PLANNING URBAN TRANSPORTATION SYSTEMS FOR PRODUCTIVITY, EFFICIENCY, AND QUALITY OF SERVICES

Anthony R. Tomazinis, Transportation Studies Center, University of Pennsylvania

This paper reports on current work and analysis of the problem carried on at the Transportation Studies Center of the University of Pennsylvania. Although the work has not yet been completed, the work undertaken enables the author to suggest that a new approach in urban transportation planning and a new type of urban transportation plan, based on studies of efficiency, productivity, and quality, may prove to be what the field needs for the 1970s. The urban transportation system is segmented into the network, the primary services offered, and auxiliary services.

NUMEROUS STUDIES in productivity and efficiency have been conducted for most sections of the economy. For the last 15 years even studies on productivity of federal services have been repeatedly undertaken and since 1970 the concern for efficiency and productivity of local government functions has grown. The studies by Kendrick (1) and Fuchs (2, 3) suggest the importance attached to productivity in the private and governmental sectors. Also the recent studies of the Urban Institute (4, 5) provide an indication of the significance attached to productivity of local government services.

On the other hand, urban transportation planning has been going on in most metropolitan regions of the country in an intensive manner since the early 1950s. In many cases the transportation planning effort resulted in the publication of impressive reports and study documents that purported to present evidence for "optimized" regional transportation plans (6, 7). Curiously enough all this effort was taking place while no overt attention was being paid to issues and problems of productivity and efficiency of the proposed systems.

Evidence clearly suggests that the primary concern in the major studies of the last 2 decades followed a long-established trend of expanding major facilities to new areas of development and of proposing new major facilities, usually highways, within the already developed part of the region. Usually, the recommendations were formed within a framework of user cost minimization as measured on a systemwide basis. Travel cost savings were then pitted against systemwide capital investment by using some of the most simplistic economic techniques, e.g., simple benefit-cost ratio, a least total cost measure, or an incremental rate of return determination. With regard to quality of service and the quality of the systems themselves, practically all major studies were concerned with only one index, that of average speed on a daily or rush-hour basis.

At the end of this prolific era of urban transportation planning, the realization has slowly emerged that the permanent accomplishments of this period have been limited indeed. The ephemeral enthusiasm of the mid-1960s gave way to the prevailing concern about the significance of what was produced at the height of the effort. Two major factors emerged in the ensuing years.

1. A vast number of individuals within urban regions discovered that the proposed transportation plans and programs included little of the quality of service of which the people were in need. In most cases plans and programs tended to ignore possible harm that the plans would produce for many individuals and whole communities and to

Publication of this paper sponsored by Committee on Transportation Systems Design.

emphasize benefits (or quality characteristics) of services that had little or no appeal to those concerned.

2. There was greater appreciation of the significance of high productivity and efficiency measurements in whatever is being done by private or public funds. A planner can no longer, with impunity, avoid issues of productivity because the investment is made through public funds. Nor can he act wisely by ignoring the efficiency rates of each major component of a complex system simply by proclaiming that the regional, total, plan is acceptable.

The three items, productivity, efficiency, and quality of services, emerge as the focus of planning activity for metropolitan transportation systems for the coming years. Their importance and centrality are indeed apparent in the midst of increasing general concern for the unit cost of all types of services produced by governmental or private organizations and for the quality of services the consumer receives. Their inseparability is also rather obvious. In fact only a transportation system that achieves a measure of all three objectives can be considered a distinct improvement over what we have and over what we have been planning.

DISSECTING THE TRANSPORTATION SYSTEM FOR PRODUCTIVITY AND EFFICIENCY STUDIES

The urban transportation system (UTS) is a complex entity. Early studies on productivity, efficiency, and quality of such a system indicate that it is imperative to conceive the system in its totality and then to dissect the overall system appropriately.

The urban transportation system is composed of, and then divided into, the network, the services, and the auxiliaries. This division differs considerably from previous breakdowns of UTS into distinctive submodes, nodes and links, or lines and terminals. The proposed new division directs analytical efforts along new lines of thought and investigation.

