48-59

DESIGNING URBAN TRANSIT SYSTEMS: AN APPROACH TO THE ROUTE-TECHNOLOGY SELECTION PROBLEM

John C. Rea, Pennsylvania State University

The service specification model is a tool for generating and screening public transportation systems during the initial planning stages. It is based on the concept of a service specification or supply function that integrates hardware system attributes and operating policy. A service specification is an integrated set of statements that defines which hardware-headway combination is to be used for any level of flow across a link. Walk mode may be included in the specification. The model defines a transit system within a network which includes all potential and existing transit links. The current model assumes that transit demand is known. The mechanism of the model is an iterative assignment procedure that is similar to the capacity restraint model. The template network is started at the "best" hardware-headway service level. Link service levels are iteratively adjusted to correspond to link flow level as specified by the service specification. The iterative process ends when no further changes in link service level are required. Empirical tests show that the model is sensitive to the policy decisions and hardware mix incorporated in the service specification and to the size and orientation of the transit demand. The attainment of an equilibrium flow distribution appears to be influenced by the form of the service specification, the percentage of nonplanar links, and the presence of fixed transit-time links in the template network. The model appears to be a useful tool for generating alternative transport system configurations based on different technology mixes and operating policies in any transportation context for which a service specification can be formulated.

•CONCERN for the quality of urban life has, in recent years, resulted in a renewed interest in public transportation as a possible means of improving the environment of our cities. Although much attention has been directed toward innovative hardware systems, relatively little attention has been given to the development of models specifically oriented to public transportation planning.

The models currently used in the public transportation planning process are, on the whole, those developed for the planning of highway transportation. It is surprising that more models have not been developed to take advantage of the unique characteristics of public transportation systems. Two examples will serve to illustrate some basic differences between private and public transportation. The level of service provided by a public transportation system improves as demand increases because of lower headways and the viable use of higher performance hardware systems (assuming that an acceptable level of comfort is maintained and that the supply of public transit capacity is adequate). In contrast, the level of service offered to a highway user declines as demand increases because of vehicular congestion. The automobile is, at least in North America, the only practical private passenger transportation system; in the case of public transportation, a wide array of technologies and operating policies are possible.

Some models that incorporate the inherent characteristics of public transportation modes have of course been developed. Among them are, for instance, a minimum path

---

Sponsored by Committee on Transportation Systems Design.

algorithm for transit networks (1), Morlok's model for integrating intercity transportation networks and technologies (4), a large number of scheduling algorithms (5), and an array of modal split models (3). Perhaps the most important missing element in the public transportation modeling process is a model capable of designing transit networks that take into account the particular characteristics of the hardware systems to be used, the manner of their use, and the size and locational pattern of the demand to be served.

PURPOSE OF THE MODEL

The model presented here is an attempt to take advantage of the special characteristics of public transportation systems. It allows the planner to easily manipulate and explore the wealth of alternative hardware systems and operating methods. The model is a tool for generating and planning public transportation networks. In particular, the model is primarily intended to be an exploratory screening technique. It is used to quickly explore a wide range of public transportation alternatives based on different mixes of hardware systems and operating methods and to thereby identify systems worthy of further detailed study. The model translates a selection from the option set into an impact set as shown in Figure 1. Varying the attributes of the option set produces different impact sets, and alternatives may be evaluated in terms of the quality of the impact set.

The place of the model in the transportation planning process is shown in Figure 2. The service specification model is intended to be used as a screening model for selecting those alternatives worthy of more detailed study.

There are three basic inputs to the model. The first describes the potential transit network, the second describes the proposed hardware systems and operating methods, and the third describes the size and orientation of the transit demand. The relation between the model inputs and the option set is shown in Figure 3. The formulation of these inputs is now described and the model's philosophy developed in the process.

TEMPLATE NETWORK

The first input is a combination of link and node options. This network, termed a template network, is a synthesis of all possible and acceptable route alignments in the study area; i. e., it encompasses all of the potential links of the public transportation system. The concept of allowing the planner to select his system configuration only from among a predefined set of links is somewhat novel in transportation planning. Traditionally, the planner has been virtually unconstrained in laying out a system configuration, provided of course that the alignments were feasible and available.

A potential route is represented by a link in the template network; any restraint (with regard to the hardware system that may be used on the route) is affected by attaching a hardware usage constraint to the link. Nodes in the template network represent loading, unloading, and/or transfer points. The process of constructing the template network offers a framework for discussions with each community prior to, rather than after, the preparation of the transportation plan. A second feature of the template network is that it effectively deals with the usual combinatorial problem involved in generating and planning alternative system components and configurations. The problem becomes, in effect, one of link elimination rather than one of link addition. An example of a template network is shown in Figure 4. The problem is to define, within the template network, a subset of links that serve the imposed demand in a manner consistent with the proposed service specification. The latter input is now explained.

