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# The Appropriate Measures of Productivity and Output for the Evaluation of Transit Demonstration Projects



**Final Report
March 1982**

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Service and Methods Demonstration Program

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16. Abstract

The current usage of the concepts of productivity and output in transit demonstration evaluations appears to differ from the accepted usage in the economics profession. This difference certainly causes communication problems and might actually result in different conclusions.

The pure economic theory of productivity and its relationship to the theory of production and the equilibrium between supply and demand is outlined. It is then explained why this model should be modified in order to be used in the analysis of urban transportation systems. An approach is developed which will allow for less ambiguous communication between the transportation industry and outside observers. The major component of this suggested approach is that the measures of productivity and output presently being used by the transportation industry need to be modified for use in the evaluation of transit demonstration projects, and these modifications are presented in the final section.

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# PREFACE

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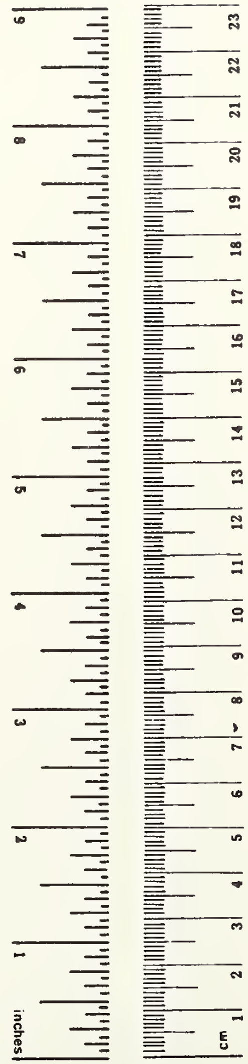
# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

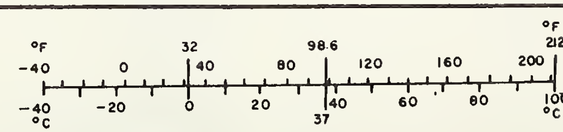
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | cantimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | squere centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilogrems | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | querts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fehrenheit tempereture | 5/9 (efter subtracting 32) | Celsius temperature | °C |

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286. Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.




## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | faet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | squere inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



## INTRODUCTION

Output and productivity, two economic concepts which have important applications in the evaluation of transportation demonstrations, are discussed in this paper. The focus of these discussions is on how the terms' typical definitions in transportation analysis differ from their accepted usages in the economics profession, apparently due to unawareness on the part of economists to the particular problem of evaluating transit demonstration projects. Such definitional differences can lead, at best, to otherwise avoidable misunderstandings and, at worst, to misleading conclusions being drawn from demonstration results. This paper is intended to stimulate discussion of the appropriate definitions of the economic concepts being used.

The body of this paper is divided into three sections. The first section briefly outlines the pure economic theory of productivity and its relationship to the theory of production and market equilibrium. The second section attempts to explain why this model and its definitions must be modified for use in analyzing changes in urban transportation systems. The final section suggests an approach which might clarify present ambiguities in communication between the transportation industry and those outside observers (economists, politicians, union leaders, voters, etc.) with whom the industry must deal in order to obtain subsidies or carry out innovations. The major component of this suggested approach is that the measures of productivity and output presently being used by the transportation industry need to be modified for use in the evaluation of transit demonstration projects.

## PRODUCTION, MARKET EQUILIBRIUM, AND THE CONCEPT OF PRODUCTIVITY

This section is a brief discussion of the pure economic theory which underlies the concepts of productivity, production, and market equilibrium. Most transportation analysts have been exposed to a healthy amount of economics in their careers, so this discussion will focus on the facets of the theory which are most relevant to the topics to be analysed in the sections that follow. Readers with strong backgrounds in this area are encouraged to skip directly to the next section. A reader interested in a more detailed theoretical description should consult a traditional microeconomic text such as Ferguson (2), Henderson and Quandt (5), or Hirshleifer (6), from which the following discussion draws heavily.