The Network

The analyst of the network of a transportation system emphasizing productivity, efficiency, and quality of the system has to investigate three aspects of the system:

1. The geographic location, distribution, and linkages of the various nodes and links of the network with regard to every combination of origin and destination points;
2. The magnitude, sequence, and consistency of the various attributes of each node and link (such as capacity and safety); and
3. The interrelationships between network characteristics and the surrounding elements of the other urban systems (land use, utilities, facilities).

Several studies, of course, examined networks from other points of view. Geographers' studies are well known (8, 9) as are the ones on electric network theory (10, 11) and graph theory (12, 13). Nonetheless, seemingly there has been very little thinking concerning network analysis with productivity, efficiency, and quality issues in central focus. For instance, it is obvious that a network design with 200 miles of links and 50 nodes of which only one is a central node permitting complete transfer from one section of the network to another would facilitate movement and interchanges in a much more limited manner than design with the same 200 miles of links and 50 nodes of which more than a half dozen are multiple-transfer nodes facilitating transfers from one section to another. Whatever services can be provided on such a network, the basic efficacy of transfers built in the network design will affect all measurements of productivity, efficiency, and quality.

The Services

The analyst of services that an urban transportation system offers over its network with emphasis on productivity, efficiency, and quality of the overall system has to separate the system into several components, preferably by mode, but also by link and node. The cardinal rule seems to be the closest possible matching of the demand for services to the supply. Some parts of an urban transportation system have special flexibility in providing services, whereas others have a fixed provision (capacity) regardless of demand variation. For instance, a transit system can contract or expand the provision of services by varying the frequency of vehicle departures, by increasing the size of the trains, by increasing the legal number of standees on each vehicle, or by any similar combination of actions. A highway system has much more rigid characteristics, although on several occasions flexibility can be achieved by limiting curb parking, reversing a central lane, reserving a lane for special vehicles, altering signalization, opening a bypass, or, more recently, by electronically controlling the inflow of vehicles into the traffic stream. In all cases the essential objective is to match the supply of services to the demand for services.

Several complications appear from the outset in these efforts. First, services may be provided automatically or by simple regulation as in the highway system, or by special provision of facilities and crews as in mass transit. Second, services may not be provided in a manner consistent with the demand and supply. A good example follows. The demand profile may have an extraordinary peak followed by a low point in terms of both location and time. The profile of the supply, therefore, would have to provide (if it is to be matched well) for such an extraordinary variation of peaks and valleys. On the other hand, the supply mechanisms have limitations; e.g., a train cannot add cars beyond the length of the station platforms, nor can it drop cars between major stations. Also, highways cannot, as a rule, reverse or reserve more than one lane.

The matching of the profiles of demand and supply is one component of efficiency analyses; another deals with the flexibility and feasibility of adding, reducing, and shifting services within and among the various parts of the network. A third component deals with the matching of network characteristics and service requirements or objectives. This constitutes a bridge between requirements and capabilities of the network and the services taken together.

The Auxiliaries

In many cases the productivity, efficiency, and quality of the network and the services depend on the performance of the auxiliary services. Recent statistics indicate that there is a vast difference among cities in the average number of hours that buses stay in the shop for repairs and in the number of buses that are available for assignment from system to system. For example, in one city it was found that as many as one-third of the buses were inoperable on a random day as opposed to only 5 percent of the buses in other systems. Similarly, many highway sections and intersections can be kept out of use for repairs and modification throughout the year, which reduces the efficiency of all neighboring facilities.

The condition of the auxiliary services of UTS can be evaluated from several perspectives:

1. The absolute size of the auxiliary services,
2. The relative size of the auxiliary services with regard to the size of the network and the primary services of the system, and
3. The composition of the auxiliaries.

What are, for instance, the clearly supportive services, and what are the extra services that the system provides? Also, what are the services that provide for past obligations, present needs, and future plans and expectations? A fourth perspective is the impact of the auxiliary services on the network and the primary services of the entire system or any part of it.