SERVICE SPECIFICATION

The second input describes the types and performance characteristics of the proposed hardware systems and defines how they are to be used. This input takes the form of an explicit statement that defines which hardware-service frequency combination is to be used for a given level of flow across a link. This statement is termed the service specification. Every service specification or supply function represents a particular selection from the option set. The supply function consists of different service levels.

Figure 1. Function of service specification model.

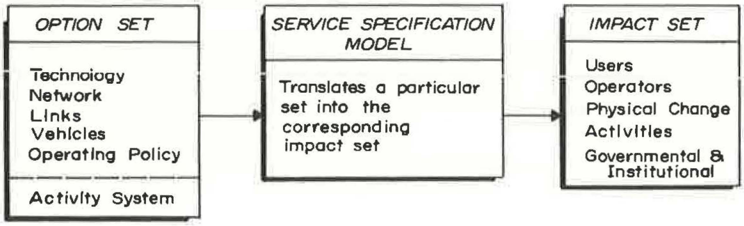


Figure 2. Relation of service specification model to transportation modeling process.

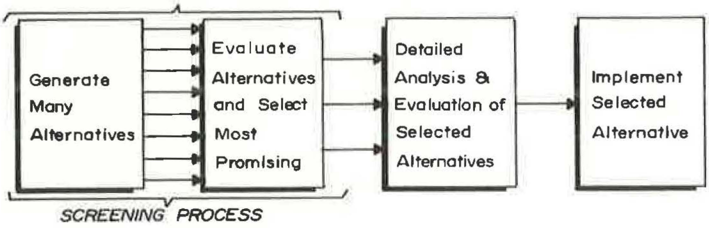


Figure 3. Relation between option set elements and model inputs.

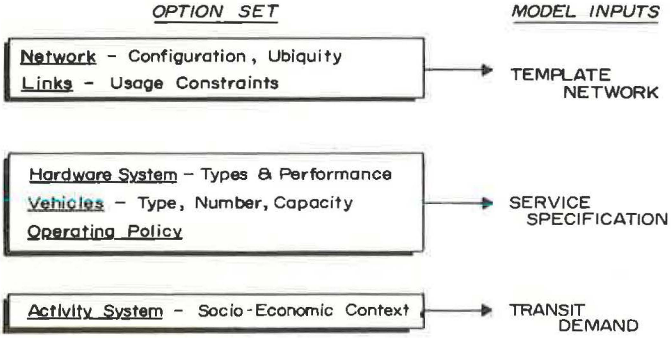


Figure 4. Example of template network.

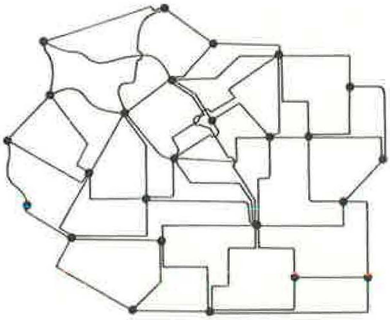
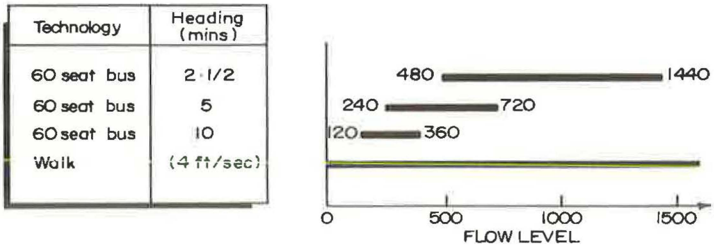


Table 1. Example of service specification.

Service Level	Type of Technology	Technology Conformation	Headway (sec)	Maximum Speed (ft/sec)	Acceleration (ft/sec^2)	Proposed Usage Range (persons/hour)
1	Rail	4 cars, 80 seats each	90	88	6	More than 6,400
2	Rail	2 cars, 80 seats each	90	88	6	3,201 to 6,400
3	Rail	2 cars, 80 seats each	180	88	6	1,441 to 3,200
4	Bus	60-seat bus	150	44	4	721 to 1,440
5	Bus	60-seat bus	300	44	4	361 to 720
6	Bus	60-seat bus	600	44	4	120 to 360
7	Walk	–	0	4	–	0 to 119

Figure 5. Service levels and corresponding flow ranges.



Technology	Heading (mins)
60 seat bus	2-1/2
60 seat bus	5
60 seat bus	10
Walk	(4 ft/sec)

Each service level corresponds to a specified range of flow levels and is defined by a technology type, a technology configuration, a service frequency, a maximum operating speed, and an acceleration (and deceleration) capability. Note that the walk mode can be encompassed by this framework. An example of a service specification is given in Table 1. This specification is obviously only one of many ways of supplying transportation service.