The concept of productivity is traditionally defined as the ratio of output to input for some productive activity. Mush of economic activity consists of transforming scarce resources (inputs) into goods or services (outputs) whose fabrication requires those resources. The tool that economists use to describe this transformation is the production function, which shows the maximum output attainable from a specified set of inputs given existing technology. An equation for a simple production function would look something like:

$$Q = f(L,K) \qquad (1)$$

which says that output (Q) is a function of the inputs of labor (L) and capital (K) devoted to that production. If the amount of relevant inputs is increased, then the amount of maximum output also increases. The production function thus can be used to predict output, to predict the inputs needed to produce a given output, and to measure the impact of changes in inputs on the total level of output. Equation (1) is true for a given level of technology, so that a change in the technology of an industry usually requires a change in the production function being used to analyze that industry. More complex production functions also include measures of technological advances and allow for changes in technology without a necessary change in the functional form. The actual calculation of the coefficients of the equation is typically accomplished by measuring output and input levels from a representative sample of production and then estimating the coefficients econometrically. Coefficients can also be derived theoretically if a rigorous functional relationship exists for a particular product. Production functions are usually assumed to be unique-valued and continuous.

While average productivity (total putput divided by the total of some input) is often calculated, most economists are much more concerned with marginal productivity (the extra output generated by the addition of another addition of another unit of an input, holding other inputs fixed). Given a particular production function, these marginal productivities can be computed by calculating the first order partial derivatives of output with respect to the inputs in question. Such marginal productivities are important because in order to decide how much of an input to purchase at a given price, a producer must have some idea of the extra output that the hiring of an additional input would generate. As long as the cost of the additional input is less than the additional revenue resulting from the input (a function of marginal product), the producer will gain by hiring more of that input. Thus the concept of productivity is a crucial link between the output market and the input market; it is important to make sure the definitions of inputs and outputs chosen for a particular productivity ratio are indeed the same definitions that are used in the input and output market. If they are not, then this linkage is no longer valid.

Several difficult theoretical and applied issues have been raised with respect to modern productivity analysis. Those of concern to transportation analysts include the concept of joint production and the inclusion of time and space in the definition of output. These complications arise because, in reality, most production facilities produce a number of goods which are readily distinguishable from each other. Decisions involving these facilities, unfortunately, involve shared factors of production, which make the exact calculation of productivities quite difficult. Examples of other issues of emerging interest are how to analyze union work rules, governmental subsidies, and complementary products over which the operator may not have control. Analysis of these issues will be reserved for future papers.

One way to better understand the concept of productivity is to recognize that various definitions of productivity can be used as tools to attack a wide range of questions. Productivity can measure the efficiency with which resources are employed as a whole (say for an entire city or state) in production, and it can also measure the efficiency of a single additional unit of a particular input in a small firm or organization. Thus, depending on the kind of question asked, different kinds of productivity measures will be best; in each of its forms, however, productivity is a comparison of an output with one or more inputs. In that sense, the higher the productivity level--other things being equal--the better off the productive unit in question is. One of the most famous productivity studies begins with the comment that "productivity, the ratio of output to input, is at heart the record of man's efforts to raise himself from poverty." (8, page 1).

In applying these theories to the transportation industry, we need to mention the concept of market equilibrium. Perhaps one of the first lessons anyone learns in economics is that supply and demand create an equilibrium which determines price and quantity in a competitive market. For a given homogenous product, we know that the quantity of a good demanded (Q(d)) is a negative function of the price of the item (P) and a function of such other variables as the price of substitutes (X) or advertising (A). In addition, the producer will be able to supply more of the item (Q(s) as the price rises, in part because of the ability to hire more inputs. Other factors, such as cost of inputs (Z) are also important:

$$Q(d) = F(d)(P,X,A) \qquad (2)$$

$$Q(s) = F(s)(P,Z) \qquad (3)$$

$$Q(d) = Q(s) \qquad (4)$$

Discussion of all the assumptions and circumstances that lead to a stable equilibrium is not needed here, but a few comments about this equilibrium should set the stage for the next section. First, the quantity supplied is assumed to be responsive to both prices and costs. Second, the equilibrium price of the product may or may not be equal to the cost of that product; while in perfect competition such an equality takes place in the long run, imperfect competition rarely ends up with cost equaling price. Third, equation four, quantity supplied equals quantity demanded, implies that the product must be homogeneous--that is, the consumers must be demanding the same good that suppliers are supplying for an equilibrium to take place. If any or all of these conditions are not met, then it is not at all likely that the conclusions, tools, and general results of the competitive market can be applied with any degree of confidence. Indeed, it may be extremely misleading to assume that such applicability exists when in fact it does not.