Not all parts of the UTS have auxiliaries of equal significance. For instance, an urban transit system has more auxiliaries than a highway system. Whether it needs all of these auxiliaries is, of course, a question that should be answered by an efficiency analysis. Also, there is increased emphasis on flexibility and management of highway systems and the associated growth in importance and size of auxiliaries in highway systems. The trend started with the provision and management of service (reversal of lanes, curb parking, reserved lanes) and is now characterized by the introduction of complete systems for urban freeway surveillance and control. In all cases the investigation should leave the question of the function and utility of the auxiliaries open inasmuch as services and subsystems can be found that are pro, con, or completely neutral to the objectives of better efficiency, productivity, and quality.

SYSTEM ASSESSMENT AND SYSTEM PARTS

A second major understanding seems necessary. The concepts of productivity, efficiency, and quality of service should be examined together. On the other hand, the UTS should also be divided into three major parts. The two sets form a symmetric matrix with nine cells (Fig. 1).

Based on the matrix shown in Figure 1, different levels of association among the three concepts and the three system parts can be discussed.

Productivity

The concept of productivity is primarily concerned with total system inputs and outputs; therefore, the unit measurement of this concept (number of units of output per unit of input, such as thousands of travelers per man-hour, per dollar, per mile, per bus) must be expressive of the total output of the system. No partial productivity measure really makes sense. Of course, if an urban transportation system consists of a single part, (e.g., network), the measure of productivity of the system is also the productivity of the network. In all other cases the mutual dependence of the parts of the systems precludes any meaningful measure of productivity by part or by subsystem.

Efficiency

As Figure 1 shows the situation with regard to efficiency analyses is quite different. In this case it is rather meaningless to discuss the efficiency of a complex, multiple system that carries components with various oscillating rates of efficiency. The concept of efficiency deals with the rate of success of a specific process in recovering expended resources. In this respect studies in efficiency would need to dissect the system into the largest possible number of distinct, complete subprocesses and measure the efficiency of each in detail. In this division of the total system efficiency studies should focus first on the network, then on the primary services, and finally on the auxiliaries. Further, each of these parts should be divided into submode aggregates, such as efficiency of the highway network, transit network, and railroad network and the efficiency of transit service, highway service, special terminals, bridge crossings, and the like. Third, the efficiency with which auxiliary services and subsystems are made available and serve the primary services, the network, and, in general, the system itself, should be examined.

Efficiency studies usually need to be detailed if they are to be used in planning and managing a UTS. In fact, the efficiency of some key components of a subsystem is of central concern in more cases than the overall inefficiency of services and networks. Inefficiencies of the latter type are usually obvious and soon become the topic of newspaper editorials and the subject of political controversy. As a result they are subject to elimination soon after they have been discovered and discussed. Inefficiencies of the first type, however, although numerous and frequent in many a system, are difficult for the public to locate, magnify, and subsequently force out of the system. Usually they take a technical form, a residual of technology application and an unavoidable character that defies gross actions and generalized solutions. To eliminate this type of inefficiency requires technical studies. Systematic and detailed analysis of each system component and of each factor and relationship that affects system performance needs to be in central focus. This approach is advisable for efficiency studies on all three system components.

Efficiency studies must be made not only on each unit of the system (i.e., a major link, a major node, a major transit line) but also on a complete process. The first type concerns the producer of services; the second concerns the user of services. Efficiency of the operation of the unit of the system is directly related to the productivity of the unit and the system as a whole. Such an efficiency measure says very little, however, about the ease with which a particular trip is made. This is of direct concern to the consumer (the user) of the system. Therefore, it is important that studies on efficiency include measures of the efficiency with which complete (from the origin to the destination) representative trips are being made. On aggregation, efficiency of whole corridor movements should be studied. This is where major deficiencies may produce total elimination of a trip or, in the long run, a substantial change in the travel patterns of the region.