The basic rationale of a service specification or supply function is now described. As an example, consider the use of the service level offered by a 60-seat bus at a headway of 5 min. If all passengers are seated, the maximum capacity of this service level is 720 passengers per hour. This defines the capacity limit of the service level. One could theoretically offer this service level for all flows from 0 to 720 passengers per hour. In practice, a viable operation is achieved by establishing a lower limit. If the operating cost of the example service level is $12 per hour per mile and a fare of 5 cents per mile is charged, the break-even flow would be 240 passengers per hour. The range of flows for which this service level is viable and physically possible is thus from 240 to 720 passengers per hour.

This type of calculation can be performed for any technology-headway combination. An example for a 60-seat bus is shown in Figure 5.

Each technology-headway combination also implies a quality of service that, simplistically, can be taken as the overall travel speed, i. e.,

$$d/[t + (h/2) + s]$$

where

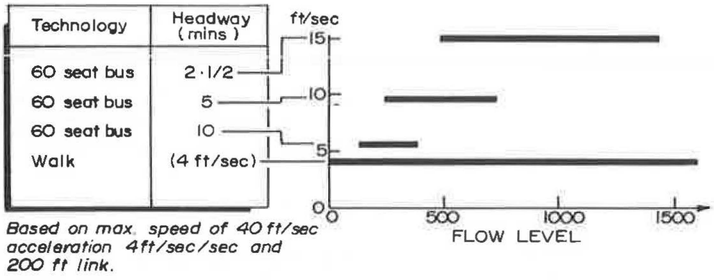
d = trip length,
t = time on vehicle in motion,
h = headway at boarding point, and
s = dwell time at intermediate stop.

More complicated formulations are possible, but this will suffice for the present purpose. By means of this interpretation of service quality (or any other), service levels can be ranked on a vertical scale as well as the horizontal flow scale. The data used in Figure 5 have been reinterpreted on this basis (for a 2,000-ft link) as shown in Figure 6. These concepts lead to the formulation of a service specification envelope for the 60-seat bus technology as shown in Figure 7. It is possible to formulate many different service specifications within this envelope to reflect different operating policies as exemplified in Figures 8a through 8d. The specification envelopes of different hardware systems can be superimposed to define an envelope for a mixed technology system as shown in Figure 9.

Note that the envelope is a guide rather than an absolute constraint in formulating specific service specifications. The viability boundary can be transgressed if one is willing to accept the economic consequences. The capacity boundary can be crossed if standees are acceptable. Each service specification will result in the definition of a different transit system and impact set.

The viability boundary of a service specification can be based on operating or total costs. Given the federal capital grants program and the communal benefits of a transit system, one could argue that the viability boundary should be based on operating costs. Economists would probably advise a total-cost criterion. Because the extent of the transit system is not known initially, there are some difficulties in basing the viability boundary on total costs unless one is willing to assume that the infrastructure cost per mile is constant. The use of a flat-fare rate instead of a per-mile rate also introduces some difficulties, but these can be overcome by assuming that a fare contributes to the support of each link in a utilized trip path on a pro rata distance basis. The income accruing to each service level can be obtained by summation. The initial arbitrary flat rate can then be adjusted as required to recover operating or total costs as the case may be. These, and other, aspects of the service specification obviously warrant more discussion than space allows here.

Figure 6. Service levels, flow ranges, and quality of service.



Based on max. speed of 40 ft/sec acceleration 4 ft/sec/sec and 200 ft link.

Figure 7. Development of service specification envelope.

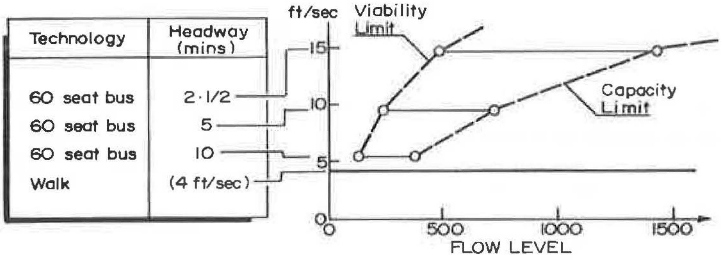


Figure 8. Hypothetical service specifications.