DIFFICULTIES IN APPLYING CONVENTIONAL ECONOMIC TOOLS TO TRANSPORTATION

This section suggests a number of ways in which the application of conventional definitions of economic concepts and conclusions needs to be improved in evaluating demonstrations in the transit industry. Unless the use of these ideas is changed, the economic analysis that is applied to transit demonstrations is apt to be of lower quality than it could be. Even if the analysis remains the same, a few changes in approach might make it significantly easier to communicate analytical results and conclusions to the rest of the country.

The single most important inspiration for the present paper is the typical use of the concept of "productivity" in urban mass transportation discussions. Within a transit property, and in most reports and evaluations dealing with such properties, productivity is defined as the ratio of revenue passengers or revenue passenger-miles to the particular measure of input in question (say labor hours). See, for example, (7). While the definition of marginal productivity typically used is the change in revenue passenger-miles divided by the change in labor hours, in actuality, most papers have compared the average productivity before the particular time period or policy being studied with the average productivity after the change without really concerning themselves with marginal productivity. Since marginal productivity is much harder to measure, and since an increase in average productivity implies a marginal productivity higher than the previously existing average productivity, there is little to criticize in this practice. Instead, the criticism has to do with the choice of revenue passengers or revenue passenger-miles as the appropriate measure of output to be utilized in calculating productivity estimates.

The use of revenue passenger-miles is not without justification. After all, the final output of any transportation process is the movement of people from one place to another, and therefore the "bottom line" is revenue passenger-miles or passenger trips. John Dendrick, the most recognized source of early thinking on and measurement of productivity, used "passenger miles" as the best measure of output in the national passenger transportation industry (8,p. 187), and he is certainly correct that from a nation-wide point of view, we must view passengers moved as the desired output of transportation activity. Since productivity is the ratio of output to input, the rationale for passenger transportation is that the appropriate measure must be revenue passenger-miles (or passenger-trips) per hour of labor or dollar of capital. This definition has been almost universally adopted by transit properties; when the work "productivity" is mentioned in a transit property setting, the definition is well-known and understood, and the question "What definition should we use?" never (or rarely) arises.

Such universality seems strange, however, when it is considered in the light of professional usage of the same terms. Two recent papers on urban transit efficiency and productivity have come up with long lists of definitions of appropriate measures to be considered, and both papers go out of their way to make it obvious that passenger-related output definitions measure "utilization" or "effectiveness" rather than "productivity." (See (9) and (12)). These differentiations are substantive in nature rather than simply semantic, and most economists would agree with them.

The basis for disagreement over the proper definition of productivity in mass transit goes back to the economic principles outlined in the previous section. Productivity, it will be remembered, is an excellent way to measure the increase in production that will take place if there is an increase in the employment of one or more inputs. This is because there is a direct relationship (the production function) between the amount of an input used and the amount of an output created. In mass transportation, however, this is not necessarily the case, because the actual output created in the production process is not passengers, it is bus-miles or seat-miles or some other measure of physical transit production. An extra worker could be simultaneously "productive" in the economic sense and yet fairly "unproductive" in a transportation sense if the extra bus-miles made available were placed in an area in which there was no excess demand for transportation services. Similarly, an increase in transit "productivity" could take place with no change whatsoever in the system or its inputs (or in bus-miles provided ) if the population increased and there had previously been excess capacity on the transit system. As mentioned before, it is still reasonable to use passenger-miles as a measure of productivity in an aggregate sense, since we want to have a transportation system that carries as many people as possible, given the resources we have to devote to that use. However, on a project-by-project basis, as is usually the case in demonstrations, a focus on the transit definition of productivity might give extrevely misleading results.