Efficiency studies can take several forms. Although systems analysis approaches may prevail, in many cases an efficiency study would clearly be drawing much from traffic engineering, in other cases from management sciences, and in many cases from straight economic theory, especially from the theory of the firm, and the consumer's behavior theory. The main issues are efficiency of production, consumption, and distribution. The analyst can be surprised when he realizes that he moves rapidly from one field to another as he traces the efficiency of the various components. TOPICS, for instance, was nothing more than a crude attempt to study efficiency problems in the highway network. Similar programs with approximate crudeness are currently in effect in the transit field: airports, harbors, and turnpike and bridge authorities.

Finally, efficiency studies do not have to be limited to existing systems. They can be of great use in planning new systems, and they should guide the planner in assessing the technical proficiency, in succession, of the proposed networks, the new service patterns, and the new combinations of auxiliaries.

Quality

The significance of attaching quality studies of the transportation system to any set of efficiency and productivity studies becomes apparent if one considers the rather obvious trade-offs between efficiency and quality of service. It is in fact the presence and feasibility of these trade-offs that foster one of the major controversies in the field of urban transportation. For the supplier of the system, the quality of the system is measured along the dimensions of efficiency and productivity. The more efficient and productive a system is, the better this system is considered by the supplier. Although aspects of efficiency also have appeal to the consumer, his concerns far exceed those of efficiency. For instance, in a recent study of the significance that consumers place on transportation system quality (14), it became rather clear that the service quality items rather than the efficiency items received top rating. Among 32 quality attributes that were included in this study, the entire population and three major subgroups (under 20 and single, elderly, and low income) chose items such as arriving when planned, having a seat, no transfers, less waiting time, shelters at pick-up points, and longer service hours instead of the traditional emphasis on items such as faster trips and more direct routes.

Unless the systems produce service that can be consumed it makes no difference how productive and efficient the system is. The most efficient service is the service that not only has the best matching of its supply profile over time and over space with the profile of demand but also meets the quality characteristics that the consumers impose. Otherwise, the consumers would not use the services of the system. Thus, the paradox can be seen of a system most efficient from the suppliers' point of view which is both going bankrupt and also castigated as completely inefficient from the user's point of view.

The quality of service of a transportation system can be thought of as a matrix. Quality can then be divided into two groups, those associated primarily with each trip (immediate factors) and those associated primarily with long-range considerations of trip patterns. The first group includes convenience, comfort, frequency, and familiarity with the system.

The second group of quality attributes is more pervasive in nature. These attributes are reliability of current and long-range system performance, availability of service for any purpose at any time, security provided by the system, travel cost and travel speed, and level of privacy and individualism in services that the system offers.

Quality of service analyses must be related to the efficiency of each component of the system and, if possible, to the productivity of the entire system.

igure 1. Matrix of associations.

		SYSTEM COMPONENTS			
		NETWORK	PRIMARY SERVICES	AUXILIARIES	TOTAL SYSTEM
ANALYTICAL CONCEPTS	PRODUCTIVITY				X
	EFFICIENCY	X	X	X	
	QUALITY		X		

Figure 2. Efficiency improvements versus productivity improvements.

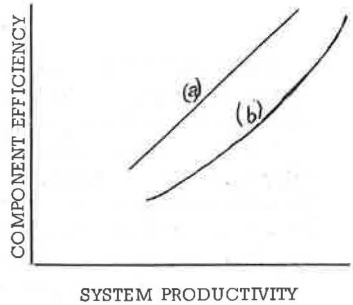


Figure 3. Efficiency improvements versus uality of service improvements.