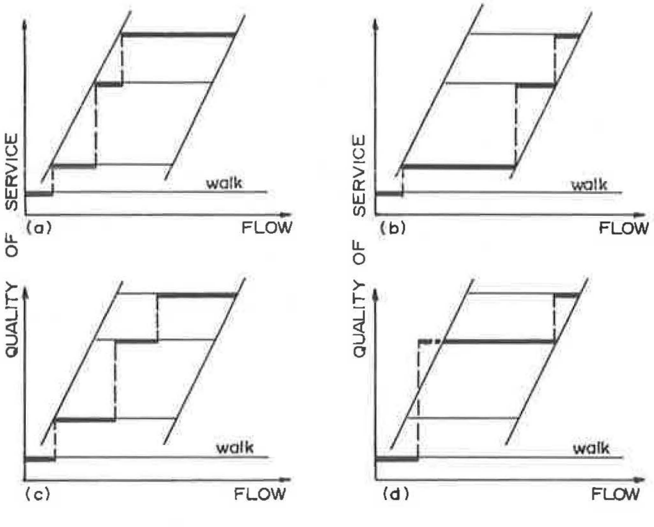
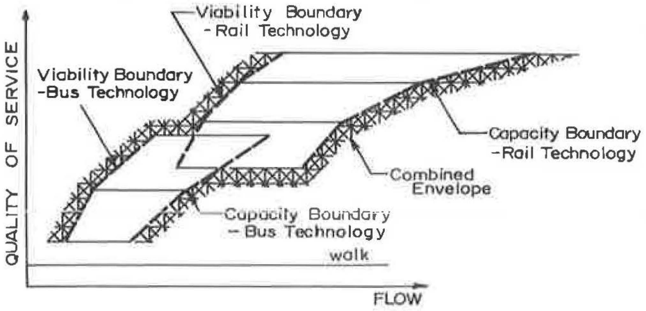


Figure 9. Specification envelope for mixed technologies.



TRANSIT DEMAND

The third input to the model describes the size and orientation of the demand that the system must accommodate and takes the form of a trip table showing morning peak-hour origin-destination (O-D) flows. The template network should preferably be formulated such that the origins and destinations are also network nodes. Although this is not a requirement, it does reduce the number of links and nodes involved in the analysis and reduces computer running time and costs. In addition, the use of a "spider" network is compatible with the use of the model for screening purposes.

The grain of the template network and the size of the demand-analysis zones should have some correlation. A coarse template network is suitable for identifying transportation corridors on a metropolitan scale, and the usual size of a demand-analysis zone would be appropriate in this case. A fine-grained template network with corresponding small-analysis zones would be appropriate for a microanalysis.

ALGORITHMIC PROCEDURE

The algorithmic procedure of the service specification model is essentially the same as that of the capacity restraint model. In the capacity restraint model, O-D flows tend to disperse across the network because, for highways, the quality of service on specific links declines as flow levels increase. Thus, a trip-maker may achieve a shorter trip time by traveling a longer distance to bypass areas of highway congestion. In the service specification model, O-D flows tend to concentrate in corridors of movement because the quality of service offered by a public transport system improves as flow levels increase. Thus, a trip-maker in this case may achieve a shorter trip time by traveling a longer distance in order to take advantage of the faster service provided on links with a high level of flow.

The effect of this concentration of flows is to leave some links with such low flows that they no longer warrant transit service (as determined by the service specification). Such links are assigned a service level equivalent to the walk mode and are in effect eliminated from the template network, thereby defining the transit system configuration. The transformation is shown in Figure 10. A more graphic way of interpreting the algorithmic process is to regard it as a battle in which links compete with each other and acquire as high a service quality as possible. As a result of the interlink competition, some links win and receive higher quality status sets and other links lose and become mere walk-mode links.

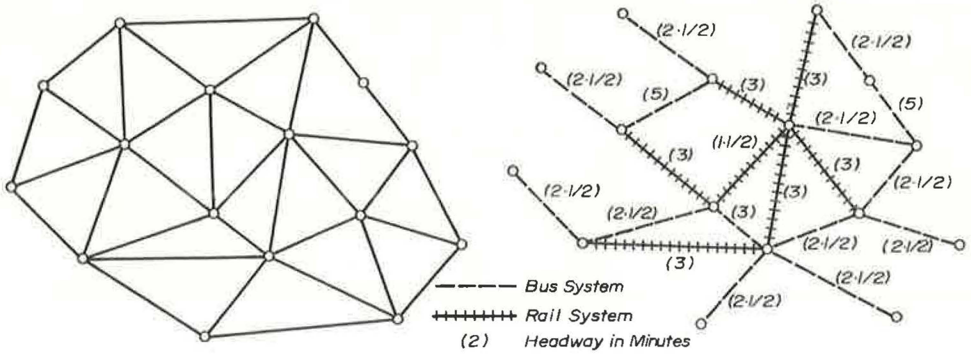
Link elimination, or, more positively, the definition of the transit system configuration, is achieved by establishing an equilibrium flow condition within the template network. The equilibrium flow condition is achieved by means of an iterative procedure, the steps of which are as follows:

1. Step 0: attribute to all links in the template network the highest service level ("initialization").
2. Step 1: determine minimum time paths through the template network between all origins and destinations.
3. Step 2: load each O-D demand onto links in the appropriate minimum paths.
4. Step 3: check each link's service level and loading for correspondence in the service specification.
5. Step 4: if correspondence is lacking, change the link service level to that warranted by its flow level in accordance with the service specification and go to step 1. If the service level and flow level of all links correspond, as defined by the service specification, stop.