Suppose, for instance, that a demonstration introduces an innovation to a transit system which makes it more difficult for transit employees to meet schedules and makes it likely that total bus-miles will decrease (or increase much less than would gave been expected). If this innovation is accompanied (as it often is during a demonstration) by increased advertising or by an increased awareness of transit by the public, then it is quite likely that ridership will go up even though the idea itself may make it more difficult for the system to serve those riders. A typical study of "productivity" would show that ridership had gone up during the period of the demonstration "even though" bus-miles per employee had not risen significantly, "proving" the worthiness of the innovation. The UMTA and TSC SMD monitors that oversee such demonstrations are usually alert to avoid such misleading conclusions, but the fact remains that "productivity" as defined by typical <u>transit property</u> or <u>consultant</u> usage has increased, even though "productivity" as measured by economists or businesses in virtually every other industry in the nation has decreased!

The major reason for the disagreement between the two approaches is that the output produced by the transit property (Q(s) in equation (3)) is not the same as the output demanded by consumers (Q(d) in Equation (2)). Thus equation (4), where Q(d)=Q(s), has little meaning. The reason for this lack of homogeneity is that transit properties produce a bus going along a route at a particular time (seat-miles), while the consumer demands transportation from one place to another. Since the use of the bus by one consumer does not necessarily mean that a second or third consumer cannot also use the bus, this market contains strong elements of a "public good" rather than a competitive good, and conclusions borrowed from the results of the theoretical competitive market equilibrium will not necessarily make sense in a transit setting. In particular, it should be clear that it is rare in transit circles that the quantity supplied actually equals quantity demanded at a given price. Usually, there are either more seats than customers or more customers than room on the bus.

In addition, because of transit subsidies, the price of a bus ride and the cost of that ride sometimes have little to do with each other except that increasing costs in the face of a constant subsidy force an increase in prices (but only after some time has gone by). Thus the ability of the concept of productivity to act as a link between supply and demand is limited. Therefore, conclusions made about the appropriateness of a particular innovation which are supported by traditional economic analysis must be examined to ensure that they do not rely on this "not necessarily so" market equilibrium concept. Indeed, since transit properties are governmentally funded (through UMTA or some other source), the goal of profit maximization has evolved into one of maximizing consumer welfare in the face of a given subsidy policy.

Today's transit properties are concerned with much more than simply providing transportation. They must think about all the attributes of that transportation, from its speed and arrival time reliability--see (13)--to its comfort, safety, and level of crowding. In this sense, properties are attempting to maximize some fairly new proxies for profit while at the same time keeping costs as low as possible, and the most interesting transit demonstrations are no longer pure productivity demonstrations at all (if they ever were). A concern with quality of service, with performance-based measures of output (and performance functions--see (11)), must therefore be included in any relevant revision of the concepts of output and productivity for transit demonstration uses.

## TOWARD MORE APPROPRIATE MEASURES OF OUTPUT AND PRODUCTIVITY

Both of the two previous criticisms of the applicability of various economic concepts to the evaluation of transportation demonstrations hinge on the same basic point. There is a disparity between the concept of transportation output as seen by the producer and that output from the viewpoint of the consumer; in other words, what is sold is different from what is provided. The best measure of the actual item that transit properties produce seems to be bus-miles or sear-miles, because they are the items that the firms physically produce. The simplest measure of the commodity that consumers desire, on the other hand, is passenger-miles or revenue-passengers transported, since most riders are simply concerned with getting from one place to another and not with the precise number of seats that accompany them (admittedly, overcrowding would change demand, but within a significant range, that would not be important). On a more complex level, the consumer is also demanding a total package of reliability, safety, comfort, etc. Thus the question of the appropriate measure of productivity and also the question of the non-existent supply-demand equilibrium are both questions of which "output" definition to include in the ratio "output divided by input." This particular conception of the problem was also seen by Manheim (11), Lee (10), Benjamin (1) and Tomazinis (14,pp. 163-173), but they did not develop any real conclusions or explanations of ways to avoid it. While it is obvious that the final output of a transportation system is the movement of people, it seems just as obvious that the system itself can only produce an intermediate product such as bus-miles; it cannot actually force the riders to consume the product at any price. Thus some concept of an intermediate linkage between supply and demand seems to be needed in transportation analysis.