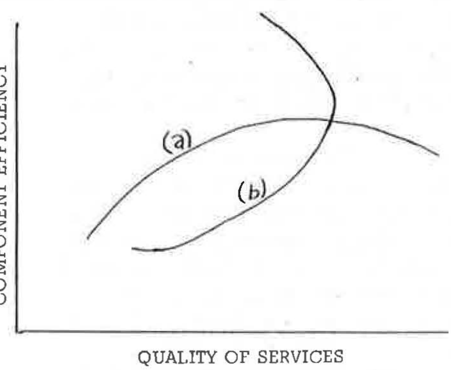
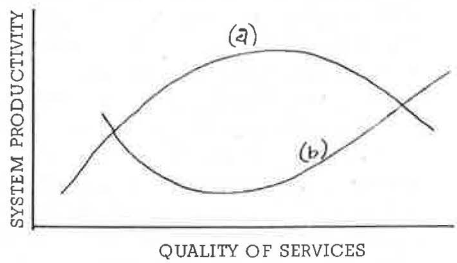
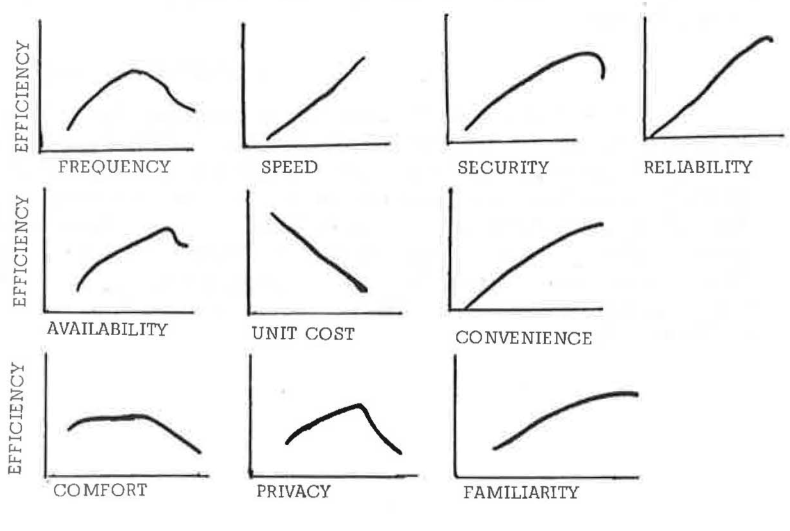


Figure 4. Productivity improvements versus quality of service improvements.



igure 5. Efficiency versus quality of ttributes.



RELATIONSHIPS AND TRADE-OFFS

The relationships and trade-offs among the three concepts (efficiency, productivity, and quality) for urban transportation systems loom from the outset as potentially complex and on occasion undefinable.

Figure 2 shows the two general forms that one would expect the relationship between efficiency and productivity to take. Clearly, as efficiency of the various system components increases so does the overall productivity of the entire system. This relationship may have one-to-one correspondence (curve a), or it can have a correspondence smaller or greater than one, depending on the specifics of the application (curve b). Based on the division of the UTS into the network, services, and auxiliaries and the variability of the circumstances prevailing in each system, the variable correspondence between partial efficiency improvements and total system productivity improvements is plausible.

Figure 3 shows the whole variation that the relationship between efficiency improvements and quality improvements can take. Normally initial improvements in efficiency measures are expected to correspond to improvements in quality measures and vice versa. However, after a particular point, improvements in one set of measures may correspond to deterioration of the other set of measures. Both curves of Figure 3 indicate this reversal of the correspondence between quality and efficiency improvements.

Figure 4 shows two other forms of the potential relationship between system productivity and quality of service. Curve a suggests an increase of productivity as quality of services improves to a certain point, beyond which the reverse takes place. This relationship can be seen within the context of consumer reaction to available services. As the quality of services improves, the consumer makes greater use of the system and, thus, more usable service is "bought" by the public. Beyond a certain point consumer response may not be so extensive as continual improvements in quality may be, and, therefore, the overall productivity of the system may decline (with respect to either labor or capital). Curve b represents the reverse sequence of events, and its plausibility can easily be constructed for each stage. Obviously, the analyst would have to carefully establish the exact point and type of relationship between productivity and quality and, further, explore the change that may occur in productivity by any measure involving change in the quality of the services offered.