A flow diagram of this algorithm is shown in Figure 11. The elements of the algorithm are now discussed.

The objective of the "initialization" process is to ensure that the template network is initially of uniform quality. Thus, no link has any initial advantage other than its inherent position and orientation characteristics. Given this condition, a link will attract flows to it only by virtue of its inherent attributes vis-à-vis the size and orientation of the O-D demand.

Figure 10. Definition of transit system within template network.



(a) Template Network

(b) Transit System Defined Within the Template

Figure 11. Algorithm flow chart.

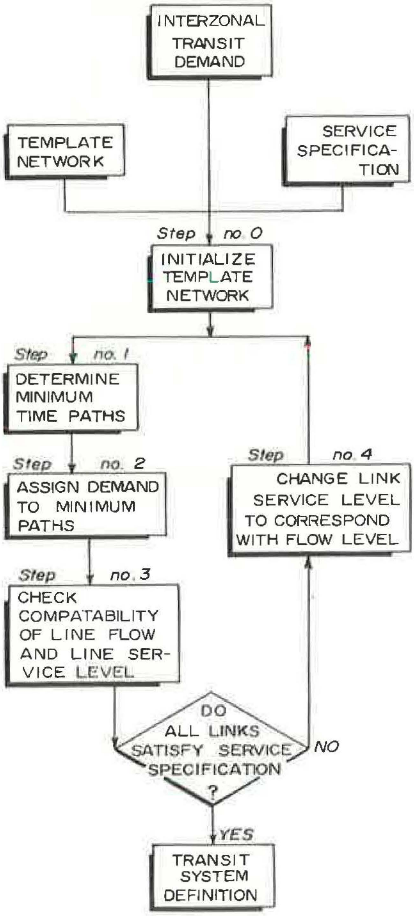
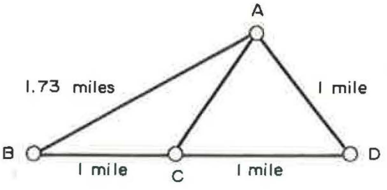


Figure 12. Input data and assumptions for example.



(a) Template Network

from \ to	B	C	D
A	200	400	100
B	0	400	400
C	500	0	300
D	400	600	0

(b) Trip Matrix (passengers/h

Service Level	Technology	Headway (secs)	Speed (ft/sec)	Link Flow Range (passengers/hr)
1	60 seat bus	150	40	720 – 1440
2	60 seat bus	300	40	400 – 719
3	Walk	0	4	0 – 399

(c) Service Specification

Note: Bus requires 132 sec to cover 1 mile and 228 sec to cover 1.73 mil
Walking requires 1320 sec for 1 mile and 2280 sec for 1.73 miles.
Waiting time assumed to be half of headway. Zero dwell time assume
No transfer if sequential links have same technology.

It is assumed that the individual trip-maker seeks to minimize his own trip time (or, more generally, his disutility) by using a route on which the trip time is less than or equal to trip times on routes not used. Minimum path rather than multiple path assignment is used for two reasons. Transit systems do not, in general, offer a variety of paths between a given pair of origins and destinations. Furthermore, minimum path assignment tends to concentrate flows, which is compatible with the intent of the model. In symmetrical networks, the node numbering system influences the selection of the minimum path; in such cases, node numbering should be done on a random basis and sensitivity checks made.

In the absence of an integrated predefined system of transit routes, obviously some assumptions are required to determine minimum path routes through the evolving network. It is assumed that, if two sequential links currently use the same technology (e.g., rail or bus), no transfer is required even if the frequency of service on the two links differs. If the technologies differ, it is assumed that a transfer is required, and the trip-maker must wait at the transfer point for a period equal to half of the service headway on the second link. The minimum path algorithm used in the model is basically an amendment to the Moore algorithm by Dial (2). The algorithm has been further amended to allow either stopping at stations enroute or continuity of through movement at intermediate stations.

Individual O-D demands are loaded onto links in the appropriate minimum path and summed to give the total flow along each link in the network. The checking routine (step 3) is achieved by referring to the service specification.