In effect, we are saying that we should add an extra equation to the model of equilibrium in a competitive industry that is described in equations 2-4 in order to get a reasonable model of equilibrium in the transit industry. This new model would look something like the following:

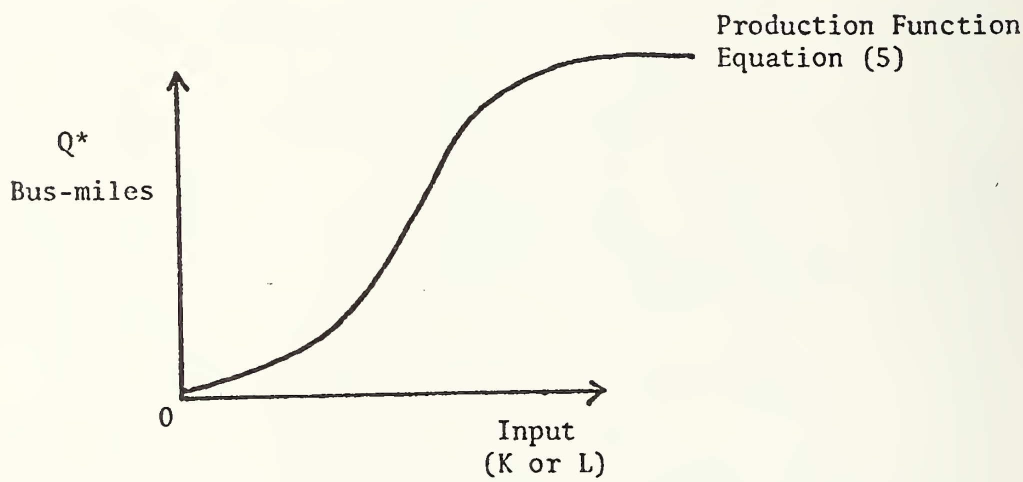
$$Q^* = f(L,K) \quad (5)$$
$$Q(d) = F(d)(P,X,A) \quad (6)$$
$$Q(s)^* = F(s)(P,Z,S) \quad (7)$$
$$Q(s) = F(link)(Q(s)^*) \quad (8)$$
$$Q(d) = Q(s) \quad (9)$$

In this model, equation (5) is nothing more than equation one, a simple production function, with Q* denoting that the actual production of a transit property is measured in units such as bus-miles, not passengers (which is indicated whenever Q is used). Given duality, this equation is not necessary for the system and is included for reference only. Equation (6) is a restating of equation (2), remembering that demand is noted in units such as revenue passengers (Q(d)). Equation (7) is similar to equation (3), the property's supply function, except that the amount of the subsidy (s) has been added to account for the fact that output is determined not by price alone, but by the combination of price and subsidy. The property is a price searcher if it is regulated with respect to routes and subsidy or a cost minimizer if regulated with respect to routes, price, and subsidy. Equation (9) is simply equation (4), the equilibrium equation, restated for convenience; however, the units of equation (9) are in passenger rides. Equation (8) contains what is new about this approach; it is a linkage function which translates the produced bus-miles or seat-miles into available rides, given the geographic distribution of the origins and destinations of the consumers and the scheduling efficiency of the transit property. The linkage function transforms the potentially producable bus-miles of the property into the maximum number of rides (revenue passengers or revenue passenger-miles) which can be offered in the market.