In exploring in detail the potential relationships and trade-offs between quality of service and efficiency of operations, the analyst may have to investigate these relationships as they emerge with each of the 10 factors of quality that were discussed earlier. Figure 5 shows a plausible form of the trade-offs between efficiencies and each quality attribute. As can be seen, the relationship depends on both the level of efficiency already achieved and the nature of the quality attribute. In most cases efficiency (or productivity) would cease beyond a certain level regardless of quality improvements. In other cases, efficiencies will clearly decrease for any increase of quality of operations. Again the analyst would have to focus on the particular quality attribute that is explored and its specific impact on the operations of the specific system component that is going to be affected.

THE NEED TO SEPARATE MODES

These concerns notwithstanding, it seems imperative that an analytical effort on productivity, efficiency, and quality of urban transportation systems not be bogged down by conceptual generalities. The UTS is made up of three essential operational parts, the highway subsystem, the mass transit subsystem, and major multimode system terminals. The operational and technological differences among these parts are profound and frequently unbridgeable. Hence the analyst should recognize these differences and try to capitalize on them, rather than ignore them and presume an ability to establish concepts, methods, and units of measurement that are equally and universally usable for all three subsystems.

CONCLUSIONS

The approach of urban transportation planning that was developed in the 1950s and 1960s appears to be inapplicable for the 1970s. That approach produced a set of monumental plans and vastly expanded networks of highway facilities, with emphasis on accommodation of new highway trips. This produced widespread opposition to these plans and a deep concern about the normative values and optimal nature of the plans themselves. Currently most urban transportation planning teams are trying to rescue whatever parts of the regional plans seem feasible. Clearly, a change in approach and an essentially different type of urban transportation plan are imperative if transportation planners are to be effective in their efforts to improve travel conditions within urban areas.

What is proposed is a set of analytical studies of the entire transportation system of each urban region with emphasis on productivity, efficiency, and quality. Only at the conclusion of such studies, and in direct response to the needs to improve productivity, efficiency, and quality, would new facilities be suggested. Meanwhile, the system in its totality, as well as each subsystem, would be analyzed by focusing on improving its total system productivity and component efficiency. Such improvements would have to be introduced in any one or all of the major parts of a UTS: its network, its primary services, and its auxiliaries (services and subsystems).

As of now, no study is known to have been designed or undertaken following this new approach. The concern for efficiency, productivity, and quality has emerged in most studies indirectly. The work carried on currently at the University of Pennsylvania on which this paper is based is the only one known to this author. It is hoped that this initiative will soon be followed by others.

REFERENCES

1. Kendrick, J. W. Productivity Trends in the United States. Princeton Univ. Press, 1961.
2. Fuchs, V. R. Measuring Productivity of Federal Government Organizations. Bureau of the Budget, 1964.
3. Fuchs, V. R. The Service Economy. National Bureau of Economic Research, 1968.
4. Hatry, H. P., and Fisk, D. M. Improving Productivity and Productivity Measurement in Local Governments. Urban Institute, 1971.
5. Winnie, R. E., and Hatry, H. P. Measuring the Effectiveness of Local Government Services: Local Transportation. Urban Institute, 1972.
6. Chicago Area Transportation Study, Final Report. Vol. 1, 1959; Vol. 2, 1960; Vol., 3, 1962.
7. Penn Jersey Transportation Study. Vol. 1, 1962; Vol. 3, 1965; Vol. 5, 1969.
8. Kansky, K. J. Structure of Transportation Networks. Univ. of Chicago, 1963.
9. Garrison, W. L., and Marble, D. P. The Structure of Transportation Networks. Transportation Center, Northwestern Univ., 1961.
10. Caurer, W. Synthesis of Linear Communication Networks. McGraw-Hill, 1958.
11. Truxal, J. G. Automatic Feedback Control System Synthesis. McGraw-Hill, 1955.
12. Berge, C. Théorie des Graphes et ses Applications. Dunod Publications, Paris, 1958.
13. Wagner, H. M. Principles of Operations Research. Prentice-Hall, 1969.
14. Gustafson, R. L., Curd, H. N., and Golob, T. F. User Preferences for a Demand-Responsive Transportation System: A Case Study Report. Highway Research Record 367, 1971.