The procedure for changing a link's service level can be formulated in a number of different ways. The most obvious is to change the service level of a directed link (differentiating between link $\underrightarrow{\text{A-B}}$ and link $\underrightarrow{\text{B-A}}$) on the basis of its own flow level. This approach may, however, result in links with common nodes being allotted different technology-headway combinations. A second approach is to give to both links (i.e., $\underrightarrow{\text{A-B}}$ and $\underrightarrow{\text{B-A}}$) the service level appropriate to the average loading on the two links. This approach ensures that the two links have the same technology and builds in vehicle "backhaul," which is an operating feature of all real-world transit systems.

By assigning the same service level to both links on the basis of their average loading, the economic use of that service level is ensured. If the link loadings are widely different, however, the demand on the more heavily loaded link could exceed the capacity limit of the assigned service level; i.e., if the capacity limit were based on all seated passengers, this approach could produce some standees. One could equally well give both links ($\underrightarrow{\text{A-B}}$, $\underrightarrow{\text{B-A}}$) the same service level by using the higher of the link loadings as the criterion. This approach satisfies the capacity constraint but may result in violating the economic constraint. Other approaches not currently in the model involve a consideration of the loading on "strings" of links as a basis for allotting service levels.

The evolution of the equilibrium flow condition during the iterations is of interest. After the first iteration, few (if any) links will show correspondence (in the service specification) between the "initialization" service level and link flow levels. Most will therefore be given a lower service level. Some links will not be downgraded as much as others by virtue of the higher flows they attract due to their inherent location and orientation attributes. In the second iteration, new minimum paths will be found that take advantage of the lower times possible via links with a high service level. Loading the O-D demands onto the new minimum paths further increases the level of flow on these links, thus enabling them to acquire a service level of yet higher quality. The enhanced quality of these links makes them even more attractive, and they will be included in more minimum paths in the subsequent iteration. This process of flow concentration will continue until the quality of such links no longer compensates for the extra distance involved in making use of them for the remaining O-D flows. For remaining O-D flows, a lower trip time is possible via a more direct path (although via links with a lower quality service level).

EXAMPLE OF ALGORITHMIC PROCEDURE

A five-link template network is shown in Figure 12a, and the demand to be accommodated is shown in Figure 12b. Suppose that we wish to find the distribution of technologies and service frequencies that derive from the service specification shown in Figure 12c.

In the "initialization" step, all links are given service level 1 as shown in Figure 13a. The minimum time paths are then derived, bearing in mind the assumptions mentioned earlier; the minimum path times are shown in Figure 13b. Loading the trip matrix onto these paths results in the link flows shown in Figure 13c. Reference to the service specification shows that some links should receive different service levels as shown in Figure 13d. New minimum time paths are computed through the amended network, resulting in the times shown in Figure 13e. Loading these minimum paths gives the flow distribution shown in Figure 13f. Once again, the link flow levels are checked against the service specification and the necessary changes in link service level made (Fig. 13g). The resultant minimum path times, which are shown in Figure 13h, lead to the same flow distribution shown in Figure 13f. Because the flow distribution is the same as that in the previous iteration, an equilibrium condition has been achieved. The distribution of hardware systems and service frequencies that are derived from the proposed service specification is shown in Figure 13g.

COMMENTS ON THE MODEL

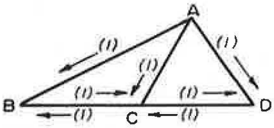
The distribution of hardware systems and service frequencies produced by the service specification model is not necessarily an operational system because the model reaches the equilibrium condition by considering the status of individual links. An operational transit system is actually an integrated set of routes or link sequences. The output of the model must be "operationalized" by the analyst; the adjusted system is then run through a final iteration, which suppresses any further changes of link status, to give the final flow distribution.

Although there is no mechanism in the model for ensuring that a reasonable route structure is produced, it appears (from testing done to date) that relatively little adjustment is required to define an acceptable route structure within the transit system configuration produced by the model, especially for node-oriented systems. This results from the fact that most minimum paths through a uniform quality network pass through or near the center of the network. Central links are thus subject to comparatively higher flows and hence warrant a higher quality of service. The tendency of minimum paths to pass through the central links is thus further emphasized. The result is that link flow levels are high on central links and decrease toward the periphery of the network. This phenomenon, in turn, leads to a gradation of transit system quality in like manner, thus facilitating the definition of a route structure within the transit system.

The preceding discussion has a bearing on the assumption built into the minimum path algorithm, namely, that no transfer occurs if sequential links have the same hardware system. It was mentioned earlier that the trip matrix should represent the morning peak hour—in which case most transit trips will be oriented toward the center of the network. A typical schedule structure, given that the quality of service declines from the center toward the periphery of a network, is shown in Figure 14. The assumption is thus quite acceptable for centrally directed transit trips, hence the reason for specifying a morning peak-hour trip matrix. If an evening peak-hour trip matrix were to be used, the assumption would result in lower trip times than would actually be the case. Various techniques can, however, be adopted to handle this condition.