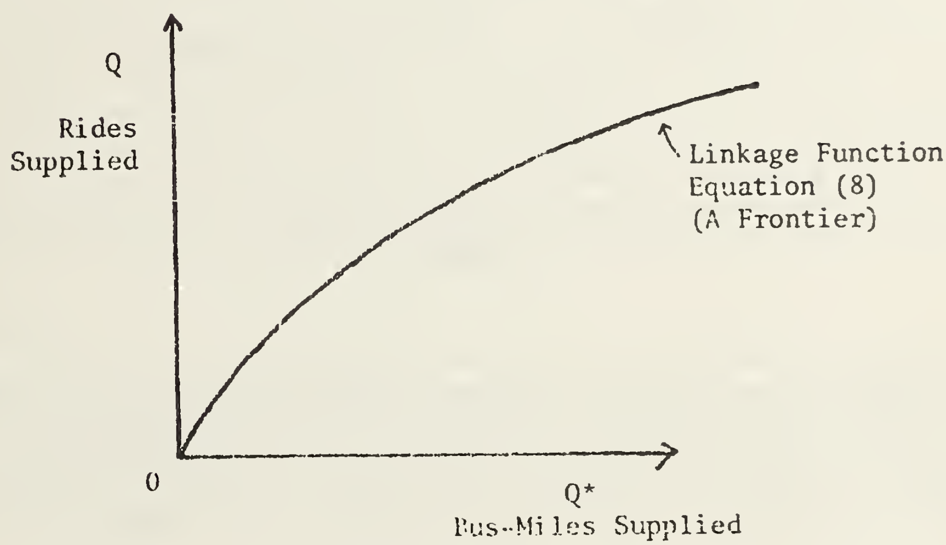
The reason we need the linkage function, again, is to connect the kind of product that the industry is producing to the kind of product that the consumer is demanding. How does this linkage function work? Given the physical production capacity of the transit system--the number of buses and drivers the property can put on the roads and the number of hours or miles those buses can handle--the linkage function analyzes the level of demand with respect to the actual distribution of origins and destinations and attempts to schedule the available buses so as to maximize the number of rides (or the number of a given class of rides if desired) that can be served. In other words, the linkage function denotes the maximum number of rides that can be provided, given the production capability of the property and the demand characteristics of the consumers.

Since the linkage function shows the maximum possible number of rides, or the maximum of many other possible levels, it is a frontier, with a whole layer of other possibilities underneath. Given a particular property, the linkage function can be thought of as a physically-based equation within the equilibrium process. It translates physical attributes into services actually seen on the road; thus, in a specific case, it would be mainly physically determined. In this sense, the impact of various union work-rules (etc.) on the linkage function is important and perhaps worth studying.

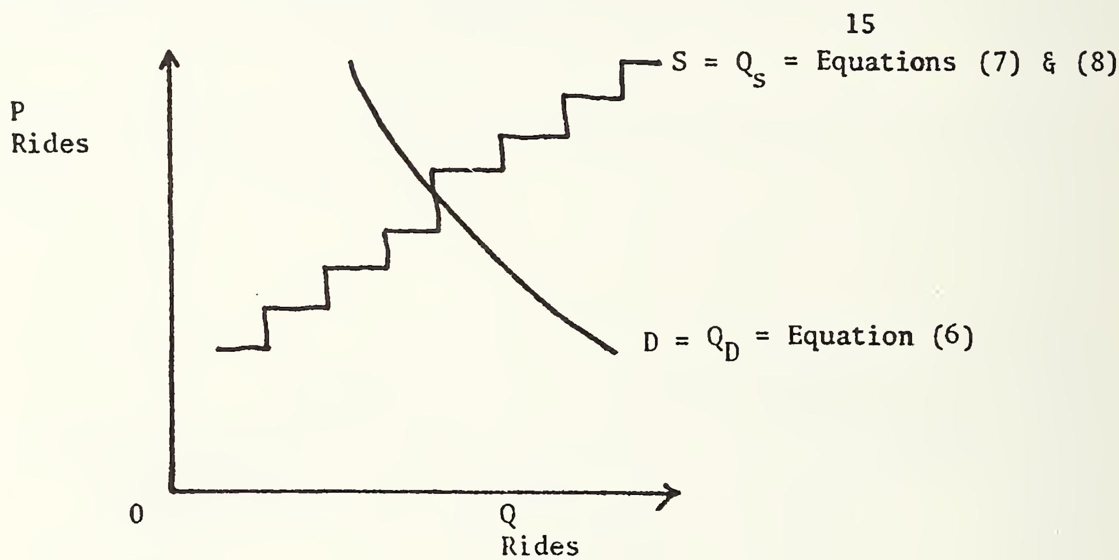
The model is analyzed graphically below. The production function (equation (5)) relates the quantity of inputs utilized to the output (in bus-miles) of the transit property:



