays that hamper route performance. Finally, its modules operate interactively or independently and can be modified by the user.

By addressing the transit problems at the route level, SOLON can facilitate management and funding decision making by determining the viability of individual routes and aid in selecting the best performance policies. Further, because it assumes no previous computer knowledge, it can substantially increase personnel training productivity.

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REFERENCES

1. Y.J. Stephanedes. A Feedback Dynamic Model for Transportation Systems. Proc., 2nd International Symposium on Large Engineering Systems, IEEE and University of Waterloo, Waterloo, Ontario, Canada, Sanford Educational Press, 1978.
2. Y.J. Stephanedes. Techniques for Analyzing the Performance of Rural Transit Systems. Final Report II, DOT-RSPA-DPB-50/80/23. Research and Special Programs Administration, Office of University Research, U.S. Department of Transportation, 1980.
3. Y.J. Stephanedes, P.G. Michalopoulos, D. Gabriel, H. Hanna, and R. Plum. Development and Implementation of Dynamic Methodologies for Evaluating Energy Conservation Strategies. Final Report DOT-MN-11-0004. UMTA, U.S. Department of Transportation, 1981.
4. Y.J. Stephanedes, P.G. Michalopoulos, and T. Bountis. Dynamic Transit Scheduling under Efficiency Constraints. Transportation Research, forthcoming 1985.
5. T. Atherton and M. Ben-Akiva. Transferability and Updating of Disaggregate Travel Demand Models. Report 76-2. Center for Transportation Studies, Massachusetts Institute of Technology, Cambridge, 1976.
6. Urban Transportation Planning System. UMTA, U.S. Department of Transportation, 1976.

7. T. Adler and M. Ben-Akiva. Joint-Choice Model for Frequency, Destination, and Travel Mode for Shopping Trips. In Transportation Research Record 569, TRB, National Research Council, Washington, D.C., 1976, pp. 136-150.
8. G.J. Fielding, R.E. Glauthier, and C.A. Lave. Development of Performance Indicators for Transit. CA-11-0014-3. Institute of Transportation Studies, University of California, Irvine, 1977.
9. J.J. Kern and G.A. Weiss. Transit Performance Evaluation Process. Presented at 63rd Annual Meeting of the Transportation Research Board, Washington, D.C., 1984.
10. J. Attanucci, I. Burns, and N. Wilson. Bus Transit Monitoring Manual. Final Report UMTA-IT-09-9008-81-1. UMTA, U.S. Department of Transportation, 1981.
11. Carter-Goble Associates. Rural Public Transportation Performance Evaluation Guide. Final Report DOT-I-83-31. Pennsylvania Department of Transportation, Harrisburg, 1982.
12. Y.J. Stephanedes. Modeling Dynamic Operating and Financial Strategies in Transportation. In Systems Dynamics and Analysis of Change, B.E. Paulre, Ed., North-Holland, Paris, France 1981, pp. 19-32.
13. P.P. Jovanis, W.K. Tip, and A.D. May. FREQ6PE--A Freeway Priority Entry Control Simulation Model. Research Report UCB-ITS-RR-78-9. Institute of Transportation Studies, University of California, Irvine, 1978.
14. T.A. Domencich and D. McFadden. Urban Travel Demand. North-Holland Publishing Co., Amsterdam, The Netherlands, 1975.
15. D. McFadden. Conditional Logit Analysis of Qualitative Choice Behavior. In Frontiers in Econometrics, P. Zarembka, Ed., Academic Press, New York, 1973, pp. 105-142.
16. D. McFadden. The Revealed Preferences of a Government Bureaucracy: Theory. The Bell Jar of Economics, Vol. 6, No. 2, 1975, pp. 401-416.
17. Y.J. Stephanedes. Improved Demand Estimation for Rural Work Trips. In Transportation Research Record 842, TRB, National Research Council, Washington, D.C., 1982, pp. 10-16.

System and Route Optimization Model for Minimizing Urban Transit Operating Deficits

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ABSTRACT

U.S. transit operators are faced with escalating operating deficits along with growing opposition to the increase in taxes required to offset them. This financial situation has created an immediate need to restructure inefficient and underproductive transit operations. In response to this need, this study developed an analytical framework to help control transit operating deficits. A bilevel optimization model based on nonlinear programming was developed at system and route levels of detail. The model postulates that transit operators could reach a feasible solution for minimizing operating deficits through modifications of current fare and service policies. The model has an economic framework (through the specification of appropriate cost and revenue functions) and solves for optimality through system supply-demand equilibrium. Solutions of the optimization model will provide transit operators with specific operating guidelines for minimizing deficits subject to resource and policy constraints. The nonlinear optimization model is solved using a large-scale (sparse matrix) successive linear programming algorithm. The model was implemented on a microcomputer and was tested with a real-world application to establish its practicality and usefulness.

The financial status of most urban transit properties in the United States is at best bleak. During the past decade, total operating deficits rose more than $4.5 billion, and the problem is likely to get worse. The underlying causes of operating deficits are escalation in transit operating costs, rapid service expansion, and operators' decisions to reduce fare levels. In the past, deficits have been met primarily by government subsidies, with a significant share coming from federal sources. However, as part of the Reagan administration's Program for Economic Recovery, federal operating assistance to