It is assumed in the current model that technology speed is not influenced by its own loading or by other flows on the same guideway. For rail systems this is acceptable, but buses are influenced adversely by automobile traffic especially in the central areas of a city. The model thus implies that buses operate on a separate right-of-way if automobile traffic is heavy enough to influence bus speed. This deficiency can be overcome by specifying that buses on central links operate at a lower speed.

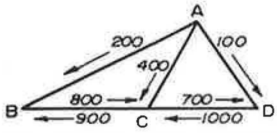
Figure 13. Example of algorithmic procedure.



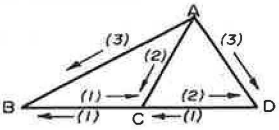
(a) Initialization

from \ to	B	C	A
A	AB, 303	AC, 207	AD, 207
B	--	BC, 207	BCD, 339
C	CB, 207	--	CD, 207
D	DCB, 339	DC, 207	--

(b) Minimum Path Travel Times Resulting from Initialization



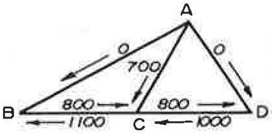
(c) Loading in 1st Iteration



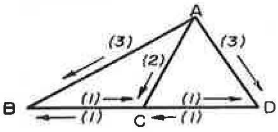
(d) Change of Link Status Sets After 1st Iteration

from \ to	B	C	D
A	ACB, 414	AC, 282	ACD, 414
B	--	BC, 207	BCD, 339
C	CB, 207	--	CD, 282
D	DCB, 339	DC, 207	--

(e) Minimum Path Travel Times Resulting from (d)



(f) Loading in 2nd Iteration

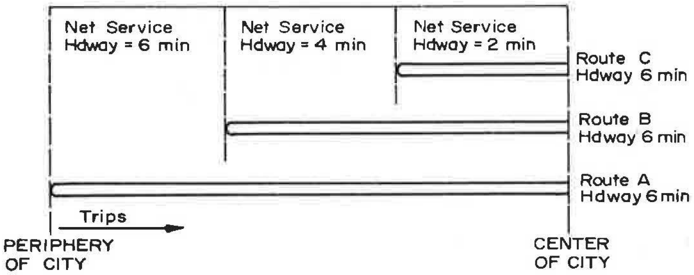


(g) Change of Link Status Sets After 2nd Iteration

from \ to	B	C	D
A	ACB, 414	AC, 282	ACD, 414
B	--	BC, 207	BCD, 339
C	CB, 207	--	CD, 207
D	DCB, 339	DC, 207	--

(h) Minimum Path Travel Times Resulting from (g)

Figure 14. Typical schedule structure.



A final comment concerns the manner in which the model realizes the minimization of individual trip times. Theoretically, the model cannot guarantee that an optimum transit network is realized in all cases because of two factors. The first relates to the step structure of the service specification (Fig. 8) and the second to the fact that, in the model, adjustment of a link's status set trails rather than leads the trip assignment step. Preliminary tests of the model, however, indicate that this may not be a serious problem. The built-in dynamism of the model appears to result in a transit network whose redundancy is so reduced that few nearly equal time paths between any origin and destination exist in the equilibrium flow condition.

EXPERIMENTAL RESULTS

A computer program to test the performance of the service specification model was initially written in Fortran IV for use on a CDC 6400 computer at the University of Washington (5). An extended version of the model was later developed for use on an IBM 360-67 computer using a WAT IV compiler at Pennsylvania State University.

Sixteen different template networks, using different hypothetical service specifications and demand patterns, were used in the tests. It was found that the attainment of an equilibrium flow condition was influenced by three factors: the location of the steps in a service specification, the status set used for "initialization" in cases where fixed transit time links are included in the template, and the percentage of nonplanar links in the template.

In most runs, an equilibrium flow condition was produced by the model within (arbitrarily chosen) 12 iterations. In the instances where convergence did not occur, changes in the preceding factors produced an equilibrium condition. In some cases, a pseudoequilibrium condition developed wherein a repeating cycle of link status changes occurred involving the same small number of links. In cases where a convergent solution was not obtained, the factors previously given were identified as contributing factors.

The model was able to achieve an equilibrium flow condition by using both planar and nonplanar templates. In the latter case, however, increasing the percentage of nonplanar links resulted in nonconvergence within the cutoff number of iterations when using a multiple-origin, multiple-destination trip matrix. The model is also able to handle networks that include single directed links between nodes, i. e., where link $(\underrightarrow{m\ n})$ exists but link $(\underrightarrow{n\ m})$ is omitted.