The linkage function can be seen as the relationship between the quantity of bus-miles produced and the number of rides thus made available to the consumer, given their geographic demand patterns:



Clearly a fairly complex supply-demand equilibrium function must (be at work here) for a full system optimization to take place. The resulting equilibrium diagram, with all items measured in terms of rides or passengers, would look very similar to a typical supply and demand diagram, except that because of the lumpiness with which bus-miles can be produced and translated into riders, the supply function is a discrete step-function rather than a continuous supply function:




The preceding discussion will help in explaining the different approaches towards the concept of average productivity that distinguish economists and transit operators. The operators are concerned with the number of revenue-passengers (R) per unit of input (say hour of labor L), but this can be shown to be equal to the number of bus-miles (B) produced per labor hour multiplied by the number of riders per bus mile:

$$\frac{R}{L} = \frac{R}{B} \times \frac{B}{L} \qquad (10)$$

or

$$\frac{Q}{L} = \frac{Q}{Q(s)^*} \times \frac{Q(s)^*}{L} \qquad (11)$$

As can readily be seen, what transit operators call productivity is actually what economists call productivity (the number of bus-miles produced per labor hour) multiplied by the items contained in the linkage function, or a ratio which has often been called "effectiveness" (the number of revenue passengers per bus-mile). Since R/L increases as either R/B or B/L increases, and since many demonstrations focus on ridership (R/B or R/L) rather than productivity, it is important to go beyond simply avoiding calling R/L a productivity. We must focus on R/B and identify the influences that such supplyside issues as routes, subsidies, work rules, etc. have on this equilibrium concept. This new focus should also allow us to distinguish technological changes which have their main impacts on productivity (B/L) rather than ridership (R/B). This distinction is important since some technological changes that would impact R/B--faster buses, for instance-- would also allow a worker to provide more bus-miles.

The same relationship holds if marginal productivity is being studied:

$$\frac{dQ}{dL} = \frac{dQ}{dQ(s)^*} \times \frac{dQ(s)^*}{dL} \qquad (12)$$

To further illutrate the difficulties caused by the difference in definitions of productivity, let's suppose a demonstration introduces a genuinely valuable innovation that allows drivers to serve more potential riders with the same number of buses by scheduling them more efficiently or allowing more rapid communication between driver and dispatcher. This would increase bus-miles/driver (or input), but its impact on riders/bus-mile would be ambiguous. Indeed, if schedules were readjusted and little money spent on marketing the changes, overall ridership might decrease within the timeframe of the demonstration, even though the innovation itself was quite productive. By breaking down passengers/input into passengers/bus-mile and bus-mile/input, we can analyze this change much more effectively.

## CONCLUSION

A change in the definitions of productivity and output used in the analysis of mass transportation demonstrations would improve the ease with which the results of these demonstrations are communicated to professionals of various backgrounds. In particular, bus-miles/input rather than revenue-passengers/input is the most appropriate definition of the concept of productivity, because it measures the productiveness of the transit property itself rather than appropriate measure may well be revenue-passengers/bus-mile. Large-scale demonstrations might well call for the more "macro-scale" definition. For the most part, however, the "micro" approach to productivity will serve SMD much better.

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## Report of Inventions Appendix

Although a diligent review of the work performed under this contract has revealed that no new innovation, discovery, or invention of a patentable nature was made, the material in the last section, in particular the linkage function, contains theoretical and practical elements which are new and have not been previously reported.



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