Tests and subsequent evaluation indicate that, for planar templates, the service level used for "initialization" does not influence the nature of the resulting equilibrium flow condition. This is not true, however, for networks that contain links whose service level is not influenced by the level of flow across them such as moving belts.

Because of time and monetary constraints, it has not been possible to empirically test and evaluate every possible combination of variables in the model. The range of tests made to date, however, indicates that the concept of the model is feasible and that it promises to be a valuable addition to the array of public transportation planning models.

GENERATING TRANSIT NETWORKS

The service specification determines the structure of the transit network. By varying the formulation of the service specification to reflect different ways of operating a given mix of hardware systems or by changing the mix of hardware systems, different networks are produced. The technologies described in the service specification need not necessarily be existing systems; i. e., they could be hypothetical systems. Such an approach could be adopted to explore the implications of some proposed hardware system or to define performance and economic parameters for a hardware system required to give normative levels of service.

If a template contains fixed performance links, it appears that different transit networks may, in some cases, be generated by establishing the template at different service levels. In this way, one could vary the degree to which a new system complements, or is complemented by, a preexisting fixed quality (belt) system.

CONCLUSIONS

The service specification model is intended as a screening model to explore the wealth of alternative hardware system combinations and operating policies in public transport system planning. As such, it fills a critical gap in the current modeling process. It has been shown that the concepts encompassed by the model are viable and that the model promises to become a practical planning tool.

Although the model has been described primarily in terms of an urban transit application, the model may be used in any transportation context for which a service specification or supply function can be formulated. Further research on the model and an examination of its utility as a planning tool in a real setting are currently being carried out at the Pennsylvania Transportation and Traffic Safety Center, Pennsylvania State University.

ACKNOWLEDGMENT

Development of the model was supported by the Pennsylvania State University Research and Training Program sponsored by the Urban Mass Transportation Administration. Further research is being done at the University under grant UMTA-PA-URT-8(71).

REFERENCES

1. Dial, R. B. Unpublished algorithm for determining minimum paths through a transit network.
2. Dial, R. B. Algorithm 360: Shortest Path Forest With Topological Ordering. Communications of ACM, Vol. 12, No. 11, Nov. 1969, pp. 632-633.
3. Fertal, M. J., et al. Modal Split: Documentation of Nine Methods for Estimating Transit Usage. Bureau of Public Roads, U. S. Dept. of Commerce, Washington, D. C., 1966.
4. Morlok, E. K., Nihan, N. L., and Sullivan, R. F. A Multiple-Mode Transportation Network Design Model. Transportation Center, Northwestern Univ., 1970.
5. Rea, J. C. Designing Urban Transit Systems: An Approach to the Route-Technology Selection Problem. Urban Transportation Program, Univ. of Washington, Res. Rept. 6 (PB204-881), 1971.
6. Wren, A. Applications of Computers to Transport Scheduling in the United Kingdom. Eng. Exp. Sta., West Virginia Univ., Bull. 91, March 1969.

SPONSORSHIP OF THIS RECORD

GROUP 1—TRANSPORTATION SYSTEMS PLANNING AND ADMINISTRATION
Charles V. Wootan, Texas A&M University, chairman

Committee on Passenger and Freight Transportation Characteristics
Warren B. Lovejoy, Port of New York Authority, chairman
Josephine Ayre, Ward D. Belding, Jr., Burton N. Behling, Dietrich R. Bergmann, Robert Brown, Jr., R. L. Carstens, Donald E. Church, John E. Clayton, William A. C. Connelly, Allen J. Dowd, Allan C. Flott, Alexander French, William L. Garrison, Jerome Gilbert, A. J. Goldenthal, Charles A. Hedges, Edgar M. Horwood, Frederick A. Koomanoff, Edward Margolin, Peter S. Parsonson, Benjamin Perry, Vincent J. Roggeveen, Charles V. Wootan

Committee on Transportation Programming, Planning and Evaluation
Michael Lash, Federal Highway Administration, chairman
Willard F. Babcock, Seymour F. Coffman, Dan C. Dees, Roger L. Hildebeidel, Robert A. Keith, Jack Kinstlinger, William L. Mertz, Ronald W. Pulling, Lloyd A. Rivard, Robert E. Spicher

Committee on Transportation Systems Design
Joseph L. Schofer, Northwestern University, chairman
Donald S. Berry, Daniel Brand, Thomas B. Deen, Ronald J. Fisher, John R. Hamburg, Kevin E. Heanue, George C. Hemmens, Marvin L. Manheim, Elizabeth J. McLean, Joseph C. Oppenlander, Louis J. Pignataro, Edward F. Sullivan, Martin Wachs, George V. Wickstrom, Richard D. Worrall, Dennis R. Young

Kenneth E. Cook, Highway Research Board staff

The sponsoring committee is identified by a footnote on the first page of